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Energy Efficiency Improvement and Cost Saving Opportunities for the Pharmaceutical Industry

**An ENERGY STAR[®] Guide for Energy and
Plant Managers**

*Christina Galitsky, Sheng-chieh Chang,
Ernst Worrell, and Eric Masanet*
Environmental Energy Technologies Division

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Energy Analysis Department
Environmental Energy Technologies Division
Ernest Orlando Lawrence Berkeley National Laboratory
University of California
Berkeley, California 94720

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ABSTRACT

The U.S. pharmaceutical industry consumes almost \$1 billion in energy annually. 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. pharmaceutical 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, system, and organizational levels. A discussion of the trends, structure, and energy consumption characteristics of the U.S. pharmaceutical industry is provided along with a description of the major process steps in the pharmaceutical manufacturing process. Expected savings in energy and energy-related costs are given for many energy efficiency measures, based on case study data from real-world applications in pharmaceutical and related facilities 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 reduce energy consumption in a cost-effective manner while meeting regulatory requirements and maintaining the quality of products manufactured. At individual plants, further research on the economics of the measures—as well as their applicability to different production practices—is needed to assess potential implementation of selected technologies.

Table of Contents

1. Introduction	1
2. The Pharmaceutical Industry.....	3
3. Process Description	7
3.1 Research & Development	7
3.2 Conversion to Bulk Pharmaceutical Substances.....	8
3.3 Formulation of Final Products	11
4. Energy Use in the U.S. Pharmaceutical Industry.....	13
5. Energy Efficiency Opportunities for the Pharmaceutical Industry	17
5.1 Energy Management Systems and Programs.....	18
5.2 Heating, Ventilation, and Air Conditioning (HVAC) Systems	21
5.3 Fume Hoods	28
5.4 Cleanrooms	29
5.5 Motors and Motor Systems.....	31
5.6 Compressed Air Systems	34
5.7 Pumps.....	40
5.8 Refrigeration	44
5.9 Lighting.....	46
5.10 Heat and Steam Distribution.....	50
5.11 Cogeneration.....	56
5.12 Miscellaneous Measures	59
6. Summary and Conclusions	61
7. Acknowledgements.....	64
8. References	65
9. Glossary	76
Appendix A: Basic Energy Efficiency Actions for Plant Personnel	78
Appendix B: ENERGY STAR Energy Management Program Assessment Matrix.....	79
Appendix C: Support Programs for Industrial Energy Efficiency Improvement	83

1. Introduction

As U.S. manufacturers face an increasingly competitive environment, they seek out opportunities to reduce production costs without negatively affecting the yield or the quality of their finished products. The volatility of energy prices in today's marketplace can also negatively affect predictable earnings. This is a concern particularly for publicly-traded companies in the pharmaceutical industry. The challenge of maintaining high product quality while simultaneously reducing production costs can often be met through investments in energy efficient technologies and energy efficiency practices. Energy efficient technologies can often offer additional benefits, such as quality improvement, increased production, and increased process efficiency, which can lead to further productivity gains. Energy efficiency is also an important component of a company's environmental strategy, as energy efficiency improvements can often lead to reductions in pollutant emissions. A strong energy management program can also provide a solid foundation for corporate greenhouse gas management programs. In short, investment in energy efficiency is a sound business strategy in today's manufacturing environment.

To help industry improve its competitiveness through increased energy efficiency and reduced environmental impact, the federal government offers several voluntary programs. The ENERGY STAR[®] program is a voluntary program operated by the U.S. Environmental Protection Agency (EPA) in coordination with the U.S. Department of Energy (DOE) that stresses the need for strong and strategic corporate energy management programs. ENERGY STAR also provides a host of energy management tools and strategies to support the successful implementation of corporate energy management programs. This Energy Guide reports on research conducted to support the U.S. EPA's ENERGY STAR Pharmaceutical Focus, which works with the U.S. pharmaceutical industry to identify information and resources for energy efficiency improvement. For further information on ENERGY STAR and its available tools for facilitating corporate energy management practices, visit <http://www.energystar.gov/>.

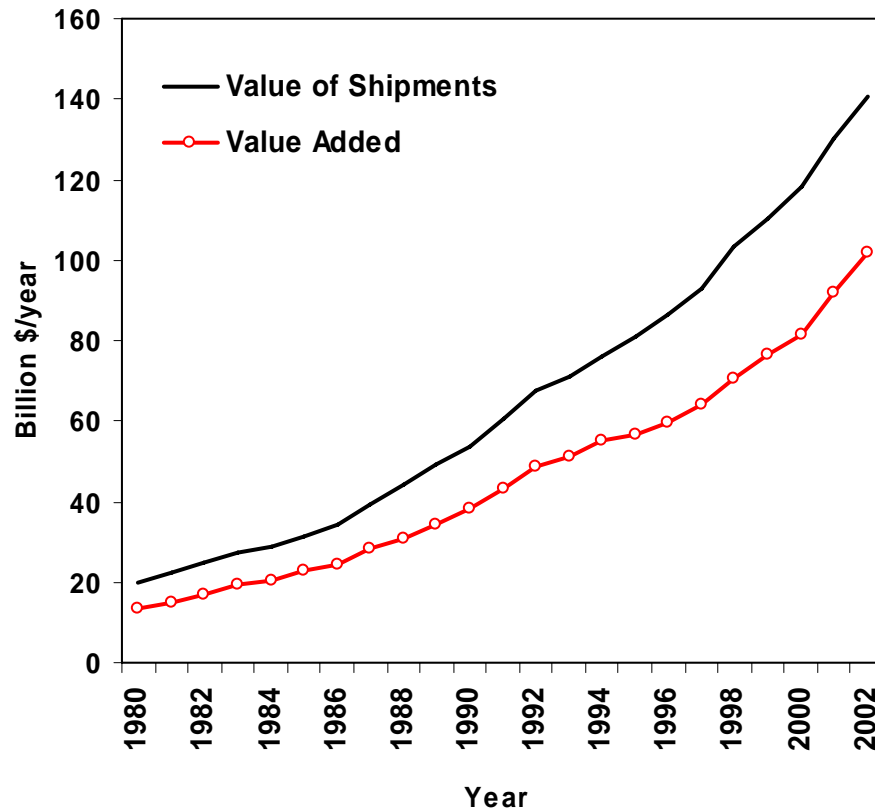
This Energy Guide assesses energy efficiency opportunities for the U.S. pharmaceutical industry. The manufacture of pharmaceuticals and medicines is a key industry in the United States. In 2002, the U.S. pharmaceutical industry generated over \$140 billion in output, up from \$108 billion in output in 1999 (U.S. Census 2001, 2005a). The industry employed nearly 250,000 people directly in 2002 (U.S. Census 2005a). Pharmaceutical production facilities can be found throughout the United States; however, production is mainly concentrated in a few states. Although energy costs typically represent a small percentage of total production costs in the pharmaceutical industry, the cost of energy is still significant. In 2002, the total cost of purchased fuels and electricity in the U.S. pharmaceutical industry was over \$920 million (U.S. Census 2005a). Furthermore, energy costs are growing rapidly due to increased costs for natural gas and electricity in the United States, making energy management an important focus area for improvement of operations and productivity.

This Energy Guide first describes the trends, structure, and production characteristics of the U.S. pharmaceutical industry. Next, a description of the main production processes and a discussion of energy use in the pharmaceutical industry, including the main end uses of energy, are provided. Due to the wide variety of products and production methods in the U.S. pharmaceutical industry, it is impossible to describe all energy end uses. Therefore, this Energy Guide focuses on the most important end uses of energy in typical U.S. pharmaceutical plants. Finally, the remainder of this Energy Guide discusses opportunities for energy efficiency improvement in U.S. pharmaceutical plants, focusing on energy efficient measures and technologies that have successfully been demonstrated in individual plants in the United States or abroad. Although new energy efficient technologies are developed continuously (see for example Martin et al. 2000), this Energy Guide focuses on those technologies and practices that are both proven and currently commercially available.

2. The Pharmaceutical Industry

The U.S. pharmaceutical industry encompasses a wide array of products. This Energy Guide focuses on the U.S. “pharmaceutical and medicine manufacturing” industry, which is designated by the North American Industry Classification System (NAICS) code 3254.¹ The U.S. pharmaceutical and medicine manufacturing industry includes medicinal and botanical manufacturing (NAICS 325411), pharmaceutical preparation manufacturing (NAICS 325412), in-vitro diagnostic substance manufacturing (NAICS 325413), and biological product (except diagnostic) manufacturing (NAICS 325414). Pharmaceutical preparation manufacturing has historically represented the vast share of total U.S. pharmaceutical and medicine production (approximately 75%). Although other industry segments have shown strong growth over the past decade, such as biological product manufacturing, these segments still produce less than 25% of the U.S. pharmaceutical industry’s total value added (U.S. Census 2005a).

Figure 1. Value of shipments and value added of the U.S. pharmaceutical industry, 1980-2002.



Sources: National Bureau of Economic Research (2000); U.S. Census (2003, 2005a).

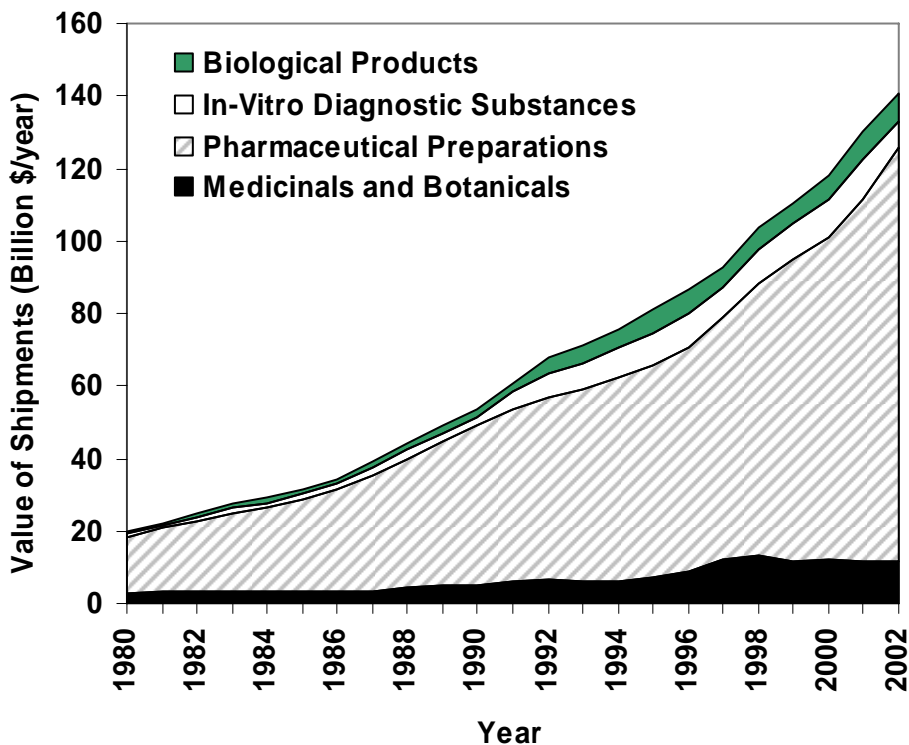
¹ Formerly Standard Industrial Classification (SIC) code 283.

Total production value of the U.S. pharmaceutical industry has increased rapidly over the past 20 years, as shown in Figure 1. Figure 1 plots value added and value of shipments for the U.S. pharmaceutical industry from 1980-2002. It can be seen in Figure 1 that the value added generated by this industry has grown almost parallel to the output growth. Value added as a function of value of shipments in the U.S. pharmaceutical industry has been nearly constant at around 70% for the past two decades. In 2002, the output of the U.S. pharmaceutical industry (\$141 billion) was more than a quarter of the output of the U.S. chemical industry (\$460 billion) as a whole (U.S. Census 2005a).

The global market for pharmaceutical products in 2002 was estimated at just over \$400 billion (IMS Health 2003). Of this, the United States was the largest market by far, accounting for nearly half of global pharmaceutical sales. The U.S. market is also the fastest growing pharmaceutical market in the world, with an average annual growth rate of 14% since 1999 (IMS Health 2005).

Figure 2 plots historical value of shipments data for the four major segments of the U.S. pharmaceutical industry, clearly demonstrating the importance of pharmaceutical preparations manufacturing despite strong growth in the other segments. Figure 2 also demonstrates the strong growth of the U.S. pharmaceutical industry overall in the past two decades.

Figure 2. Value of shipments of the four major segments of the U.S. pharmaceutical industry.



Sources: National Bureau of Economic Research (2000); U.S. Census (2003, 2005a).

Today, the U.S. pharmaceutical industry is dominated by a number of large pharmaceutical manufacturers, which also operate globally. In 2002, the top 10 companies accounted for nearly half of all global pharmaceutical sales (Sellers 2003). Often, a few drugs may be a major source of income to the industry. For example, in 2002, global sales of the top five drugs together were valued at \$28 billion (IMS Health 2003).

Major pharmaceutical companies in the United States are summarized in Table 1. While pharmaceutical production facilities can be found throughout the United States, most of the companies are headquartered in the northeastern states. The U.S. pharmaceutical industry employed nearly 250,000 people directly in 2002 (U.S. Census 2005a). United States pharmaceutical production is mainly located in Pennsylvania, North Carolina, California, New Jersey, and New York (see Table 2). There is also considerable production of pharmaceuticals occurring in the U.S. Commonwealth of Puerto Rico. According to the Pharmaceutical Industry Association of Puerto Rico, in 2003 the Puerto Rican pharmaceutical industry provided over 30,000 direct jobs and exported nearly \$37 billion worth of pharmaceuticals from the island (PIAPR 2005).

Table 1. Major pharmaceutical companies² in the United States (in alphabetical order).

Company	U.S. Headquarters	2002 Sales (Billion \$)
Abbott Laboratories	Abbot Park, Illinois	9.27
Amgen	Thousand Oaks, California	4.99
AstraZeneca	Wilmington, Delaware	17.84
Aventis	Bridgewater, New Jersey	17.25
Baxter Healthcare	Deerfield, Illinois	3.10
Bayer	West Haven, Connecticut	5.12
Boehringer Ingelheim	Ridgefield, Connecticut	7.92
Bristol-Myers Squibb	New York, NY	14.70
GlaxoSmithKline	Research Triangle Park, North Carolina	28.20
Hoffman-La Roche	Nutley, New Jersey	10.81
Johnson & Johnson	New Brunswick, New Jersey	17.20
Eli Lilly	Indianapolis, Indiana	11.07
Merck & Co.	Whitehouse Station, New Jersey	21.63
Novartis	East Hanover, New Jersey	15.36
Pharmacia ³	See note	12.03
Pfizer	New York, New York	28.28
Schering-Plough	Kenilworth, New Jersey	8.70
Wyeth	Madison, New Jersey	11.70

² Sales in Table 1 include all sales by each company categorized as “Pharmaceutical Companies” by the U.S. Census, and may include sales of products other than ethical drugs, such as healthcare or other products. Sales data are based on 2002 global sales (Sellers 2003).

³ Pfizer acquired Pharmacia in 2003, making Pfizer the largest pharmaceutical company in the world.

Table 2. Geographic distribution of the pharmaceutical industry by U.S. state in 2002.⁴ The top 10 states are given for employment and total value of shipments. States are presented in alphabetical order.

State	2002 Value of Shipments		2002 Employees	
	Billion \$	Share U.S. (%)	Number	Share U.S. (%)
California	10.60	7.5%	59,253	23.8%
Connecticut	3.09	2.2%	7,819	3.1%
Illinois	8.34	5.9%	22,373	9.0%
Indiana	7.52	5.3%	8,956	3.6%
Massachusetts	3.63	2.6%	9,118	3.7%
Michigan	3.78	2.7%	6,269	2.5%
New Jersey	13.10	9.3%	31,164	12.5%
New York	17.09	12.1%	22,264	8.9%
North Carolina	15.53	11.0%	13,413	5.4%
Pennsylvania	19.77	14.0%	11,770	4.7%
U.S.	141.15		249,384	

Sources: U.S. Census (2005a-2005e).

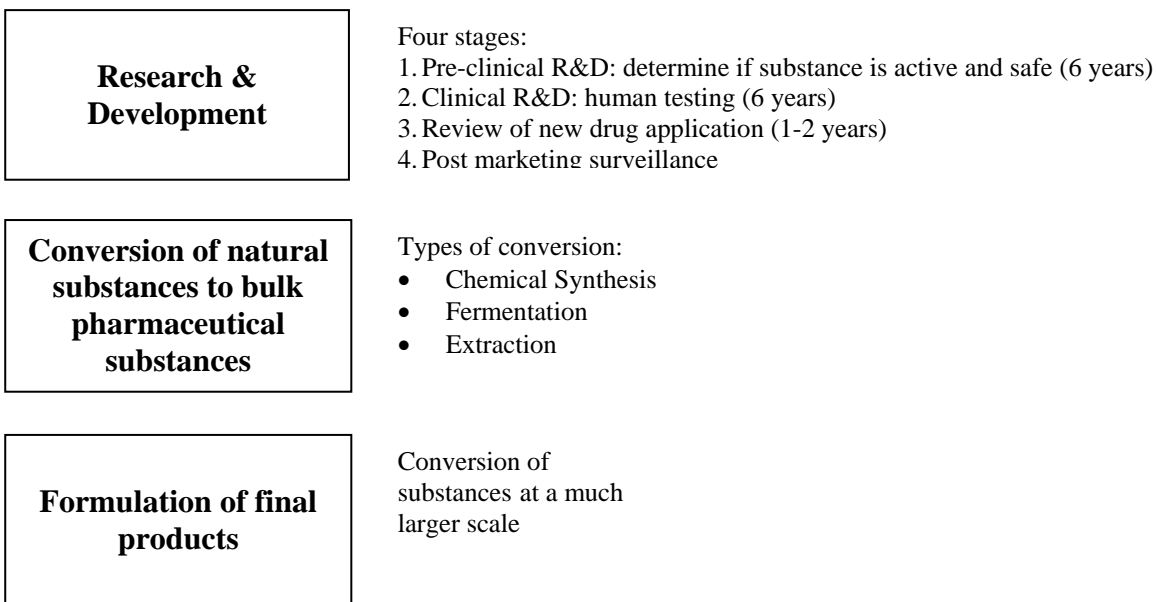
The pharmaceutical industry is also research intensive. The major pharmaceutical companies listed in Table 1 spent approximately \$42 billion in 2002 on research and development (R&D), or, on average, 17% of global sales (Sellers 2003). The pharmaceutical industry is therefore one of the most R&D intensive industries, both in the United States and in the world. Pharmaceutical production and research are also closely integrated; in fact, in many locations production facilities can be found next to R&D laboratories on the same site.

⁴ 2002 U.S. Census data for pharmaceutical manufacturing in Puerto Rico were not available at the time of this writing. However, 1997 U.S. Census data for Puerto Rico show direct employment of 24,892 and a total value of shipments of \$23.12 billion for the Puerto Rican pharmaceutical industry (U.S. Census 2000).

3. Process Description

There are three overall stages in the production of bulk pharmaceutical products: (1) R&D, (2) conversion of natural substances to bulk pharmaceuticals, and (3) formulation of final products. Figure 3 provides an overview of the main process steps in the manufacture of pharmaceuticals. Each of these stages is described in more detail below.⁵

Figure 3. Main process steps in the manufacture of pharmaceuticals.



3.1 Research & Development

Because it is highly regulated, R&D is the longest stage in pharmaceutical product manufacturing. After identifying several thousands of compounds at the beginning stages of R&D, only one will be introduced as a new pharmaceutical drug. Many resources go into this stage of development.

The four basic stages of R&D are listed above in Figure 3: (1) pre-clinical R&D, (2) clinical R&D, (3) review of new drug application, and (4) post marketing surveillance. In the pre-clinical R&D stage, compounds are tested on animals to determine biological activity and safety. This testing takes about six years on average to complete. After pre-clinical trials, an Investigational New Drug Application is filed with the U.S. Food and Drug Administration (FDA), the purpose of which is to provide data showing that it is reasonable to begin tests of a new drug on humans.

The next stage, clinical R&D, is typically conducted in three phases, each with progressively more human participants. The first phase of clinical R&D determines the safety of a new drug, the second phase determines a new drug's effectiveness, and the third phase provides

⁵ Further details on pharmaceutical manufacturing processes can be found in the U.S. EPA's *Profile of the Pharmaceutical Manufacturing Industry* (U.S. EPA 1997).

further confirmation of safety and effectiveness along with determination of any adverse reactions. The clinical R&D stage altogether takes, on average, about six years to complete.

At the next stage, the pharmaceutical company files a New Drug Application (NDA) with the U.S. FDA. As of 1996, approval times for NDAs were approximately 15 months (U.S. EPA 1997).

Finally, after a new drug has been approved for marketing, the U.S. FDA monitors the ongoing safety of marketed drugs via post marketing surveillance. Also, the pharmaceutical manufacturer will evaluate various ways of formulating the drug on a larger scale for optimum delivery.

3.2 Conversion to Bulk Pharmaceutical Substances

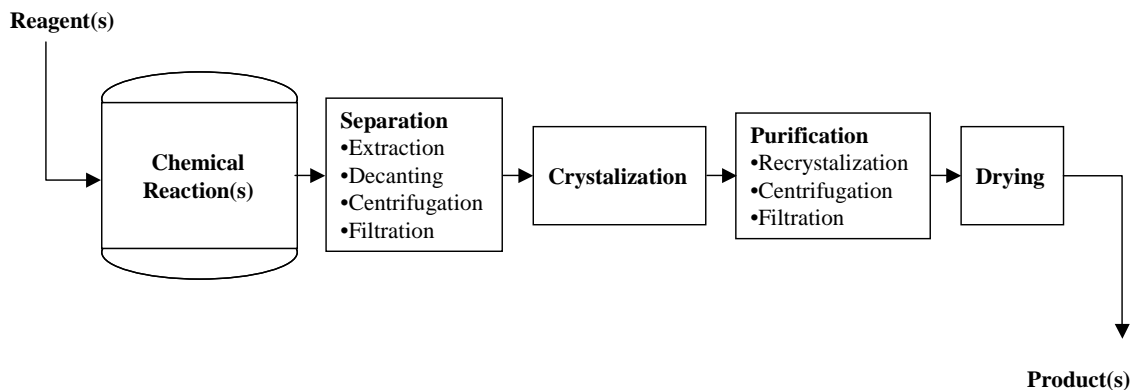
Bulk pharmaceutical substances are produced via chemical synthesis, extraction, fermentation, or a combination of these processes (U.S. EPA 1997). Antihistamines, cardiovascular agents, central nervous system stimulants, and hormones are produced by chemical synthesis. Enzymes and digestive aids, allergy relief medicines, hematological agents, insulin, anti-cancer drugs, and vaccines are extracted from naturally-occurring substances. Most steroids, antibiotics, and some food additives, like vitamins, are produced by fermentation. Antibiotics, antineoplastic agents, central nervous system depressants, and vitamins are typically produced by more than one of these three processes.

Chemical synthesis, extraction, and fermentation are discussed separately below. For further information on these processes, see the U.S. EPA's *Profile of the Pharmaceutical Manufacturing Industry* (U.S. EPA 1997).

Chemical Synthesis

Figure 4 shows a simplified diagram of the chemical synthesis process for pharmaceuticals. There are five primary stages in chemical synthesis: (i) reaction, (ii) separation, (iii) crystallization, (iv) purification, and (v) drying. Each of these five stages is described below.

Figure 4. Simplified chemical synthesis diagram (adapted from U.S. EPA 1997)



(i) *Reaction.* In the reaction process, raw materials are fed into a reactor vessel, where reactions such as alkylations, hydrogenations, or brominations are performed. The most common type of reactor vessel is the kettle-type reactor. These reactors, which are generally made of stainless steel or glass-lined carbon steel, range from 50 to several thousand gallons in capacity. The reactors may be heated or cooled, and reactions may be performed at atmospheric pressure, at elevated pressure, or in a vacuum. Generally, both reaction temperature and pressure are monitored and controlled. Nitrogen may be required for purging the reactor, and some intermediates may be recycled back into the feed. Some reactions are aided via mixing action provided by an agitator. A condenser system may be required to control vent losses. Reactors are often attached to pollution control devices to remove volatile organics or other compounds from vented gases.

(ii) *Separation.* The main types of separation processes are extraction, decanting, centrifugation, filtration, and crystallization. Crystallization is used by many plants and is discussed separately below.

The extraction process is used to separate liquid mixtures. Extraction takes advantage of the differences in the solubility of mixture components. A solvent that preferentially combines with only one of the mixture components is added to the mixture. Two streams result from this process: the extract, which is the solvent-rich solution containing the desired mixture component, and the raffinate, which is the residual feed solution containing the non-desired mixture component(s).

Decanting is a simple process that removes liquids from insoluble solids that have settled to the bottom of a reactor or settling vessel. The liquid is either pumped out of the vessel or poured from the vessel, leaving only the solid and a small amount of liquid in the vessel.

Centrifugation is a process that removes solids from a liquid stream using the principle of centrifugal force. A liquid-solid mixture is added to a rotating vessel—or centrifuge—and an outward force pushes the liquid through a filter that retains the solid phase. The solids are manually scraped off the sides of the vessel or with an internal scraper. To avoid air infiltration, centrifuges are usually operated under a nitrogen atmosphere and kept sealed during operation.

Filtration separates fluid/solid mixtures by flowing fluid through a porous media, which filters out the solid particulates. Batch filtration systems widely used by the pharmaceutical industry include plate and frame filters, cartridge filters, nutsche filters, and filter/dryer combinations.

(iii) *Crystallization.* Crystallization is a widely used separation technique that is often used alone or in combination with one or more of the separation processes described above. Crystallization refers to the formation of solid crystals from a supersaturated solution. The most common methods of super saturation in practice are cooling, solvent evaporation, and chemical reaction. The solute that has crystallized is subsequently removed from the solution by centrifugation or filtration.

(iv) *Purification*. Purification follows separation, and typically uses the separation methods described above. Several steps are often required to achieve the desired purity level. Recrystallization is a common technique employed in purification. Another common approach is washing with additional solvents, followed by filtration.

(v) *Drying*. The final step in chemical synthesis is drying the product (or intermediates). Drying is done by evaporating solvents from solids. Solvents are then condensed for reuse or disposal. The pharmaceutical industry uses several different types of dryers, including tray dryers, rotary dryers, drum or tumble dryers, or pressure filter dryers. Prior to 1980, the most common type of dryer used by the pharmaceutical industry was the vacuum tray dryer. Today, however, the most common dryers are tumble dryers or combination filter/dryers. In the combination filter/dryer, an input slurry is first filtered into a cake, after which a hot gaseous medium is blown up through the filter cake until the desired level of dryness is achieved. Tumble dryers typically range in capacity from 20 to 100 gallons. In tumble dryers, a rotating conical shell enhances solvent evaporation while blending the contents of the dryer. Tumble dryers utilize hot air circulation or a vacuum combined with conduction from heated surfaces.

Product Extraction

Active ingredients that are extracted from natural sources are often present in very low concentrations. The volume of finished product is often an order of magnitude smaller than the raw materials, making product extraction an inherently expensive process.

Precipitation, purification, and solvent extraction methods are used to recover active ingredients in the extraction process. Solubility can be changed by pH adjustment, by salt formation, or by the addition of an anti-solvent to isolate desired components in precipitation. Solvents can be used to remove active ingredients from solid components like plant or animal tissues, or to remove fats and oils from the desired product. Ammonia is often used in natural extraction as a means of controlling pH.

Fermentation

In fermentation, microorganisms are typically introduced into a liquid to produce pharmaceuticals as by-products of normal microorganism metabolism. The fermentation process is typically controlled at a particular temperature and pH level under a set of aerobic or anaerobic conditions that are conducive to rapid microorganism growth. The process involves three main steps: (i) seed preparation, (ii) fermentation, and (iii) product recovery.

(i) *Seed preparation*. The fermentation process begins with seed preparation, where inoculum (a medium containing microorganisms) is produced in small batches within seed tanks. Seed tanks are typically 1-10% of the size of production fermentation tanks (U.S. EPA 1997).

(ii) *Fermentation*. After creating the inoculum at the seed preparation stage, the inoculum is introduced into production fermentors. In general, the fermentor is agitated, aerated, and controlled for pH, temperature, and dissolved oxygen levels to optimize the fermentation process. The fermentation process lasts from hours to weeks, depending on the product and process.

(iii) *Product Recovery*. When fermentation is complete, the desired pharmaceutical by-products need to be recovered from the fermented liquid mixture. Solvent extraction, direct precipitation, and ion exchange may be used to recover the product. Additionally, if the product is contained within the microorganism used in fermentation, heating or ultrasound may be required to break the microorganism's cell wall. In solvent extraction, organic solvents are employed to separate the product from the aqueous solution. The product can then be removed from the solvent by crystallization. In direct precipitation, products are precipitated out of solution using precipitating agents like metal salts. In ion exchange, the product adsorbs onto an ion exchange resin and is later recovered from the resin using solvents, acids, or bases.

3.3 Formulation of Final Products

The final stage of pharmaceutical manufacturing is the conversion of manufactured bulk substances into final, usable forms. Common forms of pharmaceutical products include tablets, capsules, liquids, creams and ointments, aerosols, patches, and injectable dosages. Tablets account for the majority of pharmaceutical solids taken orally in the United States (U.S. EPA 1997).

To prepare a tablet, the active ingredient is combined with a filler (such as sugar or starch), a binder (such as corn syrup or starch), and sometimes a lubricant (such as magnesium stearate or polyethylene glycol). The filler ensures the proper concentration of the active ingredient; the purpose of the binder is to bond tablet particles together. The lubricant may facilitate equipment operation during tablet manufacture and can also help to slow the disintegration of active ingredients.

Tablets are produced via the compression of powders. Wet granulation or dry granulation processes may be used. In wet granulation, the active ingredient is powdered and mixed with the filler, wetted and blended with the binder in solution, mixed with lubricants, and finally compressed into tablets. Dry granulation is used when tablet ingredients are sensitive to moisture or drying temperatures. Coatings, if used, are applied to tablets in a rotary drum, into which the coating solution is poured. Once coated, the tablets are dried in the rotary drum; they may also be sent to another drum for polishing.

Capsules are the second most common solid oral pharmaceutical product in the United States after tablets (U.S. EPA 1997). Capsules are first constructed using a mold to form the outer shell of the capsule, which is typically made of gelatin. Temperature controls during the molding process control the viscosity of the gelatin, which in turn determines the thickness of the capsule walls. The capsule's ingredients are then poured (hard capsules) or injected (soft capsules) into the mold.

For liquid pharmaceutical formulations, the active ingredients are weighed and dissolved into a liquid base. The resulting solutions are then mixed in glass-lined or stainless steel vessels and tanks. Preservatives may be added to the solution to prevent mold and bacterial growth. If the liquid is to be used orally or for injection, sterilization is required.

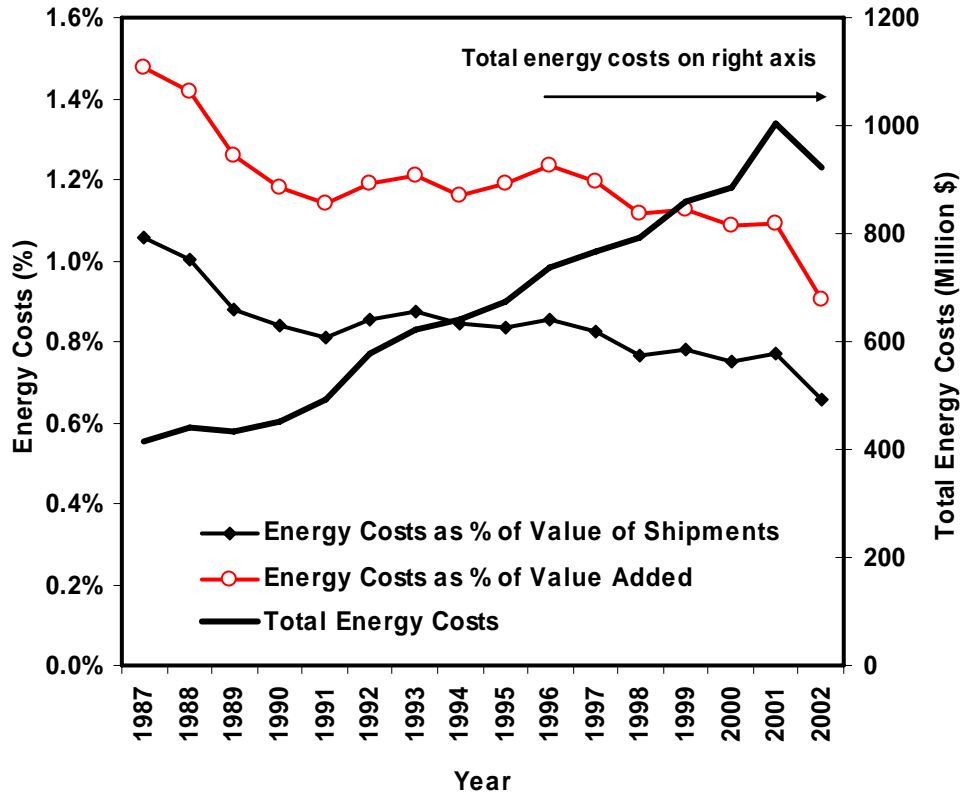
Ointments are made by blending active ingredients with a petroleum derivative or wax base. The mixture is cooled, rolled out, poured into tubes, and packaged.

Creams are semisolid emulsions of oil-in-water or water-in-oil; each phase is heated separately and then mixed together to form the final product.

4. Energy Use in the U.S. Pharmaceutical Industry

The U.S. pharmaceutical industry's energy costs have grown steadily since 1987, and closely follow the industry's increases in value added and value of shipments over the past two decades (see Figure 1). Figure 5 plots the U.S. pharmaceutical industry's energy costs, energy costs as a percentage of value added, and energy costs as a percentage of value of shipments from 1987-2002. Figure 5 shows that total energy costs have increased steadily since 1987, while energy costs as a percentage of production (i.e., value added and value of shipments) have decreased over the same period. The downward trend in energy costs as a percentage of value added and value of shipments can be due to changes in the activities and profitability of the industry, and may not necessarily indicate that the energy consumed per physical unit of product has changed over the same period.

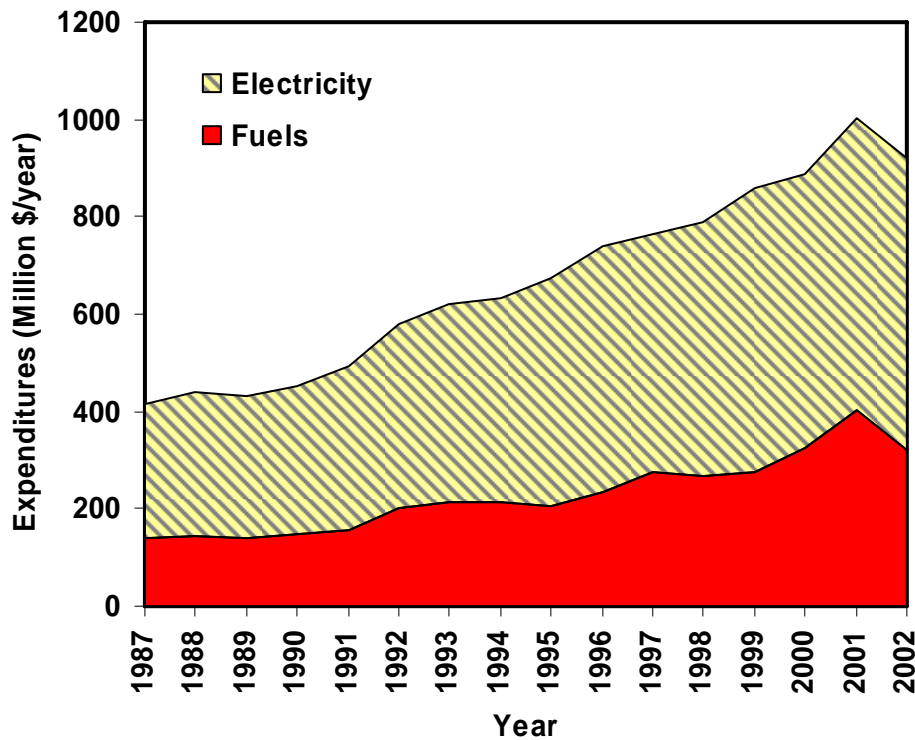
Figure 5. Historical trends in energy costs for the U.S. pharmaceutical industry.



Sources: U.S. Census (1990, 1993, 1995, 1996, 1998, 2003, 2005a).

Figure 6 shows the energy expenditures of the U.S. pharmaceutical industry from 1987-2002, broken down by electricity and fuel expenditures. Expenditures on both electricity and fuels have risen steadily since 1987. However, electricity expenditures have risen at a higher rate than fuel expenditures. The actual electricity use in the U.S. pharmaceutical industry did not increase as rapidly as electricity costs, as shown in Figure 7.

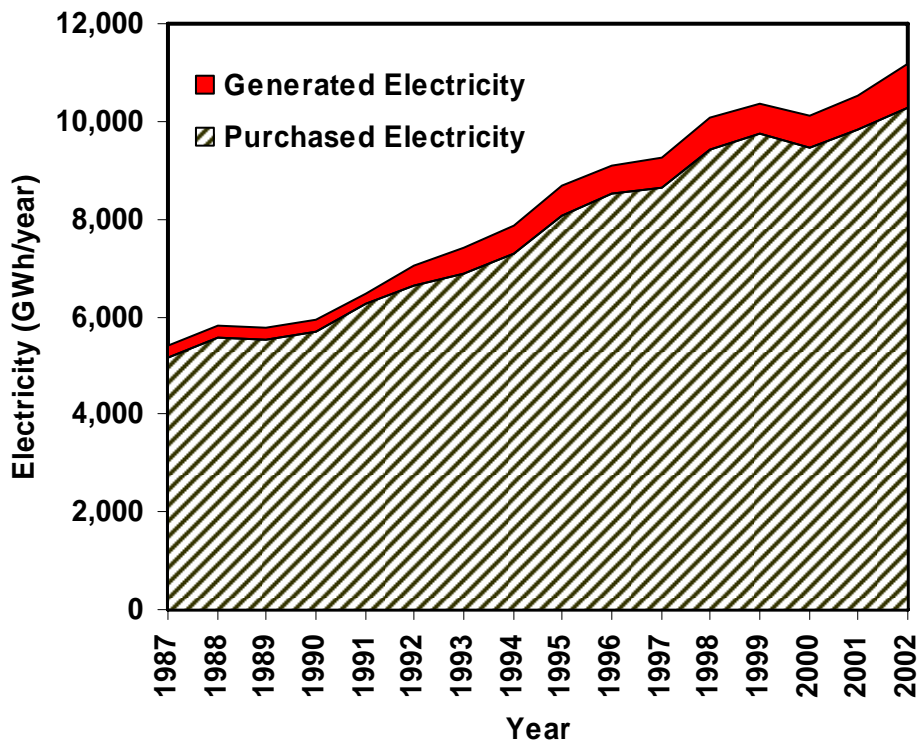
Figure 6. Historical energy expenditures of the U.S. pharmaceutical industry.



Sources: U.S. Census (1990, 1993, 1995, 1996, 1998, 2003, 2005a).

Figure 7 depicts the trend in total electricity consumption in the U.S. pharmaceutical industry from 1987-2002. It can also be seen in Figure 7 that the use of cogeneration is still limited in the U.S. pharmaceutical industry, despite a slight increase since 1987. In 1987, electricity generation accounted for 4.8% of total electricity consumption; by 2002, that percentage had risen to 8.8%.

Figure 7. Historical electricity consumption in the U.S. pharmaceutical industry.



Sources: U.S. Census (1990, 1993, 1995, 1996, 1998, 2003, 2005a).

Energy is used for a wide variety of applications within the U.S. pharmaceutical industry. Chapter 3 discussed the range of different process technologies used in pharmaceutical production; the particular processes employed in a production sequence will vary by product and by plant. Hence, energy use will vary widely from location to location. The key factors affecting a plant’s energy consumption include facility type (e.g., R&D or bulk production), the products produced, the plant’s location, and the efficiency of the plant’s major systems. However, based on the typical steps in the pharmaceutical manufacturing process and the types of energy end uses necessary to support this process, it is possible to develop a rough breakdown of the industry’s energy consumption.

Table 3 provides an estimated energy consumption breakdown for the U.S. pharmaceutical industry as a whole, categorized by major activity area (listed in rows) and end use (listed in columns). The estimates in Table 3 do not refer to any particular plant, nor do they attempt to estimate the energy use at a "typical" pharmaceutical plant.⁶ In addition, Table 3 shows the main energy uses for each activity area and end use category. The energy distribution in Table 3 may not apply to all facilities nor is it assumed to be exhaustive.

⁶ Because of the variability between plants in the pharmaceutical industry today, including some facilities that only contain one activity area listed in Table 3, this Energy Guide does not attempt to define a "typical" pharmaceutical plant.

Heating, ventilation, and air conditioning (HVAC) is typically the most important energy end use in the pharmaceutical industry. Table 3 also shows that R&D and bulk manufacturing are typically the most important energy consuming activities in the pharmaceutical industry.

Table 3. Distribution of energy use in the pharmaceutical industry.

	Overall	Plug loads and processes	Lighting	Heating, ventilation and air conditioning (HVAC)
Total	100%	25%	10%	65%
R&D	30%	Microscopes Centrifuges Electric mixers Analysis equipment Sterilization processes Incubators Walk in/reach in areas (refrigeration)	Task and overhead lighting	Ventilation for clean rooms and fume hoods Areas requiring 100% make-up air Chilled water Hot water and steam
Offices	10%	Office equipment including computers, fax machines, photocopiers, printers Water heating (9%)*	Task, overhead, and outdoor lighting	Space heating (25%)* Cooling (9%)* Ventilation (5%)*
Bulk Manufacturing	35%	Centrifuges Sterilization processes Incubators Dryers Separation processes	Task and overhead lighting	Ventilation for clean rooms and fume hoods Areas requiring 100% make-up air Chilled water Hot water and steam
Formulation, Packaging & Filling	15%	Mixers Motors	Mostly overhead, some task	Particle control ventilation
Warehouses	5%	Forklifts Water heating (5%)*	Mostly overhead lighting	Space heating (41%)* Refrigeration (4%)*
Miscellaneous	5%		Overhead	

* Percentages for water heating, space heating, cooling, refrigeration, and ventilation are derived from the U.S. DOE's Commercial Building Energy Consumption Survey (CBECS) for commercial office or warehouse buildings (U.S. DOE 1999). These numbers are only shown as first approximations and in reality will vary from facility to facility.

5. Energy Efficiency Opportunities for the Pharmaceutical Industry

A variety of opportunities exist within U.S. pharmaceutical laboratories, manufacturing facilities, and other buildings to reduce energy consumption while maintaining or enhancing productivity. Table 4 categorizes available energy efficiency opportunities by the six major activity areas listed in Table 3: (1) R&D, (2) bulk manufacturing, (3) formulation, packaging and filling, (4) warehouses, (5) offices, and (6) miscellaneous. For each major activity area, Table 4 also provides references to the sections in this Energy Guide that describe relevant energy efficiency measures. Measure descriptions include case studies for U.S. pharmaceutical plants with specific energy and cost savings data, when such case study data are available. For measures where data are not available for U.S. pharmaceutical plants, this Energy Guide includes case study data from non-U.S. pharmaceutical facilities or case study data from similar industries (for example, chemical manufacturing).

For individual pharmaceutical facilities, the actual payback period and savings associated with a given measure will vary depending on facility activities, configuration, size, location, and operating characteristics. Hence, the values presented in the Energy Guide are offered as guidelines. Wherever possible, this Energy Guide will provide a typical range of savings and payback periods for each measure found under varying conditions.

Although technological changes in equipment conserve energy, changes in staff behavior and attitude can also have a great impact. Energy efficiency training programs can help a company's staff incorporate energy efficiency practices into their day-to-day work routines. Personnel at all levels should be aware of energy use and company objectives for energy efficiency improvement. Often such information is acquired by lower-level managers but neither passed up to higher-level management nor passed down to staff (Caffal 1995). Energy efficiency programs with regular feedback on staff behavior, such as reward systems, have had the best results. Though changes in staff behavior (such as switching off lights or closing windows and doors) often save only small amounts of energy at one time, taken continuously over longer periods they can have a much greater effect than more costly technological improvements. Other staff actions such as the closing of fume hood sashes could result in significant and immediate improvement. A further discussion of energy management programs and practices is offered in section 5.1 of this Energy Guide.

Establishing formal management structures and systems for managing energy that focus on continuous improvement are important strategies for helping companies manage energy use and implement energy efficiency measures. The U.S. EPA's ENERGY STAR program has developed a framework for energy management based on the observed best practices of leading companies. Other management frameworks, such as ISO 14001, can be used to ensure better 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.

Table 4. Energy efficiency opportunities for the pharmaceutical industry, categorized by major activity area. Each entry refers to a specific section (number) in this Energy Guide.

Research and Development	Bulk Manufacturing
Energy Management (5.1) HVAC (5.2) Fume Hoods (5.3) Cleanrooms (5.4) Lighting (5.9)	Energy Management (5.1) HVAC (5.2) Cleanrooms (5.4) Motor Systems (5.5) Compressed Air Systems (5.6) Pumps (5.7) Refrigeration (5.8) Heat and Steam Distribution (5.10)
Formulation, Packaging and Filling	Offices
Energy Management (5.1) HVAC (5.2) Cleanrooms (5.4) Motor Systems (5.5) Compressed Air Systems (5.6) Pumps (5.7) Refrigeration (5.8) Lighting (5.9)	Energy Management (5.1) HVAC (5.2) Lighting (5.9) Miscellaneous (5.12)
Warehouses	Miscellaneous
Energy Management (5.1) HVAC (5.2) Motor Systems (5.5) Refrigeration (5.8) Lighting (5.9)	Energy Management (5.1) HVAC (5.2) Motor Systems (5.5) Lighting (5.9) Heat and Steam Distribution (5.10) Cogeneration (5.11) Miscellaneous (5.12)

5.1 Energy Management Systems and Programs

Improving energy efficiency should be approached from several directions. A strong, corporate-wide energy management program is essential. Ideally, such a program would include facility, operations, environmental, health, and safety, and management personnel. Energy efficiency improvements to cross-cutting technologies⁷, such the use of energy efficient motors and the optimization of compressed air systems, present well-documented opportunities for energy savings. Optimizing system design and operations, such as minimizing laboratory ventilation, can also lead to significant reductions in energy use. In addition, production process can often be fine-tuned to produce similar savings.

⁷ Cross-cutting technologies are defined as equipment that is commonly used in many different sectors, such as boilers, pumps, motors, compressed air systems, and lighting.

Energy management programs. 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.

Energy efficiency does not happen on its own. A strong 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 also 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. Furthermore, 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 an effective energy management program.⁸ The major elements in a strategic energy management program are depicted in Figure 7.

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. Steps and procedures are then put in place to assess performance through regular reviews of energy data, technical 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. 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 in Appendix A.

Progress evaluation 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. Once best practices are established, the goal of the cross-functional energy team should be to replicate these practices throughout the organization. Establishing a strong communications

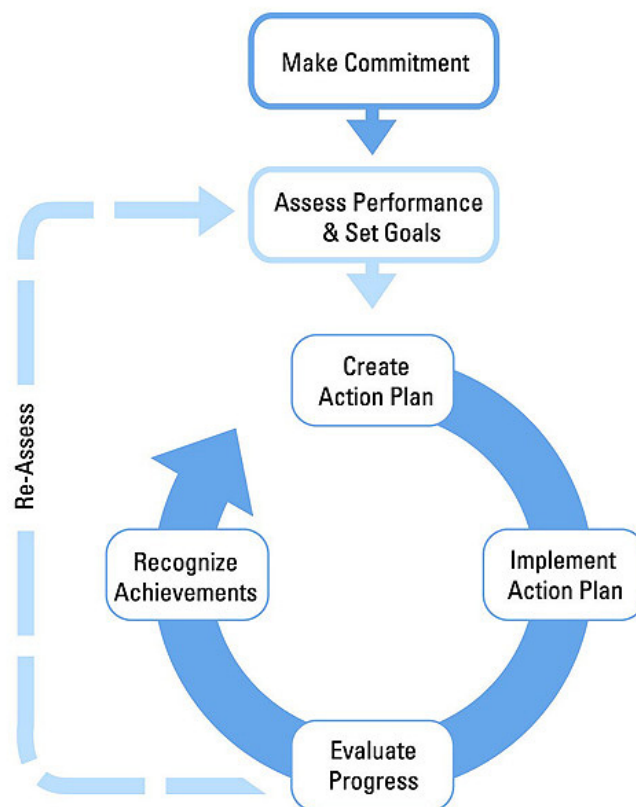
⁸ Read more about strategic energy management at www.energystar.gov.

program and seeking recognition for accomplishments are also critical steps. Strong communication and receiving 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 its current energy management program against the ENERGY STAR Energy Program Assessment Matrix provided in Appendix B.⁹

Internal support for a business energy management program is crucial; however, support for business energy management programs can come from outside sources as well. Some utility companies work together with industrial clients to achieve energy savings. In these cases, utility personnel work directly with the company onsite.

Figure 7. Main elements of a strategic energy management program.



Energy monitoring systems. Energy monitoring systems and process control systems are key tools that play an important role in energy management and in reducing energy use. Such systems may include sub-metering, monitoring, and control systems. They can reduce the time required to perform complex tasks, often improve product and data quality as well as consistency, and optimize process operations. Monitoring and metering systems also play a

⁹ Another useful reference for implementing energy management programs is the U.S. EPA and DOE sponsored report *Fifteen O&M Best Practices for Energy Efficient Buildings* (PECI 1999).

key role in alerting energy teams to problem areas and in assigning accountability for energy use. Additionally, such systems can be useful in corporate greenhouse gas accounting initiatives; they are also helpful in profiling energy use at ENERGY STAR partners. Typically, energy and cost savings are around 5% or more for many industrial applications of monitoring and control systems. These savings apply to plants without updated process control systems; many U.S. plants may already have modern process control systems in place to improve energy efficiency.

The Wyeth Fort Dodge Animal Health pharmaceutical manufacturing facility in Campinas, Brazil, installed a state-of-the-art metering, monitoring, and targeting system to help reduce electrical demand during peak periods. This project resulted in a 48% reduction in electricity use, a 10% reduction in facility utility costs, and increased energy awareness among employees (Wyeth 2004).

5.2 Heating, Ventilation, and Air Conditioning (HVAC) Systems

The components of HVAC systems generally include dampers, supply and exhaust fans, filters, humidifiers, dehumidifiers, heating and cooling coils, ducts, and various sensors (Cole 1998). In Table 3, it was estimated that the average percentage of electricity and fuel consumed by HVAC components in the pharmaceutical industry is around 65%.

Different spaces and building uses require different HVAC applications. For manufacturing facilities and some laboratory facilities in the U.S. pharmaceutical industry, HVAC components—as well as modifications to those components—are closely supervised by the U.S. FDA. Moreover, the U.S. pharmaceutical industry is required to meet a host of domestic and foreign standards (e.g., the U.S. Federal Code of Regulations, British Standards, and EU Standards). An effort to consolidate such standards into one unified set is currently underway at the International Organization of Standardization (ISO). As a result of such regulation, energy efficiency measures that affect the work environment must undergo a thorough review to ensure that proposed modifications will not affect regulatory compliance. The U.S. FDA requires companies to conform to cGMP (current Good Manufacturing Practices), which requires companies to document how they intend to design and operate a facility. While cGMP theoretically allows for new approaches, these new approaches would need to be defended. The additional defense (and risks associated with a delay in approval of building plans) may in some cases perpetuate less energy efficient designs.

When a company must retrofit an existing building to comply with new regulations, it is often advantageous to implement energy efficiency measures during the production downtime that occurs when facilities are being overhauled. However, for non-regulated buildings such as offices and warehouses, energy efficiency measures can be implemented independent of regulatory approvals that apply to production and R&D spaces.

A Novartis plant in Rzeszow (Poland) offers a good example of how investments in HVAC system efficiencies can lead to significant energy savings. At the Rzeszow plant, Novartis installed microprocessor controls on its HVAC system that could be programmed to better balance plant heating based on outside temperatures and also reduce heating loads on

weekends. It is anticipated that this modification will lead to a 10% reduction in overall heating energy consumption. Novartis also invested in a more modern HVAC system for the plant's baby food filling process. The old HVAC system was comprised of convection heaters and heating fan systems. Novartis replaced this system with an integrated heating-and-ventilation system controlled by microprocessors, which offered both improved air quality and improved temperature regulation during both winter and summer seasons. This change has led to a dramatic improvement in both air quality and comfort. A further increase in power efficiency has been achieved through the installation of heat recovery filters at the system's air outlets, which offered expected energy savings of approximately 5% (Novartis 2004).

There are many energy efficiency measures that can be applied to HVAC systems; some of the most significant opportunities are discussed below. Additionally, there are many energy efficiency measures that apply to motors, compressed air systems, and heat and steam distribution systems that can also be leveraged to improve HVAC system efficiency. Measures for motors, compressed air systems, and heat and steam distribution systems are discussed in more detail in Sections 5.5, 5.6, and 5.9 of this Energy Guide.

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 pharmaceutical manufacturer can minimize the energy consumption and operational costs of its plant 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. Later HVAC modification may also require review and approval by the U.S. FDA, which can lead to further delays and production downtime.

The U.S. EPA's Laboratories for the 21st Century (Labs 21) program has compiled tips for the energy efficient design of new labs and cleanrooms, many of which can be applied to pharmaceutical industry facilities (U.S. EPA/DOE 2000). Further information on the Labs 21 Program can be found at <http://www.labs21century.gov/>.

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>). More details on many of the measures employed in recommissioning can be found in later sections of this Energy Guide.

In 2002, Pfizer implemented an HVAC recommissioning project in four buildings at its Morris Plains, New Jersey, location (Dome-Tech 2005a). To date, Pfizer has experienced a 21% net decrease in energy consumption per degree-day as a result of this project.

At Ethicon's Somerville, New Jersey, location, a recommissioning project on a 180,000 ft² multi-use facility identified 231 opportunities for energy conservation and reduction (Dome-Tech 2005b). This recommissioning project involved design and installation reviews, data logging to identify areas of non-conformance, physical inspection of air handlers, and verification of HVAC system balance and air flows to various spaces (among other efforts). Project implementation costs were \$53,000; annual savings in gas and electricity amounted to \$48,000, leading to a payback period of just 1.1 years.

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 (U.S. EPA/DOE 2000). Several industrial case studies from the United States indicate that the average payback period for HVAC control systems is about 1.3 years (IAC 2003).

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. Similarly, reducing ventilation in cleanrooms and laboratories during periods of non-use can also lead to energy savings. In recent studies of laboratories and cleanrooms in the pharmaceutical and similar industries, HVAC systems were found to account for up to two-thirds of facility energy consumption (Tschudi and Xu 2003). Thus, scaling back HVAC energy consumption during periods of non-use can have a major impact.

At Merck's Rahway, New Jersey, laboratory facilities, HVAC systems are designed with once-through air exchange based on safety considerations. To improve the energy efficiency of these systems, Merck utilized control technologies to lower selected room temperatures from 72°F to 64°F during nights and weekends. An interlock with room lighting overrides the set-back. This control strategy was implemented for rooms where lower temperatures would not impact scientific equipment, and covered 150 individual laboratory spaces encompassing over 350,000 ft² of floor space. The energy savings associated with this project totaled nearly 30,000 MBtu per year. The energy-related carbon dioxide (CO₂) emissions avoided through this project amounted to over 1,700 tons per year (Merck 2005).

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%. 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).

Discharge air temperature management. In facilities with make-up air handling systems, energy can be wasted when cooled make-up air must be reheated. By setting higher discharge air temperatures when demand for cooling decreases, unnecessary reheating of the make-up air supply can be reduced. At Genentech's Vacaville facility, a new control system was implemented to reset the discharge air temperature from 55°F to 60°F under periods of low cooling demand. This temperature adjustment prevented overcooling and subsequent unnecessary reheating of supply air, thereby saving chilled water and steam plant energy. This measure was expected to have annual energy cost savings of around \$150,000 per year (CIEE 2000a).

Variable-air-volume (VAV) 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 optimize the air flow within HVAC ductwork. By optimizing air flow, the loads on building air handling units can be reduced, thereby leading to reduced electricity consumption.

Adjustable speed drives (ASDs).¹⁰ 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.

The Louis Stokes Laboratories of the U.S. National Institutes of Health recently implemented a VAV system with adjustable speed drives (ASDs). The ASDs control the speed of HVAC supply and exhaust fans 25% more efficiently than the standard inlet vane controls that were used the past. Although the VAV system was a more complicated and expensive control system than the previous system, the VAV system used 30-50% less energy than the previous system did and thus led to significant energy cost savings over time (U.S. EPA/DOE 2001b). The VAV also reduced the volume of air delivered when the building is unoccupied, from a maximum volume of 400,000 cfm, or 15 air changes per hour (ACH), to 160,000 cfm, or 6 ACH, delivering further energy savings. Similarly, a VAV system installed at the Fred Hutchinson Cancer Research Center in Seattle, Washington, reduced necessary air changes from 10 ACH down to 6 ACH (U.S. EPA/DOE 2001a).

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. For areas requiring 100% make-up air, studies have shown that heat recovery systems can reduce a facility's heating/cooling cost by about 3% for each degree (Fahrenheit) that the intake air is raised/lowered. The payback period is typically three years or less (Tetley 2001). Heat wheels installed at the Whitehead Biomedical Research Building in Atlanta, Georgia, demonstrated a heat exchange efficiency of 75% and a payback period of less than 4 years (U.S. EPA/DOE 2003). The efficiency of heat pipes is in the 45-65% range (U.S. EPA/DOE 2003), while the efficiency of run-around loops can be slightly higher, in the 55-65% range (U.S. EPA/DOE 2001a).

In 2004, Merck in Rahway, New Jersey, installed a glycol run-around loop system to recover heat from HVAC exhaust air at a 37,000 ft² laboratory building. After installation, the building was able to pre-heat and pre-cool up to 120,000 cfm of outside air with recovered energy. The energy savings associated with this measure amounted to roughly 265 MBtu per year, which led to avoided CO₂ emissions of over 30 tons per year (Merck 2005).

¹⁰ Several terms are used in practice to describe a system that permits a mechanical load to be driven at user-selected 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.

HVAC chiller efficiency improvement. The efficiency of chillers can be improved by lowering the temperature of the condenser water, thereby increasing the chilled water temperature differential. This can reduce pumping energy requirements. Another possible efficiency measure is the installation of separate high-temperature chillers for process cooling (Tschudi and Xu 2003).

Sizing chillers to better balance chiller load with demand is also an important energy efficiency strategy. At Genentech's facility in Vacaville, California, two 1,400 ton chillers and one 600 ton chiller were chosen instead of three equally-sized chillers. This selection was made in an effort to operate the chillers at as close to full load as possible, where they are most efficient. The two larger chillers are run at full load and the smaller chiller is run to supply additionally cooling only on an as-needed basis, reducing energy needs. The cost savings associated with this chiller selection strategy were estimated to be \$113,250 per year (CIEE 2000a).

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. At a Toyota plant, the sheaves of fans were optimized in lieu of installing ASDs on fans. Toyota found better savings and payback periods with sheave modification than they anticipated to experience from ASDs (Toyota 2002).

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 than centrifugal fans, and can also be cheaper to install and maintain. The expected payback period for this measure is around 2 years (Tetley 2001).

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 and 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 3 years. In addition to energy savings, the system provides clean fresh air for its employees, evens out hot and cold spots in the plant and reduces 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 they 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 ft² 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. Much of the existing building stock in the United States is not insulated to the best level. 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 2002a).¹¹

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 (see also section 5.8).

¹¹ For homes, ENERGY STAR has established guidelines on the preferred level of insulation for different climate zones (see: http://www.energystar.gov/index.cfm?c=home_sealing.hm_improvement_insulation_table).

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.¹²

5.3 Fume Hoods

Fume hoods are commonly installed in R&D laboratory facilities in the pharmaceutical industry. Fume hoods capture, contain, and exhaust hazardous gases generated by laboratory activities and industrial process and therefore protect workers from breathing harmful substances (Mills and Sartor 2004). The energy required to heat and cool make-up air for laboratory fume hoods can account for a significant fraction of laboratory HVAC energy consumption. Fume hoods are often operated at high air exchange rates in an effort to guarantee the safety of occupants in the facility. However, significant energy savings can often be realized by using low-flow fume hoods and variable flow exhaust systems.

Improved storage/housekeeping. Fume hoods are often used as temporary storage spaces for chemicals and instruments in laboratory environments. However, this practice can require that fume hood exhaust systems run continuously, leading to unnecessarily high energy consumption. Improved housekeeping and storage practices, whereby chemicals and instruments are always kept in their proper storage locations and unused fume hoods are kept closed, would help to reduce hood energy consumption.

Restriction of sash openings. The restriction of fume hood sash openings reduces the volumetric flow rate necessary to maintain a constant airflow velocity across the face of the hood. A reduced volumetric flow requirement can facilitate lower energy consumption in variable flow hoods. A fume hood's sash opening can be limited either by restricting the vertical sash movement or by using a horizontal sash to block the hood's entrance (Mills and Sartor 2004). Furthermore, sashes on unattended fume hoods should remain closed whenever possible. In an assumed laboratory with 48 fume hoods, it was estimated that by closing the sashes on unattended fume hoods in a VAV system (see discussion on VAV hoods below), energy savings would be around \$3,200 per year (RC Associates 2002).

Promotion of a vortex in tops of fume hoods. A "bi-stable" vortex can enhance a fume hood's containment performance while also reducing its direct and indirect energy consumption. The vortex is promoted and maintained within the hood via adjustable panels in the top of the hood. According to one manufacturer, the bi-stable vortex hood provides maximum containment but consumes only 40% of the energy required by conventional hoods (United Lab Equipment 2001). Additionally, the bi-stable vortex hood can lower necessary air exchange rates, leading to savings in facility HVAC energy consumption as well.

¹² For more information on Low-E windows see: <http://www.efficientwindows.org/>.

Variable-air-volume (VAV) hoods. Constant-air-volume (CAV) hoods, which maintain a constant volumetric exhaust rate regardless of hood face airflow requirements, have been the mainstay in many U.S. laboratories. Variable-air-volume hoods, which employ ASDs and direct digital control systems to adjust exhaust airflow based on face velocity requirements, can offer considerable energy savings compared to CAV hoods. Variable-air-volume hoods save energy by minimizing the volumetric flow rate of hood exhaust, which can lead to significant reductions in the amount of exhaust air that must be conditioned by a building's HVAC system (Mills and Sartor 2004). The Louis Stokes Laboratories of the U.S. National Institutes of Health recently installed VAV hoods and experienced savings in energy consumption of up to 70% compared with conventional CAV hoods (U.S. EPA/DOE 2001b). Pharmacia also adopted VAV hoods, which cut exhaust airflow volume by over 50% when hood sashes are closed, leading to reductions in the energy required to condition make-up air (U.S. EPA/DOE 2002a).

Berkeley Hood. The "Berkeley Hood," developed by Lawrence Berkeley National Laboratory, has several advantages over traditional fume hoods (Bell et al. 2003). First, the Berkeley Hood reduces exhaust airflow requirements by 50-70%, which can result in energy savings of around \$2,100 per year per fume hood. Exhaust airflow requirements are reduced via low velocity fans installed at the top and bottom of the hood sash, which form an "air divider" between the hood's interior and exterior, thereby reducing interior airflow requirements. Second, it offers lower installation costs than traditional VAV fume hoods. Third, its high efficiency lighting system can lower the electricity required for hood lighting by up to 50%.¹³

The Berkeley Hood is not yet commercially available. One of the primary barriers to its commercialization are current Occupational Safety and Health Administration (OSHA) standards that prescribe a fume hood face velocity of at least 100 feet per minute rather than prescribing air quality criteria for containment performance. However, future comparisons of the Berkeley Hood's containment performance to that of standard fume hoods should prove its adequacy.

5.4 Cleanrooms

A cleanroom can be defined as an enclosed area in which ambient conditions—including airborne particles, temperature, noise, humidity, air pressure, air motion, vibration, and lighting—are strictly controlled. A significant portion of floor space in pharmaceutical and biotechnology facilities can be occupied by cleanrooms (Mills et al. 1996). In general, the largest consumers of energy in cleanrooms are the HVAC system (e.g., systems for chilled water, hot water, and steam) and process machinery. A recent study found that HVAC systems accounted for 36-67% of cleanroom energy consumption (Tschudi et al. 2001). Another recent study estimated the following energy distribution for cleanroom operation: 56% for cooling, 36% for heating, 5% for fans, and 3% for pumps (IEC 2002).

In the U.S. pharmaceutical industry, proper cleanroom filtration and pressure differentials have to be maintained to meet strict U.S. FDA requirements. Many issues regarding the

¹³ Further information on the Berkeley Hood can be found at <http://ateam.lbl.gov/hightech/fumehood/fhood.html>.

optimization of HVAC systems have been addressed in the preceding section; additional energy efficiency measures specific to cleanrooms are discussed below.

The Labs 21 Program has developed an online energy benchmarking tool for cleanroom and laboratory spaces (U.S. EPA/DOE 2005). Benchmarking can help to provide information on the performance of a given facility, relative to that of peer facilities, by comparing the facility energy performance. Furthermore, this benchmarking process accounts for differences in air quality, size, and other system parameters that might exist between different facilities.

Reduced recirculation air change rates. The rate of clean room air recirculation can sometimes be reduced while still meeting quality control and regulatory standards. A simulation study of a cleanroom in Ireland showed that it was possible to reduce the hourly air change rates of air recirculation units, which would lead to significant cost savings from reduced fan energy and resultant heat load (IEC 2002).

Improved air filtration quality and efficiency. High Efficiency Particulate Air (HEPA) filters and Ultra Low Penetration Air (ULPA) filters are commonly used in the pharmaceutical industry to filter make-up and recirculated air. The adoption of alternative filter technologies might allow for lower energy consumption. For example, new air filtration technologies that trap particles in the ultra-fine range (0.001-0.1 microns), a range for which current filter technologies are not effective, might reduce the energy necessary for reheating/re-cooling cleanroom air (CADDET 1999). Low pressure drop filters can also offer energy savings: in a test conducted by the Swedish National Board for Industrial and Technical Development (Nutek), some air handling unit filters were found to maintain lower pressure drops and to reduce air handling energy consumption to half that required by normal filters. The annual energy savings associated with the top-performing filters in the Nutek tests was around \$46 per filter (Camfil 1997).

Optimized chilled water systems. Chilled water systems that supply cleanrooms are rarely optimized for energy efficiency (Tschudi et al. 2002). Chilled water system efficiency improvement has been well documented in the literature; however, many designers and operators of pharmaceutical facilities could benefit from a review of the published recommendations. Some suggestions for improving chilled water system performance have been discussed in Section 5.2.

Cooling towers. In many instances, water cooling requirements can be met by cooling towers in lieu of water chillers. Water towers can cool water much more efficiently than chillers and can therefore reduce the overall energy consumption of cleanroom HVAC systems. Operating multiple cooling towers at reduced fan speed rather than operating fewer towers at full speed is a further option for lowering cooling water energy consumption (Tschudi and Xu 2003).

Reduction of cleanroom exhaust. The energy required to heat and cool cleanroom make-up air accounts for a significant fraction of cleanroom HVAC energy consumption. Measures to reduce cleanroom exhaust airflow volume can therefore lead to significant energy savings. Such measures include the use of efficient fume hood technologies as described in the

previous section. Additionally, measures aimed at heat recovery in cleanroom exhaust systems might also be effective at reducing overall HVAC system energy consumption (see Section 5.2).

Declassification. Occasionally, a cleanroom is classified at a higher cleanliness level than is necessary for its current use, either due to conservative design or to a transition in its production characteristics over time. A simple efficiency measure that might be available for such cleanrooms is to declassify them from a higher class of cleanliness to a lower class of cleanliness, provided that the lower class still meets production requirements for contamination control and air change rates. For example, at a Motorola facility in Northbrook, Illinois, the classification of a cleanroom space was reduced from class 10,000 to class 100,000 in order to lower operation costs. As a result, the airflow rate was lowered, leading to annual savings of over \$150,000 at a payback period of only 7 months (CIEE 2000c).

5.5 Motors and Motor Systems

Motors and drives are used throughout the pharmaceutical industry to operate HVAC systems, to drive laboratory or bulk manufacturing equipment (including mixers, pumps, centrifuges, and dryers), and for transport and equipment operation in the formulation and packaging stages. The energy efficiency measures described in the following section apply to any system that uses motors. Where appropriate, specific examples are listed detailing to which system each measure has already been applied, and to what success.

Using a “systems approach” that looks at the entire motor system (i.e., pumps, compressors, motors, and fans) to optimize the supply and demand of energy services often yields the most cost-effective savings. A systems approach analyzes both the supply and demand sides and how they interact, shifting the focus of the analysis from individual components to total system performance. This systems approach is an important step in establishing a company-wide motor efficiency policy. This approach includes several steps. First, locate and identify all motor applications (e.g., pumps, fans) in the manufacturing facility. Second, document the conditions and specifications of these motors. Next, compare the needs and the actual use of the system to determine the energy consumption rate by the motors; this will help determine if the motors are properly sized. After the evaluation, collect information on potential upgrades or updates to the motor systems, including the cost of implementation and the anticipated annual savings to enable the decision-making process. Finally, monitor the performance of the upgraded/updated systems to determine the actual costs savings (SCE 2003).

The energy efficiency measures discussed below reflect aspects of this systems approach, including matching motor speed and load (e.g., via ASDs), sizing the system correctly, and upgrading system components. Compressed air systems and pumps are both discussed in more detail in Sections 5.6 and 5.7, respectively.

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 preventive or predictive. Preventive measures, whose purpose is to prevent unexpected downtime of motors,

include electrical consideration, voltage imbalance minimization, motor ventilation, alignment, and lubrication, and load consideration. 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 ongoing motor maintenance could range from 2-30% of total motor system energy use (Efficiency Partnership 2004b).

Properly sized motors. Motors that are sized inappropriately result in unnecessary energy losses. Where peak loads 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.

Replacement of belt drives. Inventory data suggests that 4% of pumps have V-belt drives, many of which can be replaced with direct couplings to save energy (Xenergy 1998). Based on assessments in several industries, the savings associated with V-belt replacement are estimated at 4%. Investment costs are estimated at \$0.10/kWh-saved with a simple payback period up to 2 years.

High-efficiency motors and drives. High-efficiency motors reduce energy losses through improved design, better materials, tighter tolerances, and improved manufacturing techniques. With proper installation, high-efficiency motors can run cooler than standard motors and can consequently have higher service factors, longer bearing life, longer insulation life, and less vibration.

In general, high-efficiency motors are economically justified when exchanging a motor that needs replacement, but might not be economically feasible when replacing a motor that is still in adequate working condition (CADDET 1994; Price and Ross 1989). However, according to case studies by the Copper Development Association (CDA 2000), replacing working motors with high-efficiency motors can often be beneficial. The payback period for replacing individual motors varies based on size, load factor, and running time; the best savings are achieved by replacing motors that run for long hours at high loads. When replacing retiring motors, payback periods are typically less than 1 year from energy savings alone (U.S. DOE 1998). Twenty-three case studies on high-efficiency motor installations in the U.S. pharmaceutical industry, including upgrades and replacements, showed an average payback period of less than 3 years (IAC 2003).¹⁴

To be considered energy efficient in the United States, a motor must meet performance criteria published by the National Electrical Manufacturers Association (NEMA). However, most manufacturers offer lines of motors that significantly exceed the NEMA-defined criteria, even those defined by NEMA as energy efficient (U.S. DOE 2001a). NEMA and other organizations

¹⁴ The Industrial Assessment Center (IAC) database contains case study data for a wide range of industrial energy efficiency measures. It gives a wide variety of information, including implementation costs and savings for each case study. Using the IAC database, the average payback period for all 23 case studies was calculated. In order to accurately represent applicable technology for the pharmaceutical industry, only data from the SIC codes that pertained to the pharmaceutical industry were used in this calculation.

are sponsoring a “Motor Decisions Matter” campaign to market NEMA-approved premium efficient motors to industry (NEMA 2001). Even these premium-efficiency motors can have a low payback period. According to data from the Copper Development Association, an upgrade to high-efficiency motors, as compared to motors that achieve the minimum efficiency, can have a payback period of less than 15 months for 50 horsepower (hp) motors (CDA 2001). Because of the fast payback period, it almost always makes sense not only to buy an energy efficient motor, but also to buy the most energy efficient motor available (U.S. DOE 1998).

Replacing a motor with a high-efficiency motor is often a better choice than rewinding a motor. The practice of rewinding motors currently has no quality or efficiency standards. The efficiency of a motor decreases after rewinding; typically by anywhere from 2-25%. Recent case study data show that new motors are not only more energy efficient, but also reduce overall operation costs (CDA 2003). When considering whether to rewind a motor or to replace it with a higher-efficiency model, several guidelines have been offered: (1) never rewind a motor damaged by excessive heat; (2) replace motors that are less than 100 hp and more than 15 years old; and (3) replace previously rewound motors (CEL 2002).

At Minnesota Mining and Manufacturing (3M), an in-house motor system performance optimization was conducted in Building 123. Building 123 houses pilot plants, mechanical and electrical maintenance shops, laboratories, and support functions. An evaluation of all electric motors larger than 1.5 hp in the building identified 50 older, standard-efficiency motors that operated more than 6,000 hours per year. Twenty-eight of these motors were exchanged to energy efficient motors. An energy efficiency improvement of 2-5% for each motor replacement was expected. Other measures were also taken, such as sheave changes to reduce the driven load, downsizing of motors to better match system requirements, and repair and cleaning of components to reduce efficiency losses. The payback period for this project was estimated at 3.1 years (U.S. DOE 2002b).

Adjustable speed drives (ASDs) Adjustable-speed drives better match speed to load requirements for motor operations. Adjustable-speed drive systems are offered by many suppliers and are 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%. Four case studies in the U.S. pharmaceutical industry have demonstrated an average payback period for ASDs of less than 2 years (IAC 2003). These four case studies included the installation of ASDs on cooling tower fans, ventilation equipment, and a dust collector motor.

Genentech installed ASDs on VAV air handlers in its Vacaville, California, facility, leading to significant reductions in energy consumption. The annual energy cost savings associated with this measure were expected to be around \$23,000 per year (CIEE 2000a). At Hine Design in Sunnyvale, California, ASDs and related controls were installed on cleanroom recirculation fans, leading to expected energy savings of \$36,000 per year with a simple payback period of 1.5 years (CIEE 2000b).

5.6 Compressed Air Systems

Compressed air is required in many applications in the pharmaceutical industry, for example, for the operation of equipment, for use in vacuum cleaning systems, spray systems, and breathing air, and as instrument air in hazardous areas (Cole 1998). In pharmaceutical facilities, compressed air often comes in contact with products, such as in spray coating operations or in packaging. Hence, compressed air is also often fitted with filters to meet strict contamination control standards.

Compressed air generally represents one of the most inefficient uses of energy in a pharmaceutical plant because of poor system efficiency. Typically, the efficiency of a compressed air system—from compressed air generation to end use—is only around 10% (U.S. DOE 1998). Because of this inefficiency, if compressed air is used, it should be of minimum quantity for the shortest possible time; it should also be constantly monitored and weighed against potential alternatives.

Many opportunities to reduce energy consumption in compressed air systems are not prohibitively expensive; payback periods for some options can be extremely short. Energy savings from compressed air system improvements can range from 20-50% or more of total system electricity consumption (Efficiency Partnership 2004a). Common energy efficiency measures for compressed air systems are discussed below. Additionally, many motor-directed measures, which were discussed in Section 5.5, can also be applied to compressors to reduce their energy consumption.

System improvements. Adding additional compressors should be considered only after a complete system evaluation. In many cases, compressed air system efficiency can be managed and reconfigured to operate more efficiently without purchasing additional compressors. System improvements utilize many of the energy efficiency measures for compressors discussed below. Compressed air system service providers offer integrated services both for system assessments and for ongoing system maintenance needs, alleviating the need to contact several separate firms. The Compressed Air Challenge® (<http://www.compressedairchallenge.org>) offers free web-based guidance for selecting the right integrated service provider, as well as guidelines defining walk-through evaluations, system assessments, and fully instrumented system audits (CAC 2002).

Maintenance. Inadequate maintenance can lower compression efficiency and increase air leakage or pressure variability, as well as lead to increased operating temperatures, poor moisture control, and excessive contamination. Improved maintenance will reduce these problems and save energy. Proper maintenance includes the following (U.S. DOE 1998):

- *Keep the compressor and intercooling surfaces clean and foul-free.* Blocked filters increase the pressure drop. By inspecting and periodically cleaning filters, the pressure drop may be kept low. Seek filters with just a 1 psig pressure drop over 10 years. The payback for filter cleaning is usually under 2 years (Ingersoll-Rand 2001). Fixing improperly operating filters will also prevent contaminants from entering into equipment, which can cause premature wear. Generally, when pressure drop exceeds 2-3 psig, replace the particulate and lubricant removal elements, and inspect all

systems at least annually. Also, consider adding filters in parallel that decrease air velocity, and, therefore, decrease air pressure drop. A 2% reduction of annual energy consumption in compressed air systems is projected for more frequent filter changing (Radgen and Blaustein 2001).

- *Keep motors properly lubricated and cleaned.* Poor motor cooling can increase motor temperature and winding resistance, shortening motor life, and increase energy consumption. Compressor lubricant should be changed every 2 to 18 months and checked to make sure it is at the proper level. In addition, this will reduce 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 energy and should never be undertaken. Instead, install simple pressure driven valves. Malfunctioning traps should be cleaned and repaired instead of left open. Some auto drains, such as float switch or electronic drains, do not waste air. 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).
- If using compressors with belts, *check belts for wear* and adjust them. A good rule of thumb is to adjust them every 400 hours of operation.
- *Replace air lubricant separators* according to specifications or sooner. Rotary screw compressors generally start with their air lubricant separators having a 2-3 psi pressure drop at full load. When this increases to 10 psid, change the separator (U.S. DOE 1998).
- *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 the "Leak Reduction" section below).
- *Specify pressure regulators that close when failing.*
- 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 waste excess energy. System

pressures operating too high also result in shorter equipment life and higher maintenance costs. Case studies demonstrated that the payback period for this measure would be shorter than half a year (IAC 2003).

Monitoring. Proper monitoring (and maintenance) can save significant energy and cost in compressed air systems. Proper monitoring includes the following (CADET 1997a):

- 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.
- Kilowatt-hour (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 psig of differential (U.S. DOE 1998; Ingersoll-Rand 2001). The 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, after-coolers, moisture separators, dryers and filters.
- Check for compressed air use outside production hours.

Leak reduction. Air leaks can be a significant source of wasted energy. A typical industrial facility that has not been well maintained will likely have a leak rate equal to 20-50% of total compressed air production capacity (Ingersoll-Rand 2001; Price and Ross 1989). Leak maintenance can reduce this number to less than 10%. Overall, a 20% reduction of annual energy consumption in compressed air systems is projected for fixing leaks (Radgen and Blaustein 2001).

The magnitude of the energy loss 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 per year; 0.04 inches (1 mm) to lose 1,100 kWh per year; 0.08 inches (2 mm) to lose 4,500 kWh per year; and 0.16 in. (4 mm) to lose 11,250

kWh per year (CADET 1997a). Case studies show that the payback period is generally shorter than two months (IAC 2003).

In addition to increased energy consumption, leaks can make air-powered equipment less efficient and adversely affect production, shorten the life of equipment, lead to additional maintenance requirements and increased unscheduled downtime. Leaks also 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. 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.

In 1994, Mead-Johnson Nutritionals (a subsidiary of Bristol-Myers Squibb) implemented a compressed air system improvement project at its plant in Evansville, Indiana. Energy efficiency measures included the introduction of a monitoring system, the installation of new compressors, and the repair of leaks. The improved compressed air system of this plant functioned so efficiently that only two-thirds of the compressed air capacity had to be kept online. Total capital costs of this project were \$412,000. With total annual compressed air energy savings of \$102,000 (4% of the total power costs of the plant) and a rebate from the utility of \$148,000, the payback period was just over 2.5 years. The project additionally saved the plant the purchase of a new (\$900,000) compressor (DOE 2001b).

Turning off unnecessary compressed air. Equipment that is no longer using compressed air should have the air turned off completely. This can be done using a simple solenoid valve (Scales 2002). Compressed air distribution systems should be checked when equipment has been reconfigured to ensure that no air is flowing to unused equipment or to obsolete parts of the compressed air distribution system.

Modification of system in lieu of increased pressure. For individual applications that require a higher pressure, instead of raising the operating pressure of the whole system, special equipment modifications should be considered, e.g., a booster, increasing a cylinder bore, changing gear ratios, or changing operation to off peak hours.

Replacement of compressed air by alternative sources. Many operations can be accomplished more economically and efficiently using energy sources other than compressed air. Some industry engineers believe this measure has the largest potential for compressed air energy savings. Various options exist to replace compressed air use, including:

- Air motors should only be used for positive displacement.
- Cooling electrical cabinets: air conditioning fans should be used instead of using compressed air vortex tubes.

- Flowing high-pressure air past an orifice to create a vacuum: a vacuum pump system should be applied instead of compressed air venturi methods.
- Cooling, aspirating, agitating, mixing, or package inflating: use blowers instead of compressed air.
- Cleaning parts or removing debris: brushes, blowers or vacuum pump systems, or nozzles that are more efficient should be used instead of compressed air.
- Moving parts: blowers, electric actuators, or hydraulics should be used instead of compressed air.
- Blowguns, air lances, and agitation: low-pressure air should be used instead of high-pressure compressed air.
- Efficient electric motors for tools or actuators: electric motors should be considered because they are more efficient than using compressed air (Howe and Scales 1995). Some, however, have reported motors can have less precision, shorter lives, and lack safety. In these cases, using compressed air may be a better choice.

Based on numerous case studies, the average payback period for replacing compressed air with other applications is estimated at 11 months (IAC 2003).

Improved load management. Because of the large amount of energy consumed by compressors, whether in full operation or not, partial load operation should be avoided. For example, unloaded rotary screw compressors still consume 15-35% of full-load power while delivering no useful work (U.S. DOE 1998). Centrifugal compressors are cost effective when operated at high loads (Castellow et al. 1997).

Air receivers can be employed near high demand areas to provide a supply buffer to meet short-term demand spikes that can exceed normal compressor capacity. In this way, the number of required online compressors may be reduced. Multi-stage compressors theoretically operate more efficiently than single-stage compressors. Multi-stage compressors save energy by cooling the air between stages, reducing the volume and work required to compress the air. Replacing single-stage compressors with two-stage compressors typically provides a payback period of 2 years or less (Ingersoll-Rand 2001). Using multiple smaller compressors instead of one large compressor can save energy as well. Large compressors consume more electricity when they are unloaded than do multiple smaller compressors with similar overall capacity. An analysis of U.S. case studies shows an average payback period for optimally sizing compressors of about 1.2 years (IAC 2003).

Pressure drop minimization. An excessive pressure drop will result in poor system performance and excessive energy consumption. Flow restrictions of any type in a system, such as an obstruction or roughness, results in higher operating pressures than would be needed. Resistance to flow increases the drive energy on positive displacement compressors by 1% of connected power for each 2 psi of differential (U.S. DOE 1998; Ingersoll-Rand 2001). The 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 on lubricated rotary compressors and after-coolers, moisture separators, dryers, and filters (supply side).

Minimizing pressure drop requires a systems approach in design and maintenance. Air treatment components should be selected with the lowest possible pressure drop at specified maximum operating conditions and best performance. Manufacturers' recommendations for maintenance should be followed, particularly in air filtering and drying equipment, which can have damaging moisture effects like pipe corrosion. Finally, the distance the air travels through the distribution system should be minimized. Audit results found that the payback period is typically shorter than 3 months for this measure (IAC 2003).

Inlet air temperature reduction. If airflow is kept constant, reducing the inlet air temperature reduces the energy used by the compressor. In many plants, it is possible to reduce the inlet air temperature to the compressor by taking suction from outside the building. As a rule of thumb, each 5°F (3°C) will save 1% compressor energy (CADDET 1997a; Parekh 2000). A payback period of 2-5 years has been reported for importing fresh air (CADDET 1997a). In addition to energy savings, compressor capacity is increased when cold air from outside is used. Case studies have found an average payback period for importing outside air of less than 1.7 years (IAC 2003), but costs will vary strongly with plant layout.

Maximizing the allowable pressure dew point at air intake. Choose a dryer that has the maximum allowable pressure dew point and best efficiency. A rule of thumb is that desiccant dryers consume 7-14% of the total energy of a compressor, whereas refrigerated dryers consume 1-2% of the total energy of a compressor (Ingersoll-Rand 2001).

Controls. The objective of any control strategy is to shut off unneeded compressors or delay bringing on additional compressors until needed. Energy savings for sophisticated controls have been around 12% annually (Radgen and Blaustein 2001). Available controls for compressed air systems include start/stop, load/unload, throttling, multi-step, variable speed, and network controls (U.S. DOE 1998; CADDET 1997a, 1997b).

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 regulators that close when failing.

Properly sized pipe diameters. Undersized pipes 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 diameters typically reduces annual energy consumption by 3% (Radgen and Blaustein 2001).

Heat recovery for water preheating. As much as 80-90% of the electrical energy used by an industrial air compressor is converted into heat. In many cases, a heat recovery unit can recover 50-90% of the available thermal energy for space heating, industrial process heating, water heating, make-up air heating, boiler make-up water preheating, industrial drying, industrial cleaning processes, and heat pumps (Parekh 2000). It has been estimated that approximately 50,000 Btu/hour of energy is available for each 100 cfm of compressor capacity (U.S. DOE 1998). Payback periods are typically less than 1 year. Heat recovery for space heating is not as common with water-cooled compressors because an extra stage of heat exchange is required and the temperature of the available heat is lower. However, with large water-cooled compressors, recovery efficiencies of 50-60% are typical (U.S. DOE 1998). Implementing this measure saves up to 20% of the energy used in compressed air systems annually for space heating (Radgen and Blaustein 2001).

Natural gas engine-driven air compressors. Gas engine-driven air compressors can replace electric compressors with some advantages and disadvantages. Gas engine-driven compressors are more expensive but may have lower overall operating costs, depending on the relative costs of electricity and gas. Variable-speed capability is standard for gas-fired compressors, offering a high efficiency over a wide range of loads. Heat can be recovered from the engine jacket and exhaust system. This technology is new; it has currently penetrated less than 1% of the total air compressor market. Gas engine-driven compressors have some drawbacks; they need more maintenance, have a shorter useful life, and sustain a greater likelihood of downtime.

Ultra Creative Corporation, a U.S. manufacturer of specialty plastic bags, installed gas engine-driven compressors in its plant in Brooklyn, New York (Audin 1996). The initial costs were \$85,000 each for two 220 hp units and \$65,000 for one 95 hp unit. They reported savings of \$9,000 in monthly utilities (averaging \$108,000 annually). Nestlé (Canada) found their gas engine-driven air compressor system to be cost effective when it was operated properly, and felt it would eventually reach a payback period of 2.6 years with a 75% efficient heat recovery system, and 4.2 years without heat recovery (Audin 1996).

5.7 Pumps

In the United States, pumping systems account for about 25% of the electricity used in manufacturing facilities. The pumping of coolants such as glycol or chilled water is common in pharmaceutical manufacturing facilities and is also a source of significant energy consumption. Studies have shown that over 20% of the energy consumed by pumping systems could be saved through changes to pumping equipment and/or control systems (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 a mere 2.5% of the total costs (Best Practice Programme 1998). In contrast, energy costs make up about 95% of the lifetime costs of the pump. Maintenance costs comprise the remaining 2.5%. Hence, the initial choice of a pump system should be highly dependent on energy cost considerations rather than on initial costs.

Pumping systems consist of a pump, a drive motor, piping networks, and system controls (such as ASDs or throttles). The energy efficiency measures described below apply to all pump applications. Because pumps are part of a greater motor system, many of the measures described in Section 5.5 apply to pumping systems as well (including the “systems approach” to energy efficiency optimization). When available, case study data are provided to demonstrate the typical energy and/or cost savings associated with a given measure.

Maintenance. Inadequate maintenance can lower pump system efficiency, cause pumps to wear out more quickly, and increase costs. Better maintenance will reduce these problems and also save energy. Proper pump system maintenance includes the following (Hydraulic Institute 1994; U.S. DOE 1998):

- Replacement of worn impellers, especially in caustic or semi-solid applications.
- Bearing inspection and repair.
- Bearing lubrication replacement, on an annual or semiannual basis.
- Inspection and replacement of packing seals. Allowable leakage from packing seals is usually between 2-60 drops per minute.
- Inspection and replacement of mechanical seals. Allowable leakage is typically 1-4 drops per minute.
- Wear ring and impeller replacement. Pump efficiency degrades 1-6 points for impellers less than the maximum diameter and with increased wear ring clearances.
- Pump/motor alignment check.

Although energy savings for operations and maintenance are less than for other measures, typical savings at U.S. facilities are estimated to be between 2% and 7% of pumping electricity with paybacks of less than 1 year (Xenergy 1998; U.S. DOE 2002b).

Monitoring. Monitoring in conjunction with a proper maintenance program can be used to detect problems and determine solutions to create a more efficient pumping 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 the following:

- 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.

Pump demand reduction. 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. Each of these steps can save 5-10% of pump system electricity consumption, on average for U.S. facilities (Easton Consultants 1995). Total head requirements can also be reduced by lowering process static pressure, by minimizing the elevation rise from suction tanks to discharge tanks, by reducing static elevation changes via siphons, and by lowering spray nozzle velocities.

Controls. The objective of any control strategy is to shut off unneeded pumps or, alternatively, to reduce pump load until needed. In 2000, Cisco Systems upgraded the controls on its fountain pumps to turn off the pumps during peak hours (CEC and OIT 2002). A 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% in the total energy consumption of the fountain pumps. With a total cost of \$29,000, the simple payback was 11 months. In addition to energy savings, the project reduced maintenance costs and increased the pumping system's equipment life.

High-efficiency pumps. According to inventory data, 16% of pumps in use in industry are more than 20 years old. A pump's efficiency may degrade by 10-25% in its lifetime (Easton Consultants 1995). Newer pumps are typically 2-5% more efficient, while high-efficiency motors have also been shown to increase the efficiency of a pumping system by 2-5% (Tutterow 1999). More information on high-efficiency motors can be found in Section 5.5.

A number of high-efficiency pumps are available for specific pressure head and flow rate capacity requirements. Choosing the right pump often saves both operating costs and capital costs. 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 specified-speed pumps, or pumps that require a very low minimum net positive suction head at the pump inlet.

Properly sized pumps. Pumps that are sized inappropriately result in unnecessary losses. Where peak loads can be reduced, pump size can also be reduced. Replacing oversized pumps with pumps that are properly sized can save 15-25% of the electricity consumption of a pumping system (on average for U.S. industry) (Easton Consultants 1995). Where pumps are dramatically oversized, speed can be reduced with gear or belt drives or a slower speed motor. Paybacks for implementing these solutions are typically less than 1 year (U.S. DOE 2002b).

As a participant in the U.S. DOE's Motor Challenge Program, the Welches Point Pump Station (a medium-sized water treatment plant located in Milford, Connecticut) replaced one of their system's four identical pumps with a smaller model (ITT Flygt 2002). They found that the smaller pump could more efficiently handle typical system flows and the remaining three 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 resulted in savings of 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 annual 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 for the equipment. Additionally, the station noise was significantly reduced with the smaller pump.

Multiple pumps for variable loads. 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 10-50% of the electricity consumption for pumping (on average for U.S. industry) (Easton Consultants 1995). 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 per year (or 486 MWh per year) giving a payback of just 6 months (Hydraulic Institute and Europump 2001).

Impeller trimming. If a large differential pressure exists at the operating rate of flow (indicating excessive flow), the impeller diameter can be trimmed (also called "sheave shaving") 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 of a given pump (Xenergy 1998).

In one case study in the chemical processing industry, a pump impeller was reduced from 320 mm to 280 mm, which reduced the pump's power demand by more than 25% (Hydraulic Institute and Europump 2001). Annual energy demand was reduced by 83 MWh (26%). With an investment cost of \$390, the payback on energy savings alone was 23 days. In addition to energy savings, maintenance costs were reduced, system stability was improved, pump cavitation was reduced, and excessive vibration and noise were eliminated.

To reduce energy consumption and improve the performance of its beer cooling process, the Stroh Brewery Company analyzed the glycol circulation system used for batch cooling of beer products at its G. Heileman Division brewing facility in La Crosse, Wisconsin. By simply reducing the diameter of the pump impeller and fully opening the discharge gate valve, cooling circulation system energy use was reduced by 50%, resulting in savings of \$19,000 in the first year. With a cost of \$1,500, this Motor Challenge Showcase Demonstration project realized a simple payback of about 1 month (U.S. DOE 2001c).

5.8 Refrigeration

Refrigeration is another important process in the pharmaceutical industry and is used in many different applications. Energy savings in refrigeration systems can be found at the component, process, and systems levels (ATLAS Project 1997). Energy efficiency measures include reducing condenser pressures, the correct selection and sequencing of compressors, optimizing insulation, and eliminating non-essential heat loads within the plant. Additionally, many of the efficiency measures for motors, compressors, pumps, and buildings (shell) described in previous sections of this Energy Guide also apply to refrigeration systems.

Operations and maintenance. Often it is possible to achieve energy savings at very low investment costs with attention to improved operations and maintenance of refrigeration systems (Caffal 1995). Such improvements can include shutting doors, setting correct head pressure, maintaining correct levels of refrigerant, effectively maintaining cooling towers, and selecting and running appropriate compressors for part load. Energy saving can also be achieved by cleaning the condensers and evaporators. Scale on condensers increases power input and decreases refrigeration output. Three millimeters of scale can increase power input by 30% and reduce output by 20% (Kidger 2001). Water treatment and blowdown or magnetic water treatment may eliminate scales. In ammonia system evaporators, oil tends to accumulate and needs to be drained to avoid reduction of heat transfer. Additionally, cool outside air in winter months can sometimes be leveraged to reduce facility cooling energy loads (Farrell 1998).

Systems monitoring. The introduction of automatic monitoring on refrigeration systems can help energy managers and facilities engineers track energy consumption, diagnose poor performance, optimize system performance, and identify problem areas before major repairs are needed. Automated monitoring of energy performance is not yet common but can be very beneficial in exposing poor part-load efficiency and in identifying system deterioration, such as the effects of low refrigerant charge. The cost of automated monitoring is proportional to the size of the system and may be minor on new systems, where much data can often be obtained from control systems. The monitoring system should have the ability to provide system and component level information to operating staff as well as high-level performance summaries for management. It is estimated that 3% of refrigeration energy can be saved by applying this measure.

Monitoring of refrigerant charge. A low refrigerant charge can exist in many small direct expansion (DX) systems, and can also exist without obvious indicators on larger flooded or recirculation systems. Without proper monitoring to ensure that refrigerant is charged to the appropriate level, significant amounts of energy can be wasted in a refrigeration system.

Scott (2004) estimates for DX systems, one in six have a low refrigerant charge (or sometimes overcharge), which is sufficient to increase energy usage by 20%. Monitoring of refrigerant charge generally isn't necessary for large ammonia systems.

Optimization of condenser and evaporator parameters. An optimized refrigeration system works with minimized differences between condenser conditions and evaporator conditions. For the condenser, the goal is to obtain the lowest possible condensing temperature and pressure of the refrigerant. This reduces power input while increasing refrigeration output. For the evaporator, an increase in temperature and pressure increases the power input of the compressor, but can dramatically increase the refrigeration output of the system. Increasing evaporator temperature by one degree can reduce the electricity consumption of the compressor by roughly 3% (Hackensellner 2001; Lom and Associates 1998).

Monitoring of suction line filters. When a suction line filter becomes clogged with debris, the pressure drop across the filter is increased, reducing the efficiency of the system. Additionally, it is important to monitor whether or not debris is being carried out with the return vapor. If so, it is likely that erosion is occurring on the internal surface of the suction pipe, which can lead to premature pipe failure. If debris is found, a corrosion-rate testing program should be implemented (Dettmers 2004).

Generally this measure applies to smaller DX systems (usually halocarbon-based systems, but not ammonia-based systems). However, all refrigeration systems can be monitored for unusual pressure drops that can originate from many sources (Scott 2004); such monitoring can lead to energy savings of approximately 3%.

Monitoring of refrigerant contamination. Periodic monitoring for contaminants (e.g., oil, water, etc.) in refrigerants should be performed to ensure early detection of system operating and maintenance problems. Energy savings due to implementation of this measure are estimated at 2%.

Cooling line and jacket insulation. It can often be cost effective to insulate cooling lines if the lines are un-insulated and there is a significant average temperature difference between the cooling lines and the surroundings (e.g., more than 15°F). If lines are already insulated, upgrading may not be cost effective. Interestingly, insulated jacket tanks use less refrigeration energy than tanks in an insulated enclosure (cold room) due to reduced losses (Kidger 2001).

Waste heat recovery. The waste heat from refrigeration systems can be recovered to provide space heating or water heating, where feasible, to reduce the electricity and/or fuel consumed by those heating demands. The technology for waste heat recovery from refrigeration systems is similar to waste heat recovery technology for compressed air compressors (see Section 5.6).

Operation at lower system pressure. High operating pressures in refrigeration systems lead to high compressor energy consumption and head loss. Lower operating pressures can reduce

compressor energy consumption, while also leading to reduced system maintenance costs (e.g., for pipes). However, in lowering system operating pressures, one must also consider the optimal pressure and temperature requirements of condensers and evaporators (discussed previously in this section) to ensure maximum energy efficiency. Two case studies have shown the payback period associated with lowering operating pressures to be less than 1.5 years (IAC 2003).

Absorption chillers. Absorption chillers use heat to provide cooling, instead of mechanical energy. In absorption chillers, refrigerant vapor from the refrigeration system's evaporator is first absorbed by a solution contained in an absorber unit. Next, this solution is pumped from the absorber into a generator, which re-vaporizes the refrigerant using waste heat (e.g., from steam) as an energy source. Finally, the refrigerant-depleted solution returns to the absorber unit via a throttling device, completing the cycle. Absorption chillers have a lower coefficient of performance (COP) than mechanical chillers; however, absorption chillers can reduce operating costs since they use low-grade waste heat as an energy source. Low-pressure, steam-driven absorption chillers are available in capacities from 100 to 1,500 tons (U.S. DOE 2003). Absorption cooling and refrigeration may be attractive in combination with cogeneration of heat and power (so-called trigeneration; see Section 5.11).

5.9 Lighting

The energy used for lighting in the pharmaceutical industry is typically small. Still, energy efficiency opportunities may be found that can reduce lighting energy use cost-effectively. Lighting is used either to provide overall ambient lighting throughout manufacturing, storage, and office spaces or to provide low-bay and task lighting to specific areas. High-intensity discharge (HID) sources are used for the former, including metal halide, high-pressure sodium, and mercury vapor lamps. Fluorescent, compact fluorescent, and incandescent lights are typically used for task lighting in offices. ENERGY STAR provides more useful information on optimizing lighting in offices and buildings on its website (<http://www.energystar.gov>).

As with motor systems, the most effective and efficient strategy is to employ a systems approach toward meeting lighting needs. For example, the Louis Stokes Laboratories of the U.S. National Institutes of Health applied a combination of strategies to improve the efficiency of their lighting systems. First, all fluorescent light fixtures were replaced with more efficient T-8 lights and electronic ballasts. Second, motion sensor-activated lights and light emitting diode (LED) exit signs were installed. Third, a programmable lighting control system was installed. Lastly, double-height windows and curved ceilings were employed to allow more daylight into the lab space. Based on these measures, the average energy consumption rate per unit lighting area was reduced to an impressive 1.6 W per gross ft² (U.S. EPA/DOE 2001b).

The Process and Environmental Technology Laboratory of Sandia National Laboratories, located in Albuquerque, New Mexico, adopted similar measures as the Louis Stokes Labs. The expectation was to be able to reduce lighting levels to 1 W per ft², but the actual energy consumption after measure implementation was found to be 25% lower at 0.75 W per ft² (U.S. EPA/DOE 2001c).

Lighting also generates a significant amount of heat. The downstream savings of lighting efficiency measures can therefore include cost savings in facility HVAC operation and energy use. The magnitude of downstream savings depends on climate and weather conditions (Sezgen and Koomey 2000).

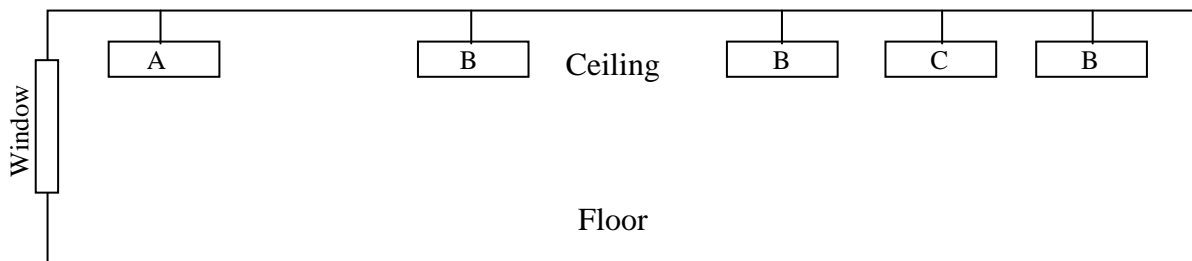
Turning off lights in unoccupied areas. An easy and effective measure is to encourage personnel to turn off lights in unoccupied building spaces. An energy management program that aims to improve the awareness of personnel with regard to energy use can help staff get in the habit of switching off lights 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 10-20% of facility lighting energy use. Numerous case studies throughout the United States suggest that the average payback period for occupancy sensors is approximately 1 year (IAC 2003).

At a 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 MBtu per year, which corresponded to avoided energy-related CO₂ 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. It is also important to make employees aware of the importance of turning off lights in unoccupied spaces (EDR 2000). Other lighting controls include daylight controls for indoor and outdoor lights, which adjust the intensity of electrical lighting based on the availability of daylight.

Figure 8. Lighting placement and controls.



An example of energy efficient lighting control is illustrated by Figure 8, 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 the rows away from the windows during the brightest parts of the day and turning on supplemental rows as needed later.)

Exit signs. Energy costs can be reduced by switching from incandescent lamps to LEDs or radium strips in exit sign lighting. An incandescent exit sign uses about 40 W, while LED signs may use only about 4-8 W, reducing electricity use by 80-90%. 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, reducing maintenance costs considerably. In addition to exit signs, LEDs are increasingly being used for path marking and emergency wayfinding systems. Their long life and cool operation allows them to be embedded in plastic materials, which makes them perfect for such applications (LRC 2001).

A new LED exit sign typically costs \$20-\$30. Kits are sold to retrofit the lamps in existing exit signs for similar prices. The payback period can be as low as 6 months. The U.S. EPA's ENERGY STAR program website (<http://www.energystar.gov>) provides a list of suppliers of LED exit signs.

An alternative is the Tritium exit sign that is self-luminous and therefore does not need any power supply. The lifetime of these signs is estimated at about 10 years, while the costs can be \$200/piece or more. The high capital costs make this type of sign attractive for new construction or if no power supply is available.

Electronic ballasts. A ballast is a mechanism that regulates the amount of electricity required to start a lighting fixture and maintain a steady output of light. Electronic ballasts save 12-30% power over their magnetic predecessors (Cook 1998; EPA 2001). 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 (Eley et al. 1993; Cook 1998). New electronic ballasts also have automatic switch-off capabilities for faulty or end-of-life lamps.

The typical energy savings associated with replacing magnetic ballasts by electronic ballasts are estimated to be roughly 25%; however, the total energy savings will depend on the number of magnetic ballasts still in use.

Replacing 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. Replacing T-12 lamps with T-8 lamps (smaller diameter) approximately doubles the efficacy of the former. Also, T-8 tubes generally last 60% longer than T-12 tubes, 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%. Based on experiences with several U.S. industrial

facilities, the investment costs for replacing a T-12 lamp by a T-8 lamp with an electronic ballast are estimated at \$0.25-\$0.30/kWh-saved.

Replacing mercury lights with metal halide or high-pressure sodium lights. Where color rendition is critical, metal halide lamps can replace mercury or fluorescent lamps with energy savings of 50%. The Gillette Company manufacturing facility in Santa Monica, California, replaced 4,300 T-12 lamps with 496 metal halide lamps in addition to replacing 10 manual switches with 10 daylight switches (U.S. EPA 2001). They reduced electricity by 58% and saved \$128,608 annually. The total project cost was \$176,534, producing a payback period of less than 1.5 years.

Where color rendition is not critical, high-pressure sodium lamps offer energy savings of 50-60% compared to mercury lamps (Price and Ross 1989).

High-intensity discharge (HID) voltage reduction. Reducing lighting system voltage can also save energy. A Toyota plant installed reduced-voltage HID lights and realized a 30% reduction in lighting energy consumption (Toyota 2002). There are commercial products on the market 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. These new systems incorporate high-efficiency fluorescent lamps, electronic ballasts, and high-efficacy fixtures that maximize output to the work plane. Advantages to the new system are many; they 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 (Martin et al. 2000). High-intensity fluorescent systems can yield 50% electricity savings over standard metal halide HID systems. Dimming controls on high-intensity fluorescent systems that are impractical in metal halide HID systems can also save significant energy. Retrofitted systems cost about \$185 per fixture, including installation costs (Martin et al. 2000).

At a Novartis plant in Rzeszow, Poland, lighting was provided by mercury lamps that offered low lighting efficiency at a high power consumption rate. The mercury lamps also did not meet Hazard Analysis and Critical Control Point (HACCP) requirements. The plant management decided to invest in a newly-designed system using highly-efficient modern fluorescent lamps within a broader framework of facility modernization plans. The result was an 85% increase in lighting intensity, a 30% reduction in power consumption, and the meeting of HACCP requirements through the special burst-safe design of the lamps (Novartis 2004).

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. The reduced heat gains will 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 often be cost-effectively refitted with daylighting systems. Various daylighting systems are available on the market, some of which can be supplied as kits to retrofit an existing building.

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 8). Daylighting technologies include properly placed and shaded windows, atria, angular or traditional (flat) roof lights, clerestories, light shelves, and light ducts. Clerestories, light shelves, and light ducts accommodate various angles of the sun and redirect daylight using walls or reflectors.

Not all parts of a facility may be suitable for the application of daylighting. Daylighting is most appropriate for those areas that are used in daytime hours by people. The savings will vary widely depending the facility and buildings. Daylighting systems typically have a payback period of around 4 years, although shorter paybacks have been achieved.

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/>). Additionally, the Labs 21 Program has developed specific guidelines for employing daylighting in laboratory space (U.S. EPA/DOE 2000) and the International Energy Agency has published a daylighting sourcebook (IEA 2000).

At Pharmacia's Building Q, located in Skokie, Illinois, windows with Low-E glass were employed to filter out infrared rays while allowing visible light to enter the building. Two skylit atria in the building also permit more light to pour into its interior. The energy consumption of their daylighting design was anticipated to be 4.5 kWh per gross ft²; upon implementation, energy consumption was found to be only 3.1 kWh per gross ft² (U.S. EPA/DOE 2002a).

5.10 Heat and Steam Distribution

Boilers are the heart of a steam system, while the purpose of distribution systems is to get steam from the boiler to the process where it will be used. Boilers and steam distribution systems are major contributors to energy losses at many industrial facilities; they are therefore an area where substantial efficiency improvements are typically feasible. Many common energy efficiency measures for boilers and steam distribution are listed below. These measures center around improved process control, reduced heat loss, and improved heat recovery. In addition to the measures below, it is important to note that new boilers should almost always be constructed in a custom configuration. Pre-designed boilers can often be out-of-date designs that cannot be tuned to the needs of a particular steam generation and distribution system (Ganapathy 1994).

Boiler process control. Flue gas monitors maintain optimum flame temperature and monitor carbon monoxide (CO), oxygen, and smoke. The oxygen content of the exhaust gas is a combination of excess air (which is deliberately introduced to improve safety or reduce emissions) and air infiltration (air leaking into the boiler). By combining an oxygen monitor with an intake airflow monitor, it is possible to detect even small leaks. A small 1% air infiltration will result in 20% higher oxygen readings. A higher CO or smoke content in the exhaust gas is a sign that there is insufficient air to complete fuel burning. Using a combination of CO and oxygen readings, it is possible to optimize the fuel/air mixture for high flame temperature (and thus the best energy efficiency) and lower air pollutant emissions. It is assumed that this measure can be applied to large boilers only because small boilers will not make up the initial capital cost as easily. Several case studies indicate that the average payback period for this measure is around 1.7 years (IAC 2003).

Reduction of flue gas quantities. Often excessive flue gas results from leaks in the boiler and/or in the flue. This reduces the heat transferred to the steam and increases pumping requirements. These leaks are often easily repaired. Savings amount to 2-5% of the energy formerly used by the boiler (U.S. DOE 2001a). This measure differs from flue gas monitoring in that it 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.

Reduction of excess air. The more excess air is used to burn fuel, the more heat is wasted in heating this air rather than in producing steam. Air slightly in excess of the ideal stoichiometric fuel/air ratio is required for safety and to reduce emissions of nitrogen oxides (NO_x), but approximately 15% excess air is adequate (DOE 2001d; Ganapathy 1994). The vast majority of boilers already operate at 15% excess air or lower, and thus this measure may not be widely applicable (Zeitz 1997). However, if the boiler is using excess air, numerous case studies indicate that the payback period for this measure is less than a year (IAC 2003). A rule of thumb often used is that boiler efficiency can be increased by 1% for each 15% reduction in excess air or 40°F (22°C) reduction in stack gas temperature (DOE 2001d). The Canadian Industry Program for Energy Conservation (CIPEC) estimates that reducing oxygen in flue gas by 1% increases boiler efficiency by 2.5% (CIPEC 2001).

Properly sized boiler systems. Correctly designing the boiler system at the proper steam pressure can save energy by reducing stack temperature, reducing piping radiation losses, and reducing leaks in traps and other sources. In a study done in Canada on 30 boiler plants, savings from this measure ranged from 3-8% of the total gas consumption (Griffin 2000). Savings were greatest when steam pressure is reduced below 70 psig.

Using smaller boilers when not operating at or near full load also reduces energy use. The Saskatchewan Penitentiary in Canada installed two new smaller boilers for their summer operations and to supplement winter operations. These replaced old oversized boilers operating at low fire for most of the year. They found gas savings of 17% (or 18,321 MBtu), resulting in annual energy cost savings of \$50,000 (CIPEC 2001). One case study has shown that correct boiler sizing led to savings of \$150,000 at a payback period of only 2.4 months (IAC 2003). Costs and savings will depend strongly on the current system utilization.

Boiler insulation. It is possible to use new materials, such as ceramic fibers, that both insulate better and have a lower heat capacity (and thus heating is more rapid). Savings of 6-26% can be achieved if improved insulation is combined with improved heater circuit controls. Due to the lower heat capacity of new materials, the output temperature of boilers can be more vulnerable to temperature fluctuations in the heating elements (Caffal 1995); improved control is therefore often required in tandem with new insulation to maintain the desired output temperature range.

Boiler maintenance. A simple maintenance program to ensure that all components of a boiler are operating at peak performance can result in substantial savings. In the absence of a good maintenance system, 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 initial efficiency over 2-3 years (U.S. DOE 2001d). On average, the energy savings associated with improved boiler maintenance are estimated at 10% (U.S. DOE 2001d). Improved maintenance may also reduce the emission of criteria air pollutants.

Fouling on the fireside of boiler tubes or scaling on the waterside of boilers should also be controlled. Fouling and scaling are more of a problem with coal-fed boilers than natural gas or oil-fed boilers (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) soot 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).

Flue gas heat recovery. According to CIPEC (2001), heat recovery from flue gas is the best opportunity for heat recovery in steam systems. Heat from flue gas can be used to preheat boiler feed water in an economizer. While this measure is fairly common in large boilers, there is often still room for more heat recovery. The limiting factor for flue gas heat recovery is that one must ensure that the economizer wall temperature does not drop below the dew point of acids contained in the flue gas (such as sulfuric acid in sulfur-containing fossil fuels). Traditionally, this has been done by keeping the flue gases exiting the economizer at a temperature significantly above the acid dew point. In fact, the economizer wall temperature is much more dependent on feed water temperature than on flue gas temperature because of the high heat transfer coefficient of water. As a result, it makes more sense to preheat feed water to close to the acid dew point before it enters the economizer. This allows the economizer to be designed so that exiting flue gas is just barely above the acid dew point. One percent of fuel use is saved for every 45°F (25°C) reduction in exhaust gas temperature (Ganapathy 1994). Case studies show an average payback period for this measure of about 2.7 years (IAC 2002). Application of this measure in the U.S. semiconductor manufacturing industry has shown a payback period as short as 11 months (Fiorino 2000).

At Merck's manufacturing facility in Elkton, Virginia, a heat recovery system was installed on two main boilers, which was used to preheat both boiler feed water and combustion feed air. The heat recovery system allowed the boiler system to approach an overall thermal efficiency of 95%. The project reduced the amount of boiler fuel by 2.85%, equivalent to

39,185 MBtu per year. Avoided CO₂ emissions amounted to nearly 2,350 tons per year (Merck 2005).

Condensate return. Reusing hot condensate in boilers saves energy, reduces the need for treated boiler feed water, and reclaims water at up to 100°C (212°F) of sensible heat. Typically, fresh feed water must be treated to remove solids that might accumulate in the boiler; however, returning condensate to a boiler can substantially reduce the amount of purchased chemical required to accomplish this treatment. The fact that this measure can save substantial energy costs and purchased chemicals costs often makes building a return piping system attractive. For example, a metal fabrication plant in the United States installed a condensate return system with an initial implementation cost of \$2,800 and realized annual savings of \$1,790 with a payback period of only 1.6 years (Kirk and Looby 1996).

A Pfizer plant in Groton, Connecticut, upgraded their condensate recovery system and realized a 9% reduction in electricity consumption, and an 8% reduction in water consumption and wastewater discharge (Pfizer 2001). As a result, Pfizer saved roughly \$175,000 per year through avoided oil, gas, and water purchases.

Blowdown steam recovery. When water is blown from a 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. The recovery of blowdown steam can save 1.3% of boiler fuel use in small boilers¹⁵. Applications in the U.S. semiconductor manufacturing industry have shown payback periods of as little as 1.5 years (Fiorino 2000). Two other audits showed payback periods of 0.8 years and 2.5 years for this measure (IAC 2003), demonstrating the importance of assessing the local conditions for a proper evaluation. In addition to energy savings, blowdown steam recovery may reduce the potential for corrosion damage in steam system piping.

Boiler replacement. Replacing inefficient coal-fired boilers with gas-fired boilers increases energy efficiency and reduces emissions. Bristol Aerospace in the United Kingdom replaced two outdated boilers with three higher efficiency dual-fired natural gas/electric boilers and realized annual energy savings of \$23,000 (Caffal 1995).

Distribution system insulation. Using more insulating material or using the best insulation material for the application can save energy in steam systems. 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. These characteristics include tolerance of large temperature variations, tolerance of system vibrations, and adequate compressive strength where insulation is load bearing (Baen and Barth 1994). Improving the insulation on the existing U.S. stock of heat distribution systems would save an average of 3-13% in all systems (U.S. DOE 2001d). Two case studies indicate that the payback period for improved insulation is about 1 year (IAC 2003). The Canadian Industry

¹⁵ Based on the following assumptions: 10% of boiler water is blown down (DOE 2001d) and 13% of the thermal energy in blowdown water can be recovered (Johnston 1995).

Program for Energy Conservation (2001a) estimates that the investment for insulating a 10 foot (3 m) long, 4 inch (10 cm) diameter steam pipe can be paid back in less than 6 months.

It is often found that after heat distribution systems have undergone some form of repair, the insulation is not replaced. In addition, some types of insulation can become brittle or rot over time. As a result, a regular inspection and maintenance system for insulation can save energy (Zeitz 1997). Exact energy savings and payback periods are unknown and vary based on the existing practices.

Steam trap improvement. Using modern thermostatic element steam traps can reduce energy use while improving reliability. The main efficiency advantages offered by these traps are that they open when the temperature is very close to that of saturated steam (within 4°F or 2°C), purge non-condensable gases after each opening, and are open on startup to allow a fast steam system warm-up. These traps also have the advantage of being highly reliable and useable for a wide variety of steam pressures (Alesson 1995).

Steam trap maintenance. A simple program of checking steam traps to ensure that they are operating properly can save significant amounts of energy for very little money. When steam traps are not regularly monitored, up to 15-20% of traps can be malfunctioning. Energy savings for a regular system of steam trap checks and follow-up maintenance is conservatively estimated at 10% (U.S. DOE 2001d; Jones 1997; Bloss et al. 1997). One case study indicates a payback period of less than 4 months (IAC 2003). Although this measure offers a quick payback period, it is often not implemented because maintenance and energy costs are separately budgeted. In addition to energy and cost savings, proper functioning of steam traps will reduce the risk of corrosion in the steam distribution system.

Steam trap monitoring. 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 failure, and can detect when a steam trap is not performing at peak efficiency. Using automatic monitoring is conservatively estimated to give an additional 5% energy savings over steam trap maintenance alone with a payback period of 1 year¹⁶ (Johnston 1995; Jones 1997). Systems that are able to implement steam trap maintenance are also likely to be able to implement automatic monitoring.

Leak repair. As with steam traps, the distribution pipes themselves often have leaks that (on average) go unnoticed without a program of regular inspection and maintenance. In addition to saving 3% of energy costs, having such a program can reduce the likelihood of having to repair major leaks, thus saving even more in the long term (U.S. DOE 2001d). One case study in the IAC database shows a payback period shorter than a week (IAC 2003).

Flash steam recovery. When a steam trap purges condensate from a pressurized steam distribution system to ambient pressure, flash steam is produced. As with flash steam produced by boiler blowdown, this steam can be used for space heating or feed water

¹⁶ 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.

preheating (Johnston 1995). The potential for this measure is extremely site dependent, as it is unlikely that a producer would build an entirely new system of pipes to transport this low-grade steam to places where it can be used. If, on the other hand, the areas where low-grade heat is useful were already very close to the steam traps, this measure would be easy to implement and could save considerable energy.

Preventive maintenance. A general preventive maintenance (PM) program institutionalizes ongoing steam system checks, repairs, and upgrades to keep steam distribution systems operating at peak efficiency. General PM programs for steam distribution systems would incorporate many of the measures described above and typically lead to significant savings. For example, at Velsicol Chemical Company's Chestertown, Maryland, facility, an improved PM program was implemented to continuously identify energy losses in its steam system. The cost to implement this PM program was \$22,000. This measure reduced the plant's energy consumption on a per production unit basis by 28% and had a payback of just over 2.5 months. The plant received a 1997 Chemical Manufacturers Association Energy Efficiency Award for the project (U.S. DOE 2000).

Process integration and pinch analysis. Process integration refers to the exploitation of potential synergies that are inherent in any system that consists of multiple components working together. In plants that have multiple heating and cooling demands, the use of process integration techniques may significantly improve plant energy efficiency. Developed in the early 1970s, it is now an established methodology for continuous processes (Linnhoff et al. 1992; CADDET 1993). The methodology involves the linking of hot and cold streams in a process in a thermodynamic optimal way. 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. It was developed originally in the late 1970s (Linnhoff 1993) in response to the "energy crisis" 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 analysis approach has been extended to resource conservation in general, whether the resource is capital, time, labor, electrical power, water, or a specific chemical species 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 and retrofits of existing plants.

The analytical approach to this analysis has been well documented in the literature (Kumana 2000; 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.

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). The use of process integration techniques for batch processes is especially important to the pharmaceutical industry, with its dominant use of batch processes.

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.

5.11 Cogeneration

For industries like pharmaceutical manufacturing that have requirements for process heat, steam, and electricity, the use of combined heat and power (CHP) systems may be able to save energy and reduce pollution. Cogeneration plants are significantly more efficient than standard power plants because they take advantage of waste heat. In addition, transmission losses are minimized when CHP systems are located at or near the plant. As Chapter 4 showed, the use of cogeneration in the U.S. pharmaceutical industry is still limited, allowing for expansion at suitable locations.

Often, utility companies will work with individual companies to develop CHP systems for their plants. In this scenario, the utility company owns and operates the plant's CHP system; therefore, the company avoids the capital expenditures associated with CHP projects, but gains the benefits of a more energy efficient source of heat and electricity.

In addition to energy savings, CHP systems also have comparable or better availability of service than utility generation. In the automobile industry, for example, typical CHP units are reported to function successfully for 95-98% of planned operating hours (Price and Ross 1989). For installations where initial investment is large, potential multiple small-scale CHP units distributed to points of need could be used cost effectively.

Currently, most large-scale CHP systems use steam turbines. Switching to natural gas-based systems will improve the power output and efficiency of the CHP system, due to increased power production capability. Although the overall system efficiency of a steam turbine-based CHP system (80%, HHV) is higher than that of a gas turbine-based CHP system (74%, HHV), the electrical efficiency of a gas turbine-based CHP system is much higher (27-37% for typical industrial scale gas turbines) (Energy Nexus Group 2002a, 2002b). The power-to-heat ratio of a steam turbine-based CHP system is very low (limited to about 0.2), limiting

the output of electricity. The power-to-heat ratio of a gas turbine-based CHP system is much higher (between 0.5 and 1.0), producing more power for the same amount of fuel. This may improve the profitability of a gas-based CHP unit, depending on the price of power to the plant. Modern gas-based CHP systems have low maintenance costs and will reduce emissions of NO_x, sulfur dioxide, CO₂, and particulate matter from power generation considerably, especially when replacing a coal-fired boiler (Energy Nexus Group 2002a, 2002b).

In general, the energy savings of replacing a traditional system (i.e., a system using boiler-based steam and grid-based electricity) with a standard gas turbine-based CHP unit is estimated at 20%-30%. The efficiency gain will be higher when replacing older or less maintained boilers.

Combined cycles (combining a gas turbine and a back-pressure steam turbine) offer flexibility for power and steam production at larger sites, and potentially at smaller sites as well. Steam-injected gas turbines (STIG) can absorb excess steam (e.g., due to seasonal reduced heating needs) to boost power production by injecting steam into the turbine. The size of typical STIGs starts around 5 MW. STIGs are found in various industries and applications, especially in Japan and Europe, as well as in the United States. For example, International Power Technology installed STIGs at Sunkist Growers in Ontario, California, in 1985. This type of turbine uses the exhaust heat from a combustion turbine to turn water into high-pressure steam. This steam is then fed back into the combustion chamber to mix with the combustion gas. The advantages of this system are (Willis and Scott 2000):

- The added mass flow of steam through the turbine increases power by about 33%.
- The machinery involved is simplified by eliminating the additional turbine and equipment used in combined cycle gas turbine.
- The steam is cool compared to combustion gases helping to cool the turbine interior.
- The system reaches full output more quickly than combined-cycle unit (30 minutes versus 120 minutes).

Additional advantages are that the amounts of power and thermal energy produced by the turbine can be adjusted to meet current power and thermal energy (steam) loads. If steam loads are reduced, the steam can then be used for power generation, increasing output and efficiency (Ganapathy 1994). Drawbacks include the additional complexity of the turbine's design. Additional attention to the details of the turbine's design and materials are needed during the design phase. This may result in a higher capital cost for the turbine compared to traditional models.

The economics of a cogeneration system depend strongly on the local situation, including power demand, heat demand, power purchasing and selling prices, natural gas prices, as well as interconnection standards and charges, and utility charges for backup power (backup

charges). In some states, programs may offer support for installation of cogeneration/trigeneration systems (see also Appendix C).

Trigeneration. Furthermore, new CHP systems offer the option of trigeneration, which provides cooling in addition to electricity and heat. Cooling can be provided using either absorption or adsorption technologies, which both operate using recovered heat from the cogeneration process.

Absorption cooling systems take advantage of the fact that ammonia is extremely soluble in cold water and much less so in hot water. Thus, if a water-ammonia solution is heated, it expels its ammonia. In the first stage of the absorption process, a water-ammonia solution is exposed to waste heat from the cogeneration process, whereby ammonia gas is expelled. After dissipating the heat, the ammonia gas—still under high pressure—liquefies. The liquid ammonia flows into a section of the absorption unit where it comes into contact with hydrogen gas. The hydrogen gas absorbs the ammonia gas with a cooling effect. The hydrogen-ammonia mixture then meets a surface of cold water, which absorbs the ammonia again, closing the cycle. Absorption coolers are produced by a number of suppliers (e.g., Carrier, York, Trane, Robur, McQuay, LG Machinery, and Century).

In contrast, adsorption cooling utilizes the capacity of certain substances to adsorb water on their surface, from where it can be separated again with the application of heat. Adsorption units use hot water from the cogeneration unit. These systems do not use ammonia or corrosive salts, but use silica gel (which also helps to reduce maintenance costs). Adsorption units were originally developed in Japan and are now also marketed in the United States.

The thermal performance of absorption and adsorption systems is similar, with a COP between 0.68 and 0.75. The capital costs of both systems are also comparable. However, the reliability of an adsorption unit is expected to be better and maintenance cost is expected to be lower.

In March 2004, Johnson & Johnson Pharmaceutical Research & Development officially dedicated the installation and operation of a new CHP trigeneration system, as part of a major R&D expansion at its La Jolla, California, facility. The 2,200 kW system will produce 15 GWh per year of electricity plus 360,000 therms of heat and 1.6 million ton-hr per year of chilled water. This will provide more than 90% of the facility's electric power and much of its heating and cooling needs. This CHP system also allows the R&D facility to fully operate independent of the State of California's electrical grid, if necessary. Furthermore, emission of greenhouse gases will be reduced by more than 3 million pounds of CO₂ per year. Plus, savings in electricity and natural gas will be over \$1 million per year. The San Diego Regional Energy Office helped fund the project (SDREO 2004).

Power recovery turbines. Steam is often generated at high pressures (typically at 120-150 psig), but often the pressure is reduced (to as low as 10-15 psig) to allow the steam to be used by different process. Typically, pressure reduction is accomplished through a pressure reduction valve, which does not recover the energy embodied in the pressure drop. This energy could be recovered by using a micro scale-back pressure steam turbine, which is

produced by several manufacturers. Applications of this technology have been commercially demonstrated for campus facilities and in the pulp & paper, food, and lumber industries. Power recovery turbines are capable of producing 13.5 kWh/MBtu steam (Casten and O'Brien 2003). The actual power generation on a particular site will vary depending on steam pressures and steam uses.

5.12 Miscellaneous Measures

Additional energy efficiency measures, which may be applicable to areas of a pharmaceutical plant not previously discussed, are presented below.

Stand-by power. Many process instruments operate continuously even when there is no demand, for example, diagnostic instruments, measuring devices, and laboratory computers. Putting such devices into stand-by mode when unused (or turning them off, where appropriate) can reduce a plant's overall energy load. In addition to the instruments in manufacturing and R&D facilities, computers, monitors, printers, copiers, and other electronic equipment in office environments should be set to enter stand-by mode during intermittent periods of non-use and should be turned off during extended periods of non-use (e.g., nights and weekends). A recent study suggests that only a small percentage of office electronics have power-saving features enabled and that many devices are left on unnecessarily overnight (Roberson et al. 2004), which can lead to significant energy losses in an office environment.

Energy efficient office equipment. When replacing or purchasing office equipment, consider purchasing only the most energy efficient models, such as those products that have earned the ENERGY STAR. ENERGY STAR qualified office products include computers, copiers, external power adapters, fax machines, mailing machines, monitors, printers, scanners, vending machines, and water coolers. Overall, ENERGY STAR qualified office products use about half as much electricity as standard equipment, which can lead to significant savings in energy across an organization. See the ENERGY STAR website for a list of ENERGY STAR qualified office products (<http://www.energystar.gov/>) as well as information on a host of other energy efficient appliances.

Membranes. Membranes selectively separate one or more materials from a liquid or a gas and can replace energy-intensive separation processes. Membranes can be made from organic or inorganic materials, or can be a hybrid of both. Organic membranes can be used for processes with temperatures below 150°C. Inorganic membranes can be used in higher temperature environments, ranging from 500-800°C using metal membranes to over 1,000°C for many ceramic membranes. Hybrid membranes have organic molecules to allow water and dissolved substances to be filtered by the membrane and inorganic molecules to provide stability.

Membranes can be used in a wide variety of applications where separation is required (Srikanth 2004). A typical use of membranes is for water and wastewater treatment. For water treatment, the application of membranes for ultra-filtration and hyper-filtration reduces the number of steps necessary for water purification. This results in reduced maintenance and operation costs, while reducing electricity consumption. Ultra-low pressure thin-film-

composite membranes need 50% less energy than cellulose acetate ones to operate (CADDET 2000).

Wastewater from the pharmaceutical industry may contain different contaminants, including bio-organic compounds and organic pollutants. Such wastewater needs to be cleaned before it can be discharged or recovered for re-use in the plant. Traditional wastewater treatment methods include the use of chemicals (coagulants) to remove impurities, flocculation, sedimentation, and fine particle (e.g. sand) filtration. The costs and energy use of wastewater treatment depends heavily on the facility, differences in flow, the type of pollutants, as well as the type of equipment used. The main driver for membrane application is the cost of wastewater treatment, and not energy use, although membranes can reduce energy use when compared to evaporation. Life-cycle costs of new, relatively small water treatment facilities (less than 20,000 m³/day) using pressure-driven membrane processes should be less or comparable to those of new facilities using conventional processes for particle removal or reduction of dissolved organic materials (Wiesner and Chellam 1999). A recent study estimated that membrane technologies for wastewater treatment average about \$30,000 in capital costs and save \$6,400 annually in operating costs, resulting in a simple payback period of just under 5 years and an internal rate of return of about 20% (Martin et al. 2000). In a number of applications, the annual operating cost savings from reductions in wastewater-related fees and associated labor costs lead to simple payback periods of 3 years or less (Nini and Gimenez-Mitsotakis 1994; Pollution Engineering 2002).

It is difficult to estimate the potential energy savings from implementation of membranes for water treatment without a detailed study of the specific situation. For specific applications, energy savings may be up to 40-55% of the energy needs for evaporation. Additional production savings are often achieved through product quality, reduced water use, and lower operation costs, which are site-specific.

6. Summary and Conclusions

Pharmaceutical manufacturing consumes a considerable amount of energy. In 2002, the U.S. pharmaceutical industry spent over \$900 million on energy, making energy a significant cost driver for the industry. Energy efficiency improvement is an important way to reduce these costs and to increase predictable earnings, especially in times of high energy price volatility.

Significant potential exists for energy efficiency improvement in the U.S. pharmaceutical industry. A focused and strategic energy management program will help to identify and implement energy efficiency measures and practices across an organization. Many companies in the U.S. pharmaceutical industry have already accepted the challenge to improve their energy efficiency due to steadily-rising energy prices; these companies have also begun to reap the rewards of energy efficiency investments.

There are a variety of opportunities available at individual plants in the U.S. pharmaceutical industry to reduce energy consumption in a cost-effective manner. This Energy Guide has identified many energy efficiency practices and energy efficient technologies that can be implemented at the component, process, system, and organizational levels. Expected 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 payback periods and references to further information in the technical literature have been provided, when available.

Table 5 summarizes the energy efficiency measures presented in this Energy Guide. While the expected savings associated with some of the individual measures in Table 5 may be relatively small, the cumulative effect of these measures across an entire plant may potentially be quite large. Additionally, the majority of the measures in Table 5 have relatively short payback periods. 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.

Table 5. Summary of energy efficiency measures for the U.S. pharmaceutical industry.

General	
Energy management programs	Energy monitoring systems
HVAC Systems	
Energy efficient system design	Recommissioning
Energy monitoring and control systems	Non-production hours set-back temperatures
Duct leakage repair	Discharge air temperature management
Variable-air-volume systems	Adjustable speed drives
Heat recovery systems	Chiller efficiency improvement
Fan modification	Efficient exhaust fans
Cooling water recovery	Solar air heating
Building reflection	Building insulation
Low-emittance windows	
Fume Hoods	
Improved storage/housekeeping	Restriction of sash openings
Vortex promotion	Variable-air-volume hoods
Berkeley Hood	
Cleanrooms	
Reduced recirculation air change rates	Improved filtration quality and efficiency
Optimized chilled water systems	Cooling towers
Reduction of cleanroom exhaust	Declassification
Motors	
Maintenance	Properly sized motors
Replacement of belt drives	High-efficiency motors and drives
Adjustable speed drives	
Compressed Air Systems	
System improvements	Maintenance
Monitoring	Leak reduction
Turning of unnecessary compressed air	Modification of system
Alternatives to compressed air	Improved load management
Pressure drop minimization	Inlet air temperature reduction
Maximizing allowable pressure dew point	Controls
Properly sized regulators	Properly sized pipe diameters
Heat recovery for water preheating	Natural gas engine-driven compressors
Pumps	
Maintenance	Monitoring
Pump demand reduction	Controls
High-efficiency pumps	Properly sized pumps
Multiple pumps for variable loads	Impeller trimming
Refrigeration	
Operations and maintenance	Systems monitoring
Monitoring of refrigerant charge	Optimization of operating parameters
Monitoring of suction line filters	Monitoring of refrigerant contamination
Cooling line and jacket insulation	Waste heat recovery
Operation at lower system pressure	Absorption chillers

Table 5. (continued)

Lighting	
Turning off lights in unoccupied areas	Lighting controls
Exit signs	Electronic ballasts
Replacing T-12 lamps with T-8 lamps	Replacing mercury lights
High-intensity discharge voltage reduction	High-intensity fluorescent lights
Daylighting	
Heat and Steam Distribution	
Boiler process control	Reduction of flue gas quantities
Reduction of excess air	Properly sized boiler systems
Boiler insulation	Boiler maintenance
Flue gas heat recovery	Condensate return
Blowdown steam recovery	Boiler replacement
Distribution system insulation	Steam trap improvement
Steam trap maintenance	Steam trap monitoring
Leak repair	Flash steam recovery
Preventive maintenance	Process integration and pinch analysis
Cogeneration	
Combined heat and power	Trigeneration
Power recovery turbines	
Miscellaneous Measures	
Stand-by power	Energy efficient office equipment
Membranes	

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9. Glossary

ACH	Air changes per hour
ASD	Adjustable speed drive
Btu	British Thermal Units
CAV	Constant-air-volume
cGMP	Current Good Manufacturing Practices
cfm	Cubic feet per minute
CHP	Combined heat and power
CIPEC	Canadian Industry Program for Energy Conservation
CO	Carbon monoxide
CO ₂	Carbon dioxide
COP	Coefficient of performance
DX	Direct expansion
ft ²	Square feet
GWh	Gigawatt-hour
HACCP	Hazard Analysis and Critical Control Point
HEPA	High efficiency particulate air
HHV	Higher heating value
HID	High-intensity discharge
hp	Horsepower
HVAC	Heating, ventilation, and air conditioning
IAC	Industrial Assessment Center
ISO	International Organization for Standardization
kWh	Kilowatt-hour

LED	Light-emitting diode
Low-E	Low emittance
m ³	Cubic meter
MASIS	Mobile aerosol-sealant injection system
MBtu	Million British Thermal Units
MW	Megawatt
MWh	Megawatt-hour
NAICS	North American Industry Classification System
NDA	New Drug Application
NEMA	National Electrical Manufacturers Association
NO _x	Nitrogen oxides
OSHA	Occupational Safety and Health Administration
PM	Preventive maintenance
psi	Pounds per square inch
psig	Pounds per square inch (gauge)
R&D	Research and development
STIG	Steam-injected gas turbine
ULPA	Ultra low penetration air
U.S. DOE	United States Department of Energy
U.S. EPA	United States Environmental Protection Agency
U.S. FDA	United States Food and Drug Administration
VAV	Variable-air-volume
W	Watt

Appendix A: Basic Energy Efficiency Actions for Plant Personnel

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 B: ENERGY STAR Energy Management Program Assessment Matrix



Introductions

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.

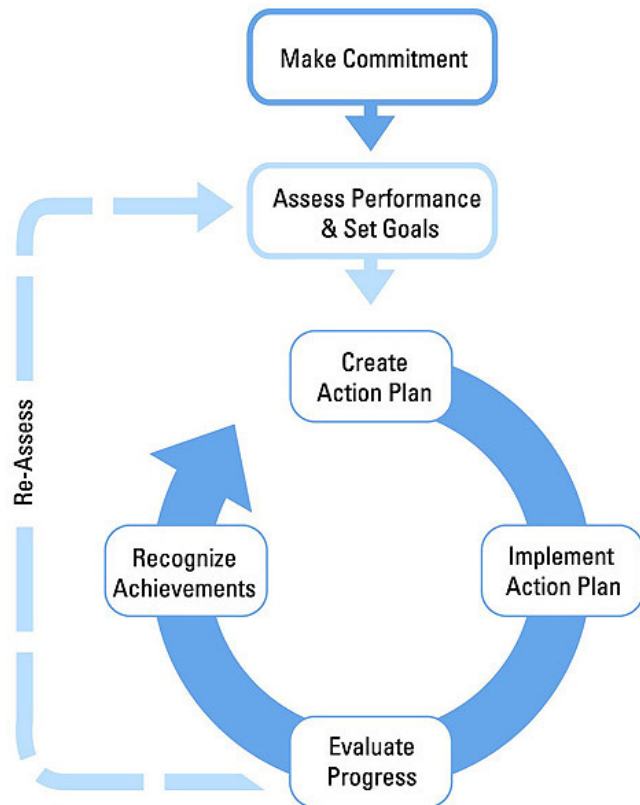
This assessment matrix is designed to help organizations and energy managers compare their energy management practices to those outlined in the Guidelines. The full Guidelines can be viewed on the ENERGY STAR web site – <http://www.energystar.gov/>.

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 of 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 C: 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, Office of Industrial Technologies

URL: <http://www.oit.doe.gov/bestpractices/steam/ssat.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, Office of Industrial Technologies

URL: http://www.oit.doe.gov/bestpractices/software_tools.shtml

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, Office of Industrial Technologies

URL: http://www.oit.doe.gov/bestpractices/software_tools.shtml

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: EPRI, (800) 832-7322

URL: <http://www.epri-peac.com/products/asdmaster/asdmaster.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, Office of Industrial Technologies

URL: http://www.oit.doe.gov/bestpractices/software_tools.shtml

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, Industry Technologies Program

URL: http://www.oit.doe.gov/bestpractices/software_tools.shtml

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, Office of Industrial Technologies

URL: http://www.oit.doe.gov/bestpractices/software_tools.shtml

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

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: Office of Industrial Technologies, U.S. Department of Energy

URL: http://www.oit.doe.gov/bestpractices/software_tools.shtml

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, Office of Industrial Technologies

URL: <http://www.oit.doe.gov/iac/>

Plant-Wide Audits

Description: An industry-defined team conducts an on-site analysis of total energy use and identifies opportunities to save energy in operations and in motor, steam, compressed air, and process heating systems. The program covers 50% of the audit costs.

Target Group: Large plants

Format: Solicitation (put out regularly by DOE)

Contact: U.S. Department of Energy, Office of Industrial Technologies

URL: http://www.oit.doe.gov/bestpractices/plant_wide_assessments.shtml

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

Technical Guidance and Case Studies

Labs for the 21st Century

Description: Labs21 is a voluntary program sponsored by the U.S EPA and U.S. DOE, dedicated to improving the environmental performance of U.S. laboratories. It consists of three components: (1) Partnership Program, (2) Training and Education, and (3) Tool Kit. The primary guiding principle of the Labs21 program is that improving the energy efficiency and environmental performance of a laboratory requires examining the entire facility from a "whole building" perspective. Adopting this perspective allows laboratory owners to improve the efficiency of the entire facility, rather than focusing on specific laboratory components.

Target Group: All public and private sector laboratories in the United States.

Format: Website

Contact: U.S. Environmental Protection Agency

URL: <http://www.labs21century.gov/index.htm>

Design Guide for Energy Efficient Research Laboratories

Description: Intended to assist facility owners, architects, engineers, designers, facility managers, and utility demand-side management specialists in identifying and applying advanced energy-efficiency features in laboratory-type environments.

Target Group: Laboratory-type facilities.

Format: Website

Contact: Lawrence Berkeley National Laboratory

URL: <http://ateam.lbl.gov/Design-Guide/>

Training

Best Practices Program

Description: The Best Practices Program of the Office for Industrial Technologies of U.S. DOE 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. A clearinghouse provides answers to technical questions and on available opportunities: 202-586-2090 or <http://www.oit.doe.gov/clearinghouse/>

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://www.oit.doe.gov/bestpractices/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/>

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).

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. Below selected programs are summarized which are earmarked specifically for support of energy efficiency activities.

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, cogeneration, 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>