Steam System Opportunity Assessment for the Pulp and Paper, Chemical Manufacturing, and Petroleum Refining Industries

Main Report

Office of Energy Efficency and Renewable Energy
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Abstract

This report assesses steam generation and use in the pulp and paper, chemical manufacturing, and the petroleum refining industries. The amount of fuel used to generate steam is determined using a U.S. Department of Energy report, titled *Manufacturing Consumption of Energy 1994*, which is based on data collected from the *Manufacturing Energy Consumption Survey 1994* (MECS). The amount of steam that is used by the three target industries is estimated by evaluating the most steam intensive products and processes, determining the amount of steam required per pound of output, and combining production data for these products and processes to determine overall industry steam use.

Estimates of the amounts of fuel used to generate steam in target industries were:

- Pulp and paper: 2,221 trillion Btu
- Chemical manufacturing: 1,540 trillion Btu
- Petroleum refining: 1,675 trillion Btu.

This report also estimated the energy savings potential available from implementing steam system performance and efficiency improvements. Using expert elicitation, the savings available from 30 steam system improvements were estimated to exceed 12 percent for each of the three industries. Significant opportunities were available in all parts of the system.

Section 1—Executive Summary

Executive Summary

Figures and Tables referenced in this section begin on page 7 in the order they are mentioned in the text.

ES.1 Introduction

The U.S. Department of Energy (DOE) Office of Industrial Technologies (OIT) BestPractices efforts aim to assist U.S. industry in adopting near-term, energy-efficient technologies and practices through voluntary technical-assistance programs on improved system efficiency. There are nine industry groups—designated Industries of the Future (IOFs)—that are the focus of the OIT efforts. These IOFs include Agriculture, Aluminum, Chemicals, Forest Products, Glass, Metal Casting, Mining, Petroleum, and Steel. BestPractices efforts cover motor-driven systems, such as pumps and fans, compressed air, steam, and process heating systems.

The overall goal of the BestPractices Steam effort is to assist steam users in adopting a systems approach to designing, installing, and operating boilers, distribution systems, and steam applications. In June 2000, Resource Dynamics Corporation (RDC), under contract with the Oak Ridge National Laboratory (ORNL) with funding from DOE-OIT, initiated an Industrial Steam System Opportunity Assessment. The purposes of the Steam System Opportunity Assessment effort are:

- To develop baseline data on steam generation and use by the pulp and paper, petroleum refining, and chemical manufacturing industries
- To develop baseline data on potential opportunities available for improving the energy efficiency of industrial steam systems for these three industries.

This Opportunity Assessment focused on the pulp and paper, chemical, and petroleum refining industries because these three industries are the major IOF steam energy users. The primary audience for the results from this assessment includes steam system end users (CEOs/CFOs, energy managers, plant managers, and operators); steam system equipment and service suppliers; and DOE program management.

The data generated from this Opportunity Assessment can be used to illustrate the magnitudes of steam system improvement opportunities available for the three targeted industries. The steam system improvement opportunity data from this assessment should also be relevant to other industries that utilize steam. This Executive Summary presents and discusses the major results from this study.

ES.2 Steam Generation in the Pulp and Paper, Chemical Manufacturing, and Petroleum Refining Industries

Steam energy accounts for a significant amount of the total industrial process energy use particularly among the IOFs. Because IOFs represent both an important national interest and a large portion of the nation's overall energy use, it is important not only to understand how these industries use energy, but especially how they generate and use steam. Section 2 of the report assesses steam generation—specifically the amount of fuel used to generate steam and the amount of steam that is generated—by three important IOF industries—pulp and paper, chemical manufacturing, and petroleum refining. Combining data from the *Manufacturing Energy Consumption Survey 1994* (MECS), with energy use estimates for key processes and products, Section 2 provides a top-down analysis of the steam generation in the three target industries.

Key Results

According to MECS data, the amounts of fuel used to generate steam in the target industries were:

- Pulp and paper manufacturing: 2,221 trillion British thermal units (Btu)
- Chemical manufacturing: 1,540 trillion Btu
- Petroleum refining: 1,675 trillion Btu.

Section 2 also estimates the amount of steam generated by this fuel, the amount of steam purchased, and the total amount of steam available to these industries. The amount of steam as a percentage of total energy used by each industry was also determined:

- Pulp and paper manufacturing: 84 percent
- Chemical manufacturing: 47 percent
- Petroleum refining: 51 percent.

ES.3 Steam Use in the Pulp and Paper Industry

Manufacturing plants in the pulp and paper industry vary by size, level of integration, process technology, wood type, and final product type. The energy used by fully integrated plants can be combined with total industry production to estimate the total thermal energy used by the pulp and paper industry. This method assumes that a fully integrated pulp and paper plant uses the same amount of energy to produce a ton of product that an equivalent supply chain of plants that are not integrated would use. Ideally, the energy data reported in the MECS is consistent with the results of this bottom up view of the process energy use.

TAPPI Journal/NREL/PIX 03221

The amount of steam energy required to produce 14 key pulp and paper products ranges between 4 and 483 trillion Btu.

Key Results

A bottom-up steam energy use evaluation of the pulp and paper industry for 14 major products indicates that the thermal energy requirements range between 1,212 and 2,735 trillion Btu. The average pulp and paper total steam energy use, based on this data, is 1,947 trillion Btu. Because this is an end-use estimate, determining the corresponding amount of fuel use requires assuming a conversion efficiency, which accounts for losses in generating and distributing the steam to the end use. Assuming 75 percent of the fuel energy is converted to steam and delivered to the end use, the fuel use data is 2,596 trillion Btu. According to MECS, the fuel used to generate steam in the pulp and paper industry was 2,221 trillion Btu, which is about 14 percent less than the 2,596 trillion Btu value. Although there are many assumptions built into this model, the relative agreement between these data indicates that these assumptions are reasonable.

The estimated steam energy requirements for these 14 major pulp and paper products are presented in Figure ES-1. The product steam energy use requirements varied between 4 and 483 trillion Btu.

The sources of the steam in pulp and paper manufacturing include recovery boilers (at chemical pulping facilities), power boilers, and waste heat recovery boilers. There is approximately 370,000 million Btu per hour (MMBtu/hr) of boiler capacity in the pulp and paper industry. Approximately half of this boiler capacity is fired by waste fuels. Most of the boiler capacity for pulp and paper plants is in the pressure range of 300 to 1,000 pounds per square inch (psig). Boilers larger than 250 MMBtu/hr account for over half of the boiler capacity in this industry.

ES.4 Steam Use in the Chemical Manufacturing Industry

The chemical manufacturing industry uses a significant amount of energy to manufacture chemical products for consumer and industrial markets. However, the processes used by chemical manufacturers to produce these products are typically considered competitive information, making it difficult to assess energy use in this industry from a process perspective. Consequently, a different approach to assessing chemical industry steam generation and use is required. Because a relatively small number of chemical products account for most of the industry's energy use, evaluating the processes used to manufacture these high energy-use chemical products can provide a reasonably accurate assessment of how energy, specifically steam energy, is used.

Key Results

The chemical industry produces over 70,000 products. In 1994, the chemical industry used about 3,273 trillion Btu of energy, of which steam energy accounts for roughly 1,540 trillion Btu (see Section 2). Within the chemical industry (SIC 28), there are nine 4-digit SIC segments that account for 1,210 trillion Btu of fuel used to generate steam, which is approximately 79 percent of the industry total. Within these nine SIC segments, there are 20 chemical products whose process steam energy requirements account for 832 trillion Btu of steam.

The estimated steam energy requirements for these 20 major chemicals are shown in Figure ES-2. The steam energy requirements for these 20 products varied between 0.3 and 343 trillion Btu.

Using a 75 percent conversion efficiency, which accounts for losses in converting fuel to thermal energy, generating steam, and delivering it to the end uses, the 832 trillion Btu of steam energy translates to 1,109 trillion Btu of fuel energy. Consequently, evaluation of the process energy requirements of these 20 chemical products accounts for 90 percent of the steam use within the nine selected SICs and 71 percent of the total industry steam use.

The sources of steam in the chemical manufacturing industry include boilers and process heat recovery heat exchangers. The estimated boiler capacity in the chemi-

Within the chemical industry, 20 major chemical products account for 832 trillion Btu of steam.

cal manufacturing industry is about 500,000 MMBtu/hr. Over half of this capacity, about 280 MMBtu/hr, is accounted for by boilers above 100 MMBtu/hr. However, small boilers between 10 and 50 MMBtu/hr account for about 120,000 MMBtu/hr of industry capacity, illustrating the wide distribution of boiler size across the industry. Natural gas is the dominant fuel type, accounting for about 205,000 MMBtu/hr of industry boiler capacity. About 60 percent of the boiler capacity lies in the pressure range between 300 and 1,000 psig.

ES.5 Steam Use in the Petroleum Refining Industry

The petroleum refining industry uses energy to convert crude oil into many different products, some of which are used directly by consumers, while others are feedstocks for other industries. Production data for these petroleum refining processes can be combined with process energy data to estimate overall industry energy use. Additionally, the component energy types, including direct-fired, electric, and steam, can be disaggregated from the energy data for each refining process. This allocation allows the total steam use within the industry to be estimated. This steam use estimate can then be compared to the amount of fuel used to generate steam as indicated by MECS.

Section 3.3 describes energy data for steam use by key end use processes. Section 3.3 also describes how steam is used by the major refining processes and discusses sources of steam generation.

Key Results

There are 11 major refining processes that represent the principal end uses of steam in the petroleum refining industry. The estimated steam energy requirements for major petroleum refining processes are presented in Figure ES-3. Process steam energy-use requirements vary between 0.5 and 246.1 trillion Btu. Note that visbreaking and coking operations are net steam producers.

The sum of the energy use for these 11 processes is 900 trillion Btu. If a steam system efficiency of 75 percent is assumed, the total fuel used to generate steam based on the process data becomes 1,200 (= 900/0.75) trillion Btu. Section 2 of this report estimates that the petroleum refining industry used 1,675 trillion Btu for steam generation. These two estimates of fuel used to generate steam in the petroleum refining industry compare favorably.

The major sources of steam generation in the petroleum refining industry are boilers and heat recovery steam generators. The estimated boiler capacity in the refining industry is about 210,000 MMBtu/hr. Boilers that generate more than 250 MMBtu/hr account for about 100,000 MMBtu/hr, or roughly 48 percent of the industry's total boiler capacity. Most of the boiler capacity in the petroleum refining industry is fired by byproduct fuels such as refinery gas and coke. In terms of steam system pressure, about 60 percent of the total industry boiler capacity is at 300 psig or less. Most of the remaining boiler capacity is between 300 and 1,000 psig.

ES.6 Steam System Performance Improvement Opportunities

Section 4 of the report estimates the potential savings available from implementing steam system improvements in the pulp and paper, chemical manufacturing, and petroleum refining industries. To develop these savings estimates, 30 performance improvement opportunities were identified that cover the most significant ways to improve steam system performance and efficiency in these target industries.

To assess the energy savings available from implementing steam system improvements, it was determined that eliciting expert opinion would be the most effective approach. Expert judgment was elicited by sending questionnaires to qualified experts. The major types of data requested were:

- Fuel savings
- Percentage of facility for which each opportunity is feasible
- Payback period
- Reasons for implementing the improvement.

Section 4 of the report presents data gathered from this approach.

Key Results

The results of this effort indicate that fuel savings from individual steam system improvements range from 0.6 percent to 5.2 percent. The payback periods for these steam system improvements range from 2 to 34 months; the majority are less than 24 months. The percentages of facilities for which these improvements are feasible range from 3.4 to 29.4 percent.

Overall industry fuel savings, which are the combination of estimates for fuel savings and the percentage of facilities for which an opportunity is feasible for each of the 30 opportunities, range from 0.02 percent to 3.0 percent. The data showing overall fuel savings for the major areas of a steam system are shown in Figure ES-4.

When combined, the total potential fuel savings from these steam system improvement opportunities totaled over 12 percent for each industry. Table ES-1 indicates that the total estimated energy savings potential for these 30 steam system improvement opportunities is 674 trillion Btu.


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The major sources of steam generation in the petroleum refining industry are boilers and heat recovery steam generators.

This data illustrates several key results.

- Individual fuel saving opportunities can be significant, especially because facilities can often implement several steam system improvements.
- Because most payback periods are less than 2 years, these improvements are generally worth considering.
- Total potential energy savings associated with steam improvements is significant, amounting to over 12 percent for each target industry.

ES.7 Summary of Information Included in the Appendices

The appendices for the report contain:

- Supporting information for the analyses
- Suggestions and recommendations for assessing the effectiveness of the U.S. Department of Energy BestPractices Steam Program.

Figure ES-1. Estimated Steam Energy Use for Major Pulp and Paper Products

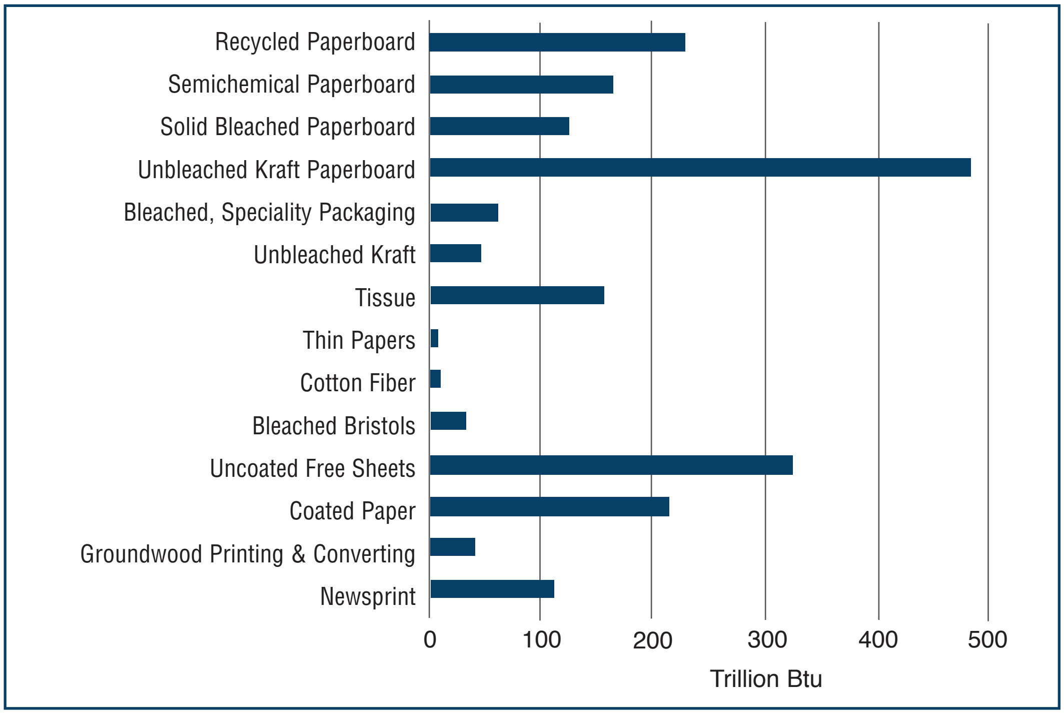


Figure ES-2. Estimated Steam Energy Use for 20 Major Chemical Products

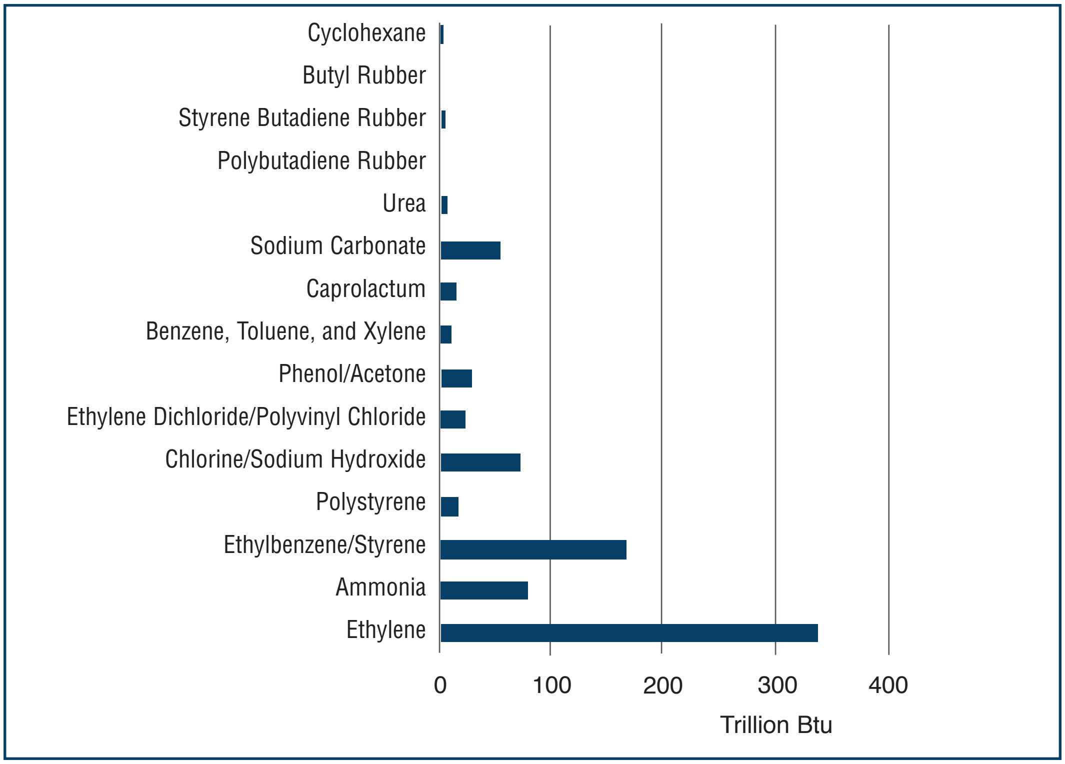


Figure ES-3. Estimated Steam Energy Use for Major Petroleum Refining Processes

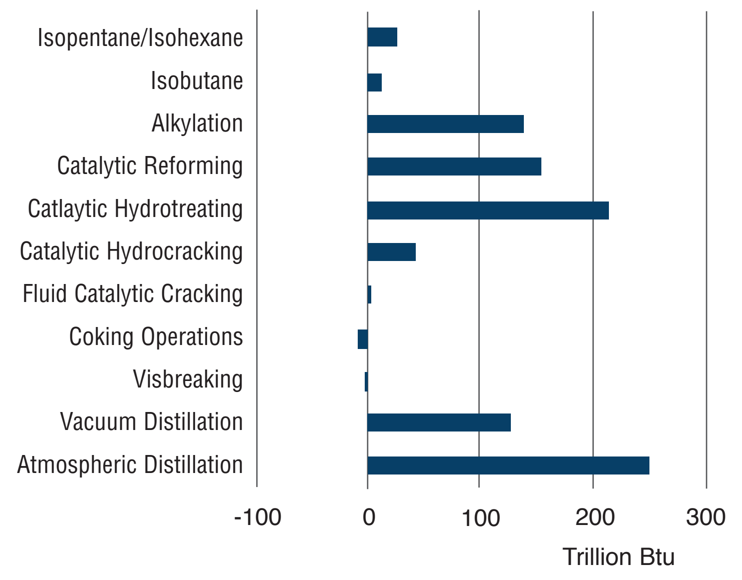
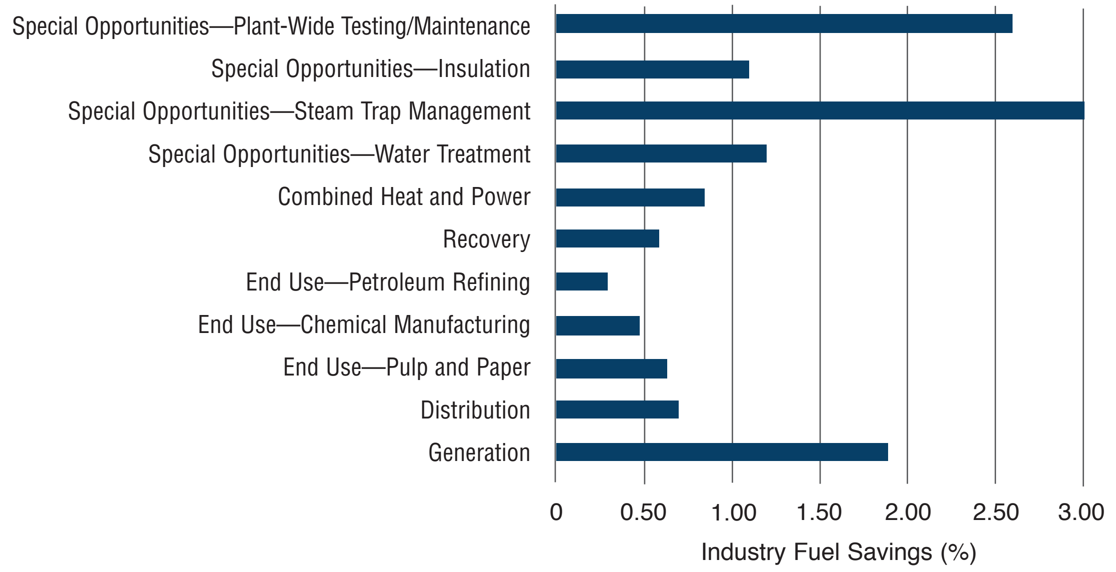


Figure ES-4. Total Industry Fuel Savings for Each Part of the Steam System



Note that the Recovery, all the End-Use Opportunities, the Distribution, and the Generation categories include multiple opportunities.

Table ES-1. Total Potential Steam System Energy Savings by Industry

Industry	Industry Fuel Savings (%)	Fuel Used to Generate Steam (Trillion Btu)	Savings Potential (Trillion Btu)
Pulp and Paper	12.5	2,221	278
Chemical Manufacturing	12.4	1,540	191
Petroleum Refining	12.2	1,675	205
Total			**674**

Steam Generation in the Pulp and Paper, Chemical Manufacturing, and Petroleum Refining Industries

Figures and Tables referenced in this section begin on page 16 in the order mentioned in the text.

Introduction

Steam energy accounts for a significant amount of the total industrial process energy use particularly among the Industries of the Future (IOFs)[1]. Because IOFs represent both an important national interest and a large portion of the nation's overall energy use, it is important to not only understand how these industries use energy, but especially how they generate and use steam. This section assesses steam generation—specifically the amount of fuel used to generate steam and the amount of steam that is generated—by three important IOF industries—pulp and paper, chemical manufacturing, and petroleum refining. Combining data from the *Manufacturing Energy Consumption Survey 1994* (MECS) with energy use estimates for key processes and products, this section provides a top-down analysis of the steam generation in the three target industries.

TAPPI Journal/NREL/PIX 03228

The pulp and paper industry is among the three most steam-intensive Industries of the Future. Steam accounts for 84 percent of total energy use in the industry.

Key Results

According to MECS data, the amounts of fuel used to generate steam in the target industries were:

- Pulp and paper: 2,221 trillion Btu
- Chemical manufacturing: 1,540 trillion Btu
- Petroleum refining: 1,675 trillion Btu.

This section also estimates the amount of steam generated by this fuel, the amount of steam purchased, and the total amount of steam available to these industries. The amount of steam as a percentage of total energy used by each industry was also determined:

- Pulp and paper: 84 percent
- Chemical manufacturing: 47 percent
- Petroleum refining: 51 percent.

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[1] Industries of the Future (IOF) include: Agriculture, Aluminum, Chemicals, Forest Products, Glass, Metal Casting, Mining, Petroleum Refining, and Steel.

Evaluating MECS Data

MECS provides the most comprehensive data for fuel use in the target industries. MECS provides fuel use data at the 4-digit SIC level, reporting energy data by many different criteria in 44 different tables. The basis for determining energy use in the target industries is in the MECS table titled “Total Inputs of Energy for Heat, Power, and Electricity Generation by Fuel Type, Industry Group, Selected Industries and End Use.” This table contains two parts: Part 1 reports data by the physical units of each fuel type, such as kWh, barrels of oil, and cubic feet of gas; Part 2 reports the data for all fuel types in trillion Btu. Because several different fuel types must be compared, Part 2 provides the more reasonable basis for this assessment.

However, many of the data are missing because of several possible reasons, including:

- Nondisclosure of competitive information (indicated by W)
- Insufficient statistical confidence (indicated by Q)
- Inadequate data (indicated by *).

In many instances, missing, omitted data can be inferred from other data. For example, total fuel use by fuel type or end use can provide one way of estimating fuel use where such data is omitted. Table 2-1 shows an example of how the missing data were inferred. The results of inferring this data for all target SICs are found in Appendix A, titled MECS Data for the Pulp and Paper, Chemical Manufacturing, and Petroleum Refining Industries.

Determining the Fuel Used to Generate Steam with MECS Data

After the missing data is inferred, the fuel that is used to generate steam must be assessed. Fuel use is reported in “Indirect Uses—Boiler Fuel”, in “End use not reported” (EUNR), and in “Conventional electricity generation.” EUNR data does not include fuel use listed either in the Direct or Indirect End Uses. Additionally, the EUNR data primarily consists of “Other” fuels. MECS uses the “Other” fuel column to account for energy that is not included in the major energy sources. Examples of “Other” fuels include coke, refinery gas, wood chips, and other solid waste fuels.

For the pulp and paper industry, EUNR data is allocated entirely to boiler fuels. This assumption is based on the steam-intensive nature of the processes in this industry. In the pulp and paper industry, the use of furnaces, kilns, and other direct fired equipment is relatively small with respect to the generation of steam. Additionally, although gasification technologies are available, they are not widely used, leaving boilers the dominant fuel-to-energy conversion source for waste fuels. Consequently, in the pulp and paper industry, there is relatively high confidence in assuming that waste fuel use is entirely for steam generation.

In the chemical industry segments, there are many more products and production processes. Many of these processes are steam-intensive and a large portion of the waste fuel-to-energy conversion process is performed in boilers (again, gasification is not considered a significant conversion technology). However, there are also direct-fired applications that influence the allocation of MECS fuel use data. For example, ethylene and propylene production require large quantities of fuel to fire pyrolysis furnaces. Because a significant portion of the fuel used in pyrolysis furnaces is byproduct fuel, this fuel use is listed as “Other” and is found in the EUNR classification[2].

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[2] Gas Research Institute, *1992 Industrial Process Heat Energy Analysis*, September 1996.

Similarly, in the petroleum industry, there are several processes that use waste fuels both to generate steam and to provide direct heating for other processes. To determine the appropriate allocation of "Other" fuel to steam generation, petroleum refining processes that use byproduct fuels must be assessed. Significant sources of "Other" energy in the petroleum refining processes include still gas and liquefied petroleum gas (LPG) byproducts from refining processes. Significant amounts of these gases are used in direct-fired applications, such as visbreaking heaters and other reaction vessels. For example, in 1992, 894 trillion Btu of byproduct fuel were used in direct-fired applications in the petroleum industry[3]. To infer the amount of direct-fired fuel use in 1994, the value of shipments for the petroleum refining industry during 1992 and 1994 level were compared. Assuming no significant difference in process technologies between the 2 years, this correction is simply the ratio of the values of shipments for 1994 and 1992 multiplied by the amount of direct-fired fuel use in 1992. As further information is gathered regarding the processes in the petroleum industry, this estimate may be adjusted.

Another component of fuel that is included in the industry total for generating steam is conventional electricity generation. A key assumption in allocating this fuel use to steam is that all on-site electric generation is assumed to be an electric topping-cycle cogeneration application that generates steam from the waste heat. An important factor in this assumption is that the thermal requirements for the target industries make on-site electricity generation equipment, such as engines and turbines, highly feasible for waste heat recovery. Because the fuel is burned to generate both electricity and steam, the conversion factors from fuel to steam will be smaller than those applied to boilers. In this study, the amount of energy available for steam generation is set at 65 percent of the fuel used to generate electricity. This assumes the efficiency of the engine or turbine is 35 percent, leaving the remaining energy available for heat recovery.

Table 2-2 provides the estimated amount of energy used to generate steam by industry.

Fuel to Steam Conversion

To convert the fuel energy data into steam usage, an assessment of the conversion equipment and efficiencies is required. Boiler efficiency can be estimated but the accuracy of this estimate depends on many factors, including operating practices, boiler age, control system sophistication, and maintenance practices. Table 2-3 provides the estimated amount of steam generated from the fuel use data provided in Table 2-2.

Table 2-3 uses several important assumptions, including:

- Boiler efficiency was calculated for each SIC group by allocating average boiler efficiencies for each fuel type to the amount of fuel used by each industry. For example, the efficiency of a boiler fired with spent liquor is 65 percent; the efficiency of a boiler fired with coal is 81 percent[4]. These boiler efficiencies are design values and do not reflect the effects of poor operating and maintenance practices.

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[3] Ibid.

[4] Giraldo, Luis and Hyman, Barry, *Energy End-Use Models for Pulp, Paper, and Paperboard Mills*, Department of Mechanical Engineering, University of Washington, 1995.

- In cogeneration applications, an estimated 52 percent of the fuel burned in the engine is recovered as steam. This estimate assumes the engine efficiency is 35 percent, leaving 65 percent of the fuel energy available as waste heat. Consequently, the fuel data from the "Conventional Electricity Generation" column in Table 2-2 of this report reflects the 65 percent of the fuel from MECS . The steam data in Table 2-3 reflects a heat recovery efficiency of 80 percent.
- Converting fuel use into a steam equivalent requires assuming a representative energy content of steam. Selecting an average steam pressure of 300 psig and a feedwater temperature of 80°F results in an energy content of 1,150 Btu/lb.

Purchased Steam

Another source of steam for many plants is through purchases from utility or nonutility suppliers. Utility suppliers are typically electric power producers that have cogeneration equipment and export steam to nearby industrial customers. Nonutility suppliers are typically industrial facilities that cogenerate a sufficient quantity of steam to meet their internal requirements and to export to nearby plants. Much of the market for purchased steam is attributable to the Public Utility Regulatory Policies Act (PURPA), which Congress enacted in 1977 to reduce many of the barriers to industrial cogeneration of electricity and steam. A major intent of PURPA was to expand cogeneration in an effort to improve overall industrial energy efficiency and to reduce reliance on energy imports. A result of PURPA was increased investment in cogeneration capacity that continued into the late 1980s.

Many cogenerating facilities sell steam to nearby industrial customers. The amount of steam purchased by the target industries in 1994 is shown in Table 2-4. The data are provided in terms of energy (trillion Btu) and mass (millions of pounds), and the conversion assumes steam contains 1,150 Btu/lb. In some industries, specifically Alkalies and Chlorine (SIC 2812), Inorganic Pigments (SIC 2819), and Synthetic Rubber (SIC 2822), the amount of purchased steam compared to the total amount of steam is relatively high.

Total Steam Available to the Target Industries

The total amount of steam available to industry is the sum of the steam generated on site and the steam purchased from suppliers. Table 2-5 provides the total amount of steam energy available to the target industry processes. The on-site generated steam data for Table 2-5 takes the steam data from Table 2-3 and performs the conversion to trillion Btu using a steam energy value of 1,150 Btu/lb.

Table 2-6 shows the percentages of purchased steam with respect to the total available steam.

Cost of Steam

Table 2-7 estimates the costs of steam generation in these industries. In this table, steam is valued at $6.00 per 1,000 lbs. However, steam costs can vary widely, depending on factors such as fuel type, fuel purchase contracts, and labor and maintenance costs. Additionally, labor and maintenance costs vary according to system size, complexity, and operating characteristics. If waste fuels account for most of the steam production, then cost of steam may be below $2.00 per 1,000 lbs.

Conversely, if natural gas is purchased on the spot market, with prices as high as \$10.50 per MMBtu[5], then steam costs can reach \$17.25 per 1,000 lbs (assuming 1,150 Btu/lb steam and 70 percent boiler efficiency).

Steam Use as a Percentage of Overall Energy Use

Table 2-8 shows how much of an industry's total energy use is accounted for by steam. In the pulp and paper industry, steam is by far the dominant form of energy use, representing between 84 and 92 percent of the total energy used. The steam-intensive nature of these industries reflects the large process heating requirement and the availability of waste-fuel energy that is typically used to generate steam.

The chemical manufacturing industry shows a greater variance in steam use because of its wide range of manufacturing processes. However, in general, the chemical industry is steam intensive, using about 47 percent of its total energy in the form of steam. The chemical industry segments have steam use characteristics that range from 30 to 70 percent of their respective total energy use. The petroleum refining industry uses about 51 percent of its energy in the form of steam.

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[5] Henry Hub market price, Energy Information Administration, Oil and Gas Office, February 26, 2001.

Table 2-1. Example of Inferring Missing Data in MECS

Total Inputs for Heat, Power, and Electricity Generation by Fuel Type, Industry Group, Selected Industries and End Use, 1994: Part 2.

Original Results Data

	Inputs							
Paper Mills (SIC 2621)	**Total**	**Net Electricity**	**Residual Fuel Oil**	**Distillate Fuel Oil**	**Natural Gas**	**LPG**	**Coal**	**Other**
Total Inputs	**1,292**	**117**	**94**	**4**	**271**	**2**	**195**	**609**
Indirect Uses—Boiler Fuel	**-**	**1**	**76**	**2**	**195**	**w**	**w**	-
Total Process (Direct Uses)	**-**	**106**	**17**	**1**	**48**	**1**	**w**	-
Process Heating	-	1	17	1	44	1	w	-
Process Cooling and Refrigeration	-	1	0	0	*	0	0	-
Machine Drive	-	102	1	*	w	0	w	-
Electro-Chemical	-	*	-	-	-	0	-	-
Other	-	2	0	*	w	0	0	-
Total Non-Process (Direct Uses)	**-**	**8**	**w**	**1**	**26**	**1**	**w**	-
Facility HVAC	-	4	w	0	3	0	w	-
Facility Lighting	-	3	0	0	0	0	-	-
Facility Support	-	1	w	0	0	0	0	-
On-Site Transportation	-	*	0	1	0	1	-	-
Conventional Electricity Generation	-	-	w	0	23	0	w	-
Other Non-Process Use	-	*	w	0	0	0	0	-
End Use Not Reported	**614**	**2**	**w**	**0**	**2**	**0**	**0**	**609**

Results of Inferring Data

Paper Mills (2621)	**Total**	**Net Electricity**	**Residual Fuel Oil**	**Distillate Fuel Oil**	**Natural Gas**	**LPG**	**Coal**	**Other**
Total Inputs	**1,292**	**117**	**94**	**4**	**271**	**2**	**195**	**609**
Indirect Uses—Boiler Fuel	-	**1**	**76**	**2**	**195**	**0**	**185**	**0**
Total Process (Direct Uses)	-	**106**	**17**	**1**	**48**	**1**	**5**	**0**
Process Heating	-	1	17	1	44	1	0	**0**
Process Cooling and Refrigeration	-	1	0	0	**0**	0	0	**0**
Machine Drive	-	102	1	**0**	**0**	0	**0**	**0**
Electro-Chemical	-	**0**	**0**	**0**	**0**	0	**0**	**0**
Other	-	2	0	**0**	**0**	0	0	**0**
Total Non-Process (Direct Uses)	-	**8**	**0**	**1**	**26**	**1**	**5**	**0**
Facility HVAC	-	4	**0**	0	3	0	**0**	**0**
Facility Lighting	-	3	0	0	0	0	0	**0**
Facility Support	-	1	**0**	0	0	0	0	**0**
On-Site Transportation	-	**0**	0	1	0	1	0	**0**
Conventional Electricity Generation	-	**0**	**0**	0	23	0	**0**	**0**
Other Non-Process Use	-	**0**	**0**	0	0	0	0	**0**
End Use Not Reported	**613**	**2**	**0**	**0**	**2**	**0**	**0**	**609**

indicates inferred data

- indicates no data entered

* indicates a value less than 0.5

w indicates data withheld to avoid disclosing establishment

Table 2-2. Estimated Amount of Fuel Used to Generate Steam by Industry

	SIC	Indirect Uses Boiler Fuel	End Use Not Reported	Conventional Electricity Generation	Total
Pulp and Paper	**26**	**849**	**1,351**	**20**	**2,221**
Pulp Mills	2611	40	191	0	231
Paper Mills	2621	459	611	15	1,085
Paperboard Mills	2631	288	533	6	827
Other Pulp and Paper Segments		62	16	0	78
Chemicals	**28**	**1,229**	**184**	**127**	**1,540**
Alkalies and Chlorine	2812	51	30	0	81
Inorganic Pigments	2816	10	10	0	20
Inorganic Chemicals	2819	101	23	1	126
Plastics and Resins	2821	137	50	0	187
Synthetic Rubber	2822	23	9	0	32
Organic Fibers, Noncellulosic	2824	72	8	0	80
Cyclic Crudes and Intermediates	2865	81	27	3	111
Organic Chemicals	2869	389	11	88	488
Nitrogenous Fertilizers	2873	72	13	1	86
Other Chemical Segments		293	3	34	330
Petroleum	**29**	**304**	**1,323**	**47**	**1,675**
Petroleum Refining	2911	295	1,313	47	1,655
Other Petroleum Refining Segments		9	11	0	20

Units are Trillion Btu

Table 2-3. Estimated Amount of Steam Generated from Fuel by Industry

Industry Description	SIC	Indirect Uses Boiler Fuel	End Use Not Reported	Conventional Electricity Generation	Total
Pulp and Paper	**26**	**527,857**	**840,094**	**14,153**	**1,382,103**
Pulp Mills	2611	23,617	112,891	0	136,509
Paper Mills	2621	278,992	371,382	10,400	660,774
Paperboard Mills	2631	177,308	328,143	4,070	509,520
Other Pulp and Paper Segments		47,939	27,678	0	75,301
Chemicals	**28**	**841,277**	**125,952**	**88,348**	**1,055,577**
Alkalies and Chlorine	2812	34,396	20,233	0	54,629
Inorganic Pigments	2816	6,870	6,938	0	13,808
Inorganic Chemicals	2819	69,892	16,054	904	86,851
Plastics and Resins	2821	92,505	33,761	45	126,311
Synthetic Rubber	2822	15,726	6,154	0	21,880
Organic Fibers, Noncellulosic	2824	50,450	5,707	0	56,157
Cyclic Crudes and Intermediates	2865	55,643	18,548	1,809	76,000
Organic Chemicals	2869	257,687	7,287	61,217	326,191
Nitrogenous Fertilizers	2873	50,895	9,189	904	60,988
Other Chemical Segments		207,213	2,081	23,468	232,762
Petroleum	**29**	**207,052**	**901,063**	**32,696**	**1,140,811**
Petroleum Refining	2911	200,857	893,709	32,696	1,127,262
Other Petroleum Refining Segments		6,196	7,353	0	13,549

Note: Row and column totals are subject to rounding errors.

Units are Million Lbs. of Steam

Table 2-4. Estimated Amount of Purchased Steam by Industry

		Trillion Btu			Million Lbs of Steam		
Industry Segment	**SIC**	**Utility**	**Non-Utility**	**Total**	**Utility**	**Non-Utility**	**Total**
Paper and Allied Products	**26**	**15**	**15**	**31**	**13,362**	**13,198**	**26,560**
Pulp Mills	2611	0	2	2	0	1,598	1,598
Paper Mills	2621	5	8	14	4,743	7,355	12,097
Paperboard Mills	2631	8	2	11	7,351	2,078	9,430
Chemicals and Allied Products	**28**	**26**	**87**	**112**	**22,270**	**75,246**	**97,517**
Alkalies and Chlorine	2812	4	12	15	3,097	10,078	13,176
Inorganic Pigments	2816	0	5	5	0	4,348	4,348
Inorganic Chemicals	2819	1	1	2	737	584	1,322
Plastics Materials and Resins	2821	3	6	9	2,423	5,491	7,915
Synthetic Rubber	2822	8	3	11	6,959	2,820	9,779
Organic Fibers, Noncellulosic	2824	0	5	5	0	4,348	4,348
Cyclic Crudes and Intermediates	2865	2	2	5	2,137	1,833	3,970
Organic Chemicals	2869	8	51	59	6,916	43,957	50,872
Nitrogenous Fertilizers	2873	0	2	2	0	1,787	1,787
Petroleum and Coal Products	**29**	**23**	**19**	**42**	**19,957**	**16,309**	**36,265**
Petroleum Refining	2911	23	19	41	19,597	16,309	35,905

Table 2-5. Estimated Total Steam Available to the Target Industry Segments

		On-Site Generated Steam				Purchased Steam			
Industry Description	**SIC**	**Indirect Uses Boiler Fuel**	**End Use Not Reported**	**Conventional Electricity Generation**	**Total On-Site Steam**	**Utility**	**Non-Utility**	**Total Purchased Steam**	**Total Available Steam**
Pulp and Paper	**26**	**607**	**966**	**16**	**1,589**	**15**	**15**	**31**	**1,620**
Pulp Mills	2611	27	130	0	157	0	2	2	159
Paper Mills	2621	321	427	12	760	5	8	14	774
Paperboard Mills	2631	204	377	5	586	8	2	11	597
Other Pulp and Paper Segments		55	32	0	87	1	2	4	91
Chemicals	**28**	**967**	**145**	**102**	**1,214**	**25**	**87**	**112**	**1,326**
Alkalies and Chlorine	2812	40	23	0	63	4	12	15	78
Inorganic Pigments	2816	8	8	0	16	0	5	5	21
Organic Chemicals	2819	80	18	1	100	1	1	2	101
Plastics and Resins	2821	106	39	0	145	3	6	9	154
Synthetic Rubber	2822	18	7	0	25	8	3	11	36
Organic Fibers, Noncellulosic	2824	58	7	0	65	0	5	5	70
Cyclic Crudes and Intermediates	2865	64	21	2	87	2	2	5	92
Organic Chemicals	2869	296	8	70	375	8	51	59	434
Nitrogenous Fertilizers	2873	59	11	1	70	0	2	2	72
Other Chemical Segments		238	2	27	268	0	0	0	268
Petroleum	**29**	**238**	**1,036**	**38**	**1,312**	**23**	**19**	**42**	**1,354**
Petroleum Refining	2911	231	1,028	38	1,296	23	19	41	1,338
Other Petroleum Refining Segments		7	8	0	16	0	0	0	16

Units are Trillion Btu

Table 2-6. Purchased Steam as a Percentage of Total Available Steam by Industry

Industry	SIC	Purchased Steam as a % of Total Steam
Pulp and Paper	**26**	**2.0%**
Pulp Mills	2611	1.2%
Paper Mills	2621	1.9%
Paperboard Mills	2631	1.9%
Chemicals	**28**	**8.8%**
Alkalies and Chlorine	2812	20.1%
Inorganic Pigments	2816	24.8%
Inorganic Chemicals	2819	1.6%
Plastics and Resins	2821	6.1%
Synthetic Rubber	2822	31.8%
Organic Fibers, Noncellulosic	2824	7.5%
Cyclic Crudes and Intermediates	2865	5.2%
Organic Chemicals	2869	14.0%
Nitrogenous Fertilizers	2873	3.0%
Petroleum and Coal Products	**29**	**3.2%**
Petroleum Refining	2911	3.2%

Based on MECS and Resource Dynamics Corporation estimates

Table 2-7. Cost of Steam by Industry

Industry Description	SIC	Steam Cost ($ Million)	Value of Shipments ($ Million)*	Steam Cost as % of Value Shipments
Pulp and Paper	**26**	**8,459**	**143,761**	**5.9%**
Pulp Mills	2611	829	4,424	18.7%
Paper Mills	2621	4,041	35,071	11.5%
Paperboard Mills	2631	3,116	18,749	16.6%
Other Pulp and Paper Segments		473	85,517	0.6%
Chemicals	**28**	**6,945**	**333,259**	**2.1%**
Alkalies and Chlorine	2812	410	2,171	18.9%
Inorganic Pigments	2816	110	3,320	3.3%
Inorganic Chemicals	2819	529	16,032	3.3%
Plastics and Resins	2821	808	36,965	2.2%
Synthetic Rubber	2822	193	4,984	3.9%
Organic Fibers, Noncellulosic	2824	364	12,213	3.0%
Cyclic Crudes and Intermediates	2865	481	11,152	4.3%
Organic Chemicals	2869	2,276	57,671	3.9%
Nitrogenous Fertilizers	2873	377	4,246	8.9%
Other Chemical Segments		1,397	184,505	0.8%
Petroleum	**29**	**7,072**	**128,236**	**5.5%**
Petroleum Refining	2911	6,989		5.4%

*1994 Annual Survey of Manufacturers

Table 2-8. Steam Energy as a Percentage of Total Energy by Industry

Industry	SIC	Steam Energy as a % of Total Energy
Pulp and Paper	**26**	**84%**
Pulp Mills	2611	92%
Paper Mills	2621	84%
Paperboard Mills	2631	89%
Chemicals	**28**	**47%**
Alkalies and Chlorine	2812	63%
Inorganic Pigments	2816	50%
Inorganic Chemicals	2819	37%
Plastics and Resins	2821	59%
Synthetic Rubber	2822	51%
Organic Fibers, Noncellulosic	2824	70%
Cyclic Crudes and Intermediates	2865	71%
Organic Chemicals	2869	36%
Nitrogenous Fertilizers	2873	30%
Petroleum	**29**	**51%**
Petroleum Refining	2911	53%

Section 3

Steam Use in the Pulp and Paper, Chemical Manufacturing, and Petroleum Refining Industries

In Section 2, fuel use in the pulp and paper, chemical manufacturing, and petroleum refining industries was estimated using data from the *Manufacturing Energy Consumption Survey 1994* (MECS). These estimates comprise a top-down view of fuel use in the target industries. Because several assumptions were used to extract useful information from the MECS data, to check the accuracy of these assumptions, a bottom-up analysis of the processes in these industries was performed. This bottom-up view evaluated the products and processes that accounted for most of the steam use in these industries.

This section contains three subsections, each evaluating steam end uses in one of the target industries. Ideally, determining the amount of steam used in these industries allows a reasonable fuel-to-steam conversion factor to provide fuel use estimates that are consistent with the Section 2 results.

3.1 Assessing Steam Use in the Pulp and Paper Industry

Figures and Tables referenced in this section begin on page 32 in the order they are mentioned in the text.

Introduction

Manufacturing plants in the pulp and paper industry vary by size, level of integration, process technology, wood type, and final product type. The energy used by fully integrated plants can be combined with total industry production to estimate the total thermal energy used by the pulp and paper industry. This method assumes that a fully integrated pulp and paper plant uses the same amount of energy to produce a ton of product that an equivalent supply chain of plants that are not integrated would use. Ideally, the energy data reported in the *Manufacturing Energy Consumption Survey 1994* (MECS) is consistent with the results of this bottom-up view of the process energy use.

Key Results

A bottom-up steam energy use evaluation of the pulp and paper industry for 14 major products indicates that the thermal energy requirements range between 1,212 and 2,735 trillion Btu. Based on this data, the average pulp and paper total steam energy use is 1,974 trillion Btu. Because this is an end-use estimate, determining the corresponding amount of fuel use requires assuming a conversion efficiency, which accounts for losses in generating and distributing the steam to the end use. Assuming 75 percent of the fuel energy is converted to steam and delivered to the end use, the fuel use data is 2,596 trillion Btu. According to MECS, the fuel used to generate steam in the pulp and paper industry was 2,221 trillion Btu, which is about 14 percent less than the 2,596 trillion Btu value. Although there are many assumptions built into this model, the relative agreement between these data indicates that these assumptions are reasonable.

The estimated steam energy requirements for these 14 major pulp and paper products are presented in Figure 3.1-1. The product steam energy-use requirements varied between 4 and 483 trillion Btu.

The sources of the steam in pulp and paper manufacturing include recovery boilers (at chemical pulping facilities), power boilers, and waste heat recovery boilers. There is approximately 370,000 MMBtu/hr of boiler capacity in the pulp and paper industry. Approximately half of this boiler capacity is fired by waste fuels. Most of the boiler capacity for pulp and paper plants is in the pressure range of 300 to 1,000 psig. Boilers larger than 250 MMBtu/hr account for over half of the boiler capacity in this industry.

Method

A barrier to assembling precise process energy data is that industrial facilities, including pulp and paper manufacturers, consider their processes to be proprietary. Consequently, they are resistant to revealing how they use energy. However, there are data available that describe typical energy requirements for integrated pulp and paper facilities. Integrated mills include all three major process steps: preparation, pulping, and paper or paperboard manufacturing. Table 3.1-1 shows the range of thermal and electric energy use for these integrated plants.

To assemble overall industry energy use estimates without access to specific plant data, industry production data must be evaluated. Most industry shipments can be grouped into 14 categories of paper and paperboard products. Energy use data can be allocated to these product categories. Assigning production processes to these product classes—and the energy use associated with them—provides one way of estimating thermal energy use for each class. Table 3.1-2 shows the results of assigning major product categories to the integrated plant process.

The energy data for the production processes is provided in terms of tons of product; consequently, multiplying the production quantity of each product class by the unit energy data provides an estimate of the overall thermal energy use for the industry. Summing the thermal energy requirements of each product class provides the thermal energy requirements for the industry.

Table 3.1-3 shows production and energy data by product class for the pulp and paper industry. To illustrate how the energy use in Table 3.1-3 was determined, consider the unbleached kraft paper product category. In an integrated kraft pulp and paper mill, the thermal energy requirements are between 16,000 and 33,000 thousand Btu/ton. An estimate of the average energy requirements for bleaching kraft pulp is 3,000 thousand Btu/ton [1]. Subtracting this value from the minimum and maximum thermal energy requirements provides an estimated range of 13,000 to 30,000 thousand Btu/ton for unbleached kraft. Because 2,308 tons of unbleached kraft was produced in 1994, a range of 30 to 69 trillion Btu in thermal energy use was allocated to that product category.

In pulp and paper manufacturing, thermal energy is provided almost entirely by steam. Consequently, applying a reasonable boiler efficiency factor to the thermal energy required for each ton of product and multiplying that result by the industry output for that year determines boiler fuel use. A fuel-to-steam conversion efficiency of 75 percent was assumed. This conversion accounts for losses in burning the fuel, generating the steam, and distributing it to the end uses. As indicated in Table 3.1-3, the total thermal energy requirement for the pulp and paper industry was 1,974 trillion Btu. Applying a 75 percent conversion factor results in an estimated boiler fuel use of 2,596 trillion Btu.

Overview of Pulp and Paper Plant Operation

To determine how steam is used within pulp, paper, and paperboard plants, the manufacturing processes must first be assessed. These plants use steam primarily for electric power generation and process heating. On-site electric power generation reduces the costs of purchased power and exploits the availability of waste fuels that are generated by many of the production processes.

With respect to process heating services, almost all the thermal energy used at a paper plant is provided by steam. To prevent pulp degradation the temperatures of these processes are usually less than 360°F.

There are three principal process categories in the pulp and paper industry: preparation, pulping, and paper or paperboard manufacturing. Preparation is the process of converting logs into wood chips that are small enough to be sent into one of several pulping processes. Pulping is the process of obtaining fibers from the wood. Paper or paperboard manufacturing forms these fibers into final products.

Preparation

Preparation is electric-energy intensive, relying on motor-driven equipment to debark logs and grind them into chips. There are several types of preparation equipment, but the output of these processes are wood chips, which are then sent into the pulping processes.

Pulping

Pulping processes can be grouped into four basic categories: chemical, mechanical, semichemical, and chemi-mechanical. Chemical pulping relies on a chemical reaction to disassociate lignin (the "glue" that binds the wood together) from the wood fibers. Mechanical pulping uses a grinding action to isolate the pulp fibers. Semichemical and chemi-mechanical processes combine aspects of the chemical and mechanical processes to produce pulp.

Chemical Pulping. There are two principal types of chemical pulping: kraft and sulfite. The kraft process is the most common type of pulping, producing approximately 85 percent of the pulp in the United States in 1994. The sulfite process serves a smaller segment of the industry, accounting for just over 2 percent of U.S. pulp production.

In chemical pulping processes, the wood chips are immersed in pulping chemicals and the digesting reaction is maintained at the proper temperatures with steam. The thermal energy required for cooking varies according to the type of wood and the requirements of the final product.

Kraft Pulping. Kraft pulping produces fibers that form strong paper and paperboard products, and is suitable for many different types of wood. In a kraft process, the wood chips are introduced into a cooking vessel containing a highly basic mixture of sodium hydroxide (NaOH) and sodium sulfide (Na_2S). The chips are cooked at high temperatures, usually between 329° and 347°F, for 1 to 1.5 hours. Table 3.1-4 describes the thermal energy characteristics of processes associated with the kraft pulping process.

The total thermal energy requirement for these processes range from 7,760 to 22,830 thousand Btu/ton. This range of energy requirements is wide because of varying types of pulpwoods and the requirements of the final products.

Sulfite Pulping. Sulfite pulping chemicals are sulfite or hydrogen sulfite, which form acidic pulping solutions. There are four principal process chemicals within sulfite pulping—sodium, calcium, magnesium, and ammonium—that form the basis for a variety of pulps. These different pulping liquors produce different pulp characteristics and, similarly, have different chemical recovery requirements. Table 3.1-5 describes the thermal energy requirements of the sulfite process.

Chemical Recovery. In both the kraft and sulfite processes, the pulping liquors must be recovered to reduce disposal costs and chemical purchase costs. The chemical recovery process begins with increasing the solids content of the black liquor. After it has been rinsed from the wood pulp, black liquor contains solids content of between 10 and 20 percent. By pumping this weak black liquor through a series of evaporators that use large amounts of steam, the solids concentration increases to 60 to 75 percent. The black liquor is then sprayed into a recovery furnace where it undergoes several reactions including drying, pyrolysis, and combustion. This process is highly exothermic and a large amount of heat is recovered in the form of steam generation. The chemical recovery process is a large source of steam for the plant.

Recovery boilers typically operate at approximately 1,500°F, and they often produce superheated steam. In many plants, this superheated steam is used to turn steam turbines that drive electric generators, creating electric power for the plant or for sale. Most of these turbines are non-condensing, meaning the turbines have positive exhaust pressure that allows the exhaust steam to be sent to other steam services. Additionally, the turbines often have interstage steam taps that allow steam to be drawn off at pressures above that of the turbine exhaust.

The capital cost of chemical recovery equipment is often a significant portion of the cost of an entire pulp plant. In many cases, the ability to expand pulp production is limited by the capacity of the chemical recovery equipment.

After it is drained from the digesters, the pulping solution is known as black liquor because of the coloring provided by the dissolved lignin and organic material. The digesting process can be configured in either a batch or continuous mode depending on the plant design. Batch digesters tend to be more energy intensive than continuous digesters.

To remove the wood fibers from the black liquor, the solution undergoes a series of washing processes that rinse away the pulping solution. The wood pulp is then cleaned and filtered to remove knots and other unwanted contaminants, then prepared for further processing, such as drying, refining, and bleaching. The black liquor, on the other hand, is sent into the chemical recovery process so that the chemicals used in the digestion process can be recovered and reused.


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The preparation process generally produces wood chips, which are usually sent to a pulping process.

Mechanical Pulping. Mechanical pulping processes produced roughly 10 percent of the pulp in 1994. Mechanical pulping essentially grinds the wood chips to isolate the pulp fibers. The grinders are typically motor-driven and require significant amounts of electric power. In general, mechanical pulps are less expensive than other pulps, and because they have desirable print characteristics, mechanical pulps are often made into newsprint. Mechanical pulps produce fibers that have lower tear and burst strengths than chemical pulps.

There are five basic mechanical pulping processes:

- Stone groundwood process (SGW)
- Refiner mechanical pulp (RMP)
- Thermomechanical pulp (TMP)
- Semichemical
- Chemical thermomechanical pulp (CTMP).

SGW uses a large rotating stone to grind the wood. RMP is similar to SGW pulping except the grinding process uses discs instead of stone and the pulp is immersed in water to produce a longer fiber. In TMP, the wood chips are treated with steam to soften the wood, allowing the extraction of longer and stronger fibers than those typically obtained from SGW and RMP.

Semichemical pulping uses a combination of mechanical and chemical methods. Usually, the wood is treated chemically, but the wood pulp is not completely digested as in a chemical pulping process. Rather, the chemically treated wood is sent to a refiner where mechanical action is used to isolate the pulp fibers. CTMP is similar to TMP but a chemical agent is added to the wood prior to the TMP process. This chemical treatment facilitates the mechanical pulping process.

Table 3.1-6 describes the various energy requirements of the mechanical pulping processes. Mechanical pulps often require drying and bleaching, which can use significant amounts of thermal energy. However, mechanical pulps, unlike kraft pulps, do not have the dark coloration that occurs with the chemical pulping reaction. As a result, in general, the bleaching requirements of mechanical pulps are less energy intensive than chemical pulps.

Other Thermal-Energy-Intensive Process Steps

After isolating the wood pulp, there are several process steps that require thermal energy.

Pulp Drying. In some cases, the pulp is sold on the market to paper or paperboard manufacturers. Before it is sold, the pulp is usually dried to reduce the cost of transporting it. In integrated plants, however, the pulp is sent on to the paper or paperboard manufacturing process. The thermal energy required to dry the pulp depends on the type of pulping process used.

Washing. In chemical pulping plants, water is used to displace pulping liquors, to clean the pulp, and to recover the pulping chemicals. Washing 1 ton of pulp uses approximately 730 to 800 thousand Btu of thermal energy and roughly 30 to 50 kWh of electric energy [1,5].

Refining. Refining, also known as stock preparation, manipulates the fibers to achieve desired characteristics for the final product. A common refining task relies on fibrillation to loosen the fibers and increase their surface area to promote good fiber-to-fiber bonding. Another typical refining process cuts the pulp fibers to a certain length to promote sheet formation during manufacturing and to establish a desired final product appearance. Refining is a large user of electric energy, using 200 to 420 kWh/ton. This process also uses thermal energy to assist in maintaining temperature and moisture parameters. Many factors affect the energy requirements of the refining process, including final product requirements of the pulp and fiber quality (which itself depends on the feedstock and the pulping process).

Bleaching. Most chemical pulps are dark, and, as such, are unsuitable for hygiene or writing purposes. Consequently, they are usually bleached to establish desired brightness characteristics. There are several different chemicals and technologies used to bleach pulp. Selection of the bleaching process depends on the characteristics of the pulp and the requirements of the final product. In many bleaching processes, steam is used to maintain certain temperature requirements to promote the bleaching reaction. The thermal energy requirements of pulp bleaching processes range from 300 thousand Btu/ton for some mechanical pulps to 9,000 thousand Btu/ton for some kraft pulps. The electrical energy required for bleaching ranges from 80 to 500 kWh/ton.

Table 3.1-7 provides the thermal energy requirements for processes that are often used in pulping and papermaking processes.

Mechanical pulps usually undergo different processing than chemical pulps. Table 3.1-8 contains estimates of the drying and bleaching energy requirements for mechanical pulps.

Paper and Paperboard Manufacturing

Paper and paperboard processes convert wood fibers into the final product. Papermaking is the most energy intensive of the three major process categories (preparation, pulping, and papermaking), using approximately 36 percent of the total process energy. Most of the thermal energy required in papermaking is in the form of steam used by dryers. There are two basic types of papermaking machines, Fourdrinier and cylinder. Three basic components are common to both machines:

- A wet end, which receives a pulp slurry containing dilute suspension of pulp fibers and removes water primarily through gravity drainage
- A pressing section that dewaters this slurry with mechanical action
- A dry end that removes additional moisture through evaporation.

The principal difference between these machines is in the way the pulp slurry is handled as it enters the wet end. A Fourdrinier machine uses a wire mesh to allow the water to drain through, while a cylinder machine uses a rotating cylinder that has holes on the surface.

There are two principal types of drying equipment used in the papermaking process: drum dryers, also known as cylinder dryers, and Yankee dryers. A drum dryer works by running the wet paper over a rotating cylinder that is heated by steam. This drying equipment often combines more than 100 cylinders to achieve the correct moisture level in the paper. Drum dryers, which use between 6.5 and 12.5 million Btu/ton of thermal energy, account for 82 percent of all dryers.

Yankee dryers also use heated cylinders to dry the paper sheet, but each cylinder is equipped with an air hood positioned very close to the paper surface. The air hood increases heat transfer by impinging air on the surface of the paper sheet. Yankee dryers are somewhat more efficient than drum dryers, using approximately 5.5 million Btu/ton in thermal energy.

Table 3.1-9 provides the thermal energy requirements for drying in paper and paperboard manufacturing.

Steam Generation

The sources of the steam in pulp and paper manufacturing include recovery boilers (at chemical pulping facilities), power boilers, and waste heat recovery boilers. There is approximately 370,000 MMBtu/hr of boiler capacity in the pulp and paper industry [7].

Recovery Boilers

Recovery boilers are operated to process black liquor that is produced during pulping. The principal purpose is to recover pulping chemicals for reuse. Consequently, the steam requirements of the plant are usually secondary considerations behind the need to process the spent pulping solution. Recovery boilers tend to be relatively large and expensive. Because increasing pulp production capacity requires an accompanying increase in recovery boiler capacity, the chemical recovery boiler is often the largest restriction to increasing the production capacity at a plant. In 1994, there were about 235 recovery boilers accounting for about 130,000

MMBtu/hr of capacity [6]. (This represents a large portion of the boiler capacity that is fired by “Other” fuels, as shown in Figure 3.1-2.)

Power Boilers

Plants use power boilers to provide steam for process needs and for power generation requirements. Integrated plants often generate waste fuels, such as bark and wood chips. Boilers that can burn these fuels reduce waste disposal requirements while reducing the amount of purchased electric power. Power boilers are often capable of being fired with multiple fuels, which provides flexibility in meeting steam requirements, despite variations in the amount of available waste fuel and its heat content. Figure 3.1-2 describes the boiler population by fuel type. The “Other” fuel category includes waste fuels and accounts for the largest amount of boiler capacity.

Figure 3.1-3 shows a distribution of steam systems, disaggregated by rated pressure. The largest amount of steam system capacity falls between 300 and 1,000 psig.

Figure 3.1-4 describes boiler capacity by boiler size. The largest amount of capacity is in large boilers, exceeding 250 MMBtu/hr[1]. This indicates that pulp and paper plants tend to be large and use steam-intensive manufacturing processes.

Waste Heat Recovery Boilers

In the pulp and paper industry, waste heat recovery boilers are primarily used in combination with on-site electric power generation. Unlike some industries, such as petroleum refining, in which some chemical reactions release large amounts of energy, the processes of pulp and paper manufacturing are typically endothermic[2], and do not provide many waste heat recovery opportunities. Consequently, other than chemical recovery boilers, which were discussed separately, the most common sources of waste heat recovery are the exhaust gases of combustion turbines, which are generally used to drive electric generators. Cogeneration systems tend to be very feasible in pulp and paper plants because of the large demand for both electric and thermal energy. However, in this industry, most cogeneration uses boiler generated steam to drive steam turbines. On-site generation is discussed in greater detail in the following section.

Electricity Generation

On-site power generation is highly feasible for most large pulp and paper plants. High overall efficiencies combined with the need for large amounts of electric and thermal energy and the availability of waste fuels provide favorable economics for cogeneration systems. In 1994, the pulp and paper industry generated over 48 percent of its electric energy on site [3]. Additionally, over 86 percent of on-site generated electricity was from cogeneration systems [3].

Most on-site electric power is generated by steam turbines that are driven by boiler generated steam, as shown in Table 3.1-10. Waste products, such as bark and black liquor, account for most of the fuel used in these boilers.

Chemical recovery boilers operate at high temperatures to support the reaction that recovers pulp chemicals. These boilers often generate superheated steam,

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[1] 250,000 MMBtu/hr roughly corresponds to 220,000 lbs/hr of steam, assuming steam energy is 1,150 Btu/lb.

[2] An important exception is the recovery of pulping chemicals, which can generate large amounts of heat; however, these processes are discussed separately.

which is commonly used to drive steam turbines. Superheated steam has several advantages in turbine operation, including reduced risk of blade damage that results from droplet impingement on the blade surfaces. These turbines are connected to electric generators or mechanical drive devices, such as pumps and compressors. An important factor that determines how steam is used in a pulp and paper facility is the ratio of thermal to electric energy requirements at a plant. There are many factors that affect the relationship between electric and thermal energy including the level of integration at the plant, the wood supply, the types of processes used at the plant, and the products that are manufactured.

Mechanical Drive

In the pulp and paper industry, there are two principal prime movers of machine drives: electric motors and steam turbines. Although motors account for most of the energy used in machine drive applications, steam turbines still represent a significant portion of the energy used to drive pumps, fans, compressors, and other rotating equipment. Turbine drives have some operational advantages, such as variable operating speed characteristics that make them effective load followers. For example, in turbine-driven boiler feed pumps, the turbine load and the boiler load increase and decrease together. Additionally, the wide availability of steam in these plants also encourages the selection of steam turbines.

In 1994, the pulp and paper industry used an estimated 12 trillion Btu in fuel to generate steam for mechanical drive applications. In contrast, about 179 trillion Btu in electric energy was used in mechanical drive applications.

References

[1] *Scoping Study Pulp and Paper Industry*, EPRI, prepared by Giese & Associates, December, 1988.

[2] *Directory of the Pulp, Paper, and Allied Trades*, Lockwood Post, 1996.

[3] *Manufacturing Consumption of Energy 1994*, Energy Information Administration, U. S. Department of Energy, December, 1997.

[4] *Energy Efficiency and the Pulp and Paper Industry*, American Council for an Energy Efficient Economy, September 1995.

[5] *Energy Analysis of 108 Industrial Processes*, Drexel University Project Team; Brown, H.; Hamel, B.; Fairmont Press, 1985.

[6] *Update of the American Forest & Paper Association's Recovery Boiler Program*; Grant, T., AFPA, 1996. (Boiler capacity was calculated using AFPA estimate that recovery boilers accounted for 41 percent of industry energy use.)

[7] *Analysis of the Industrial Boiler Population*, Final Report no. GRI-96/0200, Gas Technology Institute, June 1996.

[8] Major Industrial Plant Database (MIPD^{TM}), IHS Energy, June 1999.

Figure 3.1-1. Estimated Steam Energy Requirements for Major Pulp and Paper Products

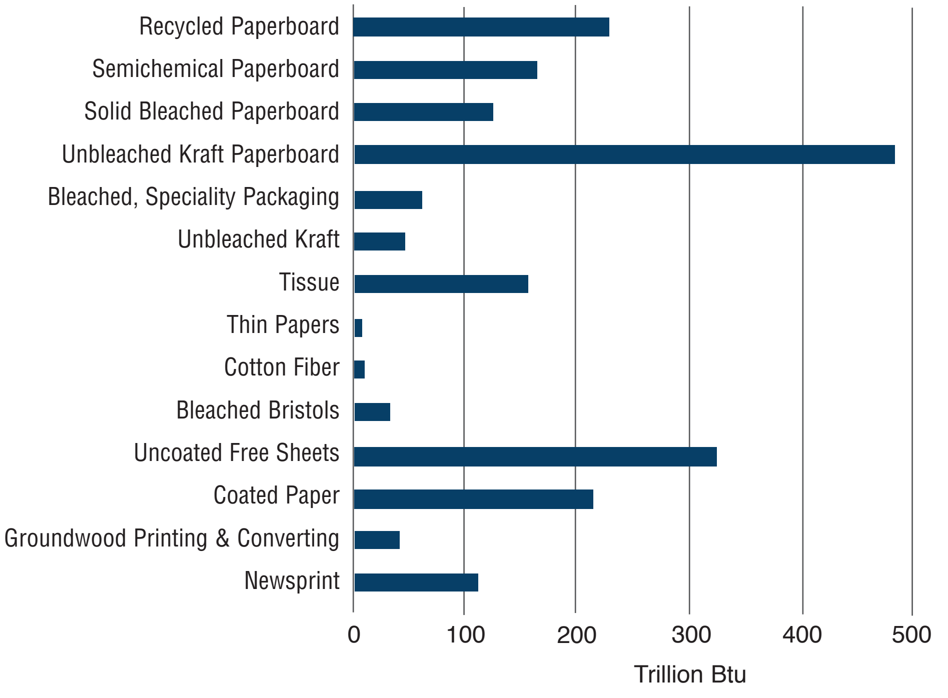


Table 3.1-1. Energy Use at Integrated Pulp and Paper Mills [1]

	Thermal		Electrical		Total	
Process Energy for Integrated Mills	**Min.**	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**
Chemical (Kraft and Sulfite)	16,000	33,000	2,400	5,500	18,400	38,500
Mechanical	8,000	25,000	6,500	17,200	14,500	42,000
Sulfite Semichemical	17,000	35,000	4,100	6,800	21,000	41,800
Chemi-Thermomechanical	9,000	25,000	7,500	16,400	16,500	41,400

Thousand Btu/ton

Table 3.1-2. Relating Major Pulp and Paper Product to Integrated Plant Type

Product Category	Integrated Plant Energy Requirement	Adjustments
Paper Products		
Newsprint	Mechanical	Removed mechanical bleaching energy
Groundwood Printing & Converting	Mechanical	Removed mechanical bleaching energy
Coated Paper	Chemical (Kraft and Sulfite)	
Uncoated Free Sheets	Chemical (Kraft and Sulfite)	
Bleached Bristols	Chemical (Kraft and Sulfite)	
Cotton Fiber	Chemical (Kraft and Sulfite)	
Thin Papers	Chemical (Kraft and Sulfite)	
Tissue	Chemical (Kraft and Sulfite)	
Unbleached Kraft	Chemical (Kraft and Sulfite)	Removed kraft bleaching energy
Bleached, Specialty Packaging	Chemical (Kraft and Sulfite)	
Paperboard		
Unbleached Kraft Paperboard	Chemical (Kraft and Sulfite)	Removed kraft bleaching energy
Solid Bleached Paperboard	Chemical (Kraft and Sulfite)	
Semichemical Paperboard	Sulfite Semichemical	
Recycled Paperboard	N/A	Derived a specific energy requirement from [1]

Table 3.1-3. Pulp and Paper Production Data and Associated Energy Use [1,2]

Energy Consumption by Product	Production (Thousand short tons)	Thermal Energy Consumption (Trillion Btu)		
		Min.	Max.	Avg.
Paper Products				
Newsprint	6,984	54	173	113
Groundwood Printing & Converting	1,915	15	47	31
Coated Paper	8,804	141	291	216
Uncoated Free Sheets	13,304	213	439	326
Bleached Bristols	1,383	22	46	34
Cotton Fiber	159	3	5	4
Thin Papers	149	2	5	4
Tissue	6,098	98	201	149
Unbleached Kraft	2,308	30	69	50
Bleached, Specialty Packaging	2,417	39	80	59
Paperboard				
Unbleached Kraft Paperboard	22,468	292	674	483
Solid Bleached Paperboard	5,029	80	166	123
Semichemical Paperboard	5,943	101	208	155
Recycled Paperboard	12,283	123	332	227
Total		**1,212**	**2,735**	**1,974**

Table 3.1-4. Thermal Energy Requirements of Kraft Pulping [1,4]

Process Step	Thermal Energy (Thousand Btu/ton)	Steam Temperature (°F)	Steam Pressure (psig)
Digesting (Batch Process)	3,000-3,500	329-347	100-130
Digesting (Continuous Process)	1,460-2,160	329-347	100-130
Chemical Recovery	2,500-5,300	292	45
Bleaching	300-9,000	260	20
Pulp Drying	3,500-5,000	260	20
Total	**7,760-22,830**		

Table 3.1-5. Thermal Energy Requirements of Sulfite Pulping [5]

Process Step	Thermal Energy (Thousand Btu/ton)	Steam Temperature (°F)	Steam Pressure (psig)
Digesting	2,030	248-275	15-30
Chemical Recovery	2,000	300	55
Bleaching	1,700	260	20
Pulp Drying	6,000	260	20
Total	**11,730**		

Table 3.1-6. Energy Requirements of Selected Mechanical Pulping Processes [1]

Energy Requirements for Mechanical Pulping Processes	Thermal Energy (Thousand Btu/ton)		Electrical (kWh/ton)	
	Min.	Max.	Min.	Max.
Stone Groundwood (SGW)	-	-	1,260	1,450
Refiner Mechanical Pulp (RMP)	-	-	1,500	1,700
Thermomechanical Pulp (TMP)	750	850	1,800	3,600
Semichemical	4,500	6,500	550	555
Chemi-Thermomechanical Pulp (CTMP)	750	850	1,700	2,200

Table 3.1-7. Other Pulp and Paper Process Thermal Energy Requirements [1,5]

Process Step	Thermal Energy (Thousand Btu/ton)	Steam Temperature (°F)	Steam Pressure (psig)
Pulp Drying	3,000-6,000	260	20
Washing	730-800	260	20
Refining	1,100-2,400	260	20
Bleaching	300-9,000	260	20

Table 3.1-8. Bleaching and Drying Energy Requirements for Mechanical Pulping [1,5]

Process Step	Thermal Energy (Thousand Btu/ton)	Steam Temperature (°F)	Steam Pressure (psig)
Drying	3,000-6,000	260	20
Bleaching (Optional)	300	260	20

Table 3.1-9. Thermal Energy Requirements for Papermaking [1]

Process Step	Thermal Energy (Thousand Btu/ton)	Steam Temperature (°F)	Steam Pressure (psig)
Drying	5,000-12,500	260	20

Figure 3.1-2. Pulp and Paper Industry Boiler Capacity by Fuel Type [7]

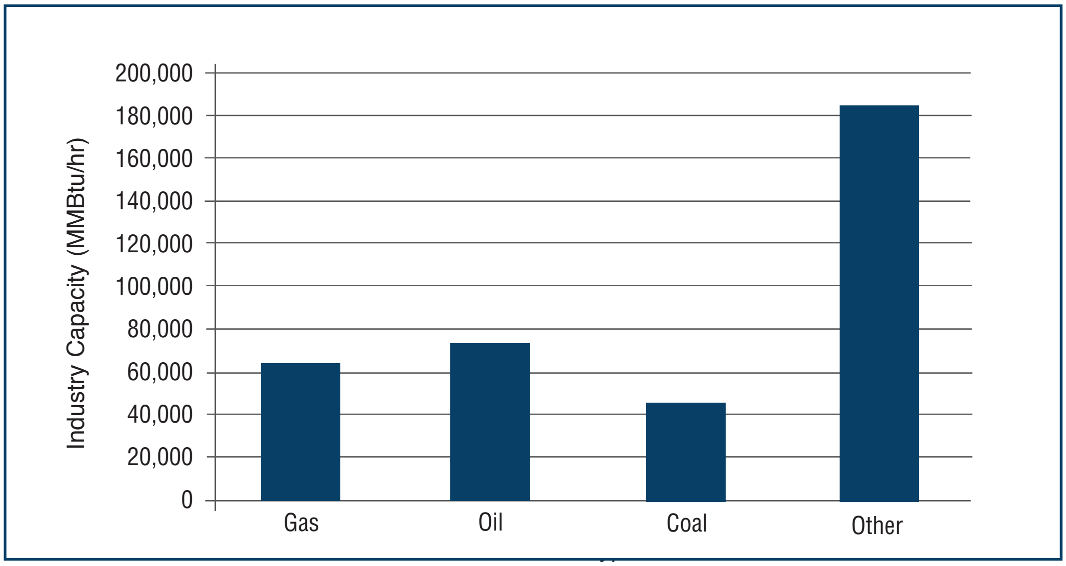


Figure 3.1-3. Pulp and Paper Industry Steam System Capacity by Pressure [7,8]

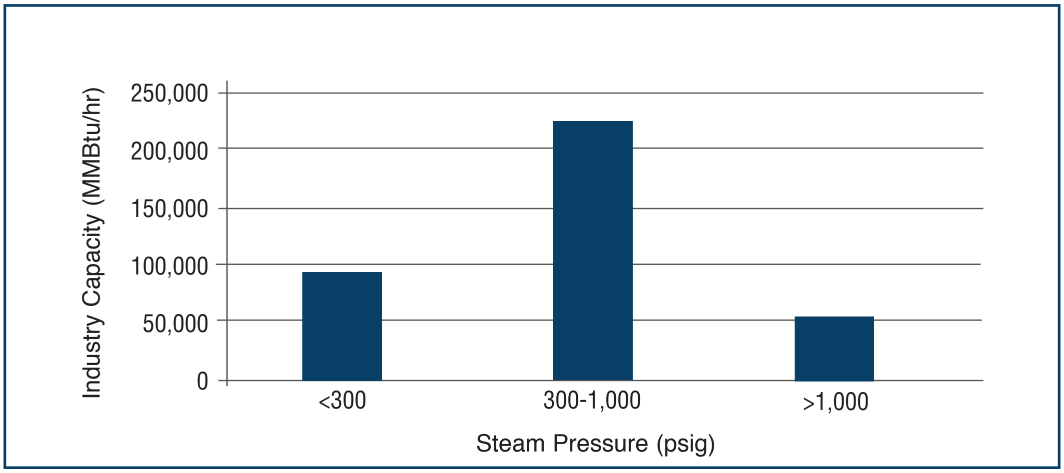


Figure 3.1-4. Pulp and Paper Industry Boiler Size Distribution [7]

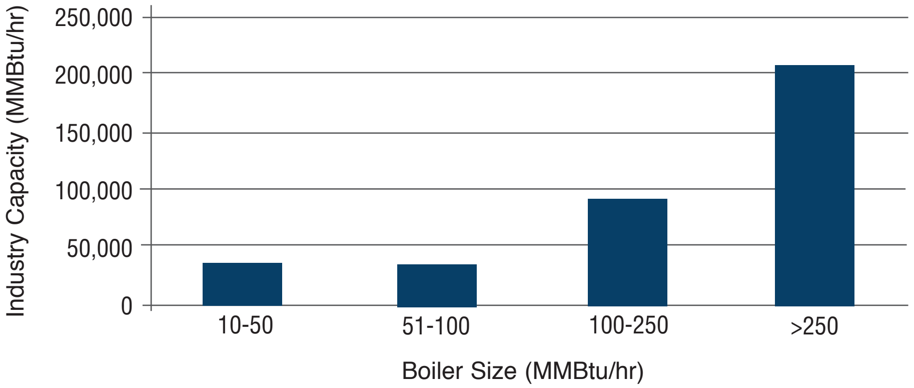


Table 3.1-10. Energy Use by Cogeneration Technology [3]

		Cogeneration Technology						
		Steam Turbines		Combustion Turbines				
Industry	**SIC**	**Boiler Generated Steam**	**Heat Recovery Heat Exchanger Generated System**	**Simple Cycle**	**Combined Cycle**	**Multiple Steam Generating Systems**	**Other Technologies**	**Total**
Paper and Allied Products	**26**	**309**	**17**	**22**	**4**	**117**	**40**	**509**
Pulp Mills	2611	39	1	0	0	2	4	46
Paper Mills	2621	163	5	14	3	95	10	290
Paperboard Mills	2631	105	10	8	1	19	25	168

Units are Trillion Btu

3.2 Assessing Steam Use in the Chemical Manufacturing Industry

Figures and Tables referenced in this section begin on page 46 in the order they are mentioned in the text.

Introduction

The chemical manufacturing industry uses a significant amount of energy to manufacture chemical products for consumer and industrial markets. However, the processes used by chemical manufacturers to produce these products are typically considered competitive information, making it difficult to assess energy use in this industry from a process perspective. Consequently, a different approach to assessing chemical industry steam generation and use is required. Because a relatively small number of chemical products account for most of the industry's energy use, evaluating these high energy-use chemical products can provide a reasonably accurate assessment of how energy, specifically steam energy, is used.

Key Results

The chemical industry produces over 70,000 products [1]. In 1994, the chemical industry used about 3,273 trillion Btu of energy, of which steam energy accounts for roughly 1,540 trillion Btu (see Section 2). Within the chemical industry (SIC 28), there are nine 4-digit SIC segments that account for 1,210 trillion Btu (see Section 2) of fuel used to generate steam, which is approximately 79 percent of the industry total. Within these nine SIC segments, there are 20 chemical products whose process steam energy requirements account for 832 trillion Btu of steam.

The estimated steam energy requirements for these 20 major chemicals are shown in Figure 3.2-1. The steam energy requirements for these 20 products varied between 0.3 and 343 trillion Btu.

Using a 75 percent conversion efficiency, which accounts for losses in converting fuel to thermal energy, generating steam and delivering it to the end uses, the 832 trillion Btu of steam energy translates to 1,109 trillion Btu of fuel energy. Consequently, evaluation of the process energy requirements of these 20 chemical products accounts for 90 percent of the steam use within the nine selected SICs and 71 percent of the total industry steam use.

The sources of steam in the chemical manufacturing industry include boilers and process heat recovery heat exchangers. The estimated boiler capacity in the chemical manufacturing industry is about 500,000 MMBtu/hr. Over half of this capacity, about 280 MMBtu/hr, is accounted for by boilers above 100 MMBtu/hr. However, small boilers between 10 and 50 MMBtu/hr account for about 120,000 MMBtu/hr of industry capacity, illustrating the wide distribution of boiler size across the industry. Natural gas is the dominant fuel type, accounting for about 205,000 MMBtu/hr of industry boiler capacity. About 60 percent of the boiler capacity lies in the pressure range between 300 and 1,000 psig.

General Applications of Steam in the Chemical Industry

Chemical manufacturers use steam for many purposes, including:

- Stripping
- Fractionation
- Power generation
- Mechanical drive
- Quenching
- Dilution

A relatively small number of chemical products accounts for most of the industry's steam energy use. The 832 trillion Btu of steam energy equates to 1,109 trillion Btu of fuel energy.

- Process heating
- Vacuum draw
- Pressure regulation
- Injection
- Source of process water.

Stripping

Steam is often used to facilitate the separation of components. In stripping towers, steam pulls unwanted contaminants from a process fluid. The steam used in these applications is not directly returned because the effluent has too many unwanted substances.

Fractionation

In fractionating towers, steam is used to assist in the separation of chemical products that contain components with different boiling points. Steam is injected in the bottom of these towers along with a feedstock. The steam helps carry the more volatile products up the tower where they condense on trays that are maintained at the condensation temperature of the desired products. The steam provides a mass transport medium, helps prevent deposition on hot surfaces, and provides favorable viscosity properties of the product within the tower.

Power Generation

In power generation, steam is often used to drive turbines, which, in turn, spin electric generators. Many chemical plants meet their electric power needs with a mixture of purchased power and on-site generation. The ratio between purchased power and self-generated power depends on several factors, including cost of electricity, availability, and capacity of on-site power generation, and on-site demand for steam.

Mechanical Drive

In many chemical manufacturing facilities, most mechanical drive energy—about 340 trillion Btu—is supplied by electric power; however, steam and natural gas account for a large portion of this energy component, roughly 39 trillion Btu [2].

Steam is used because of its reliability, availability, and favorable economic feasibility under certain conditions. Because either a turbine or a motor can equally serve many processes, deciding which option to use is typically based on relative economic advantages. Important factors are the cost of steam and net electricity price (accounting for both energy and demand charges). In many critical applications, plants incorporate redundancy by installing both types of drives, thus preventing a failure in one power source from causing a costly shutdown.

The chemical products whose production require the largest amount of mechanical drive energy are ethylene, ammonia, and organic resins, such as polyethylene and polypropylene. The industry segments that correspond to these products account for 36 trillion Btu of the 39 trillion Btu used in mechanical drive applications.

Process Heating

Steam is used in many chemical process heating applications. Favorable steam characteristics for these applications include:

- Constant temperature heat delivery
- Effective temperature control through regulation of the steam pressure
- Large heat content per unit mass.

Steam provides an excellent heat source for applications that require temperatures between 250° and 500°F. Competing sources of process heat include direct-fired furnaces and process fluid heat recovery heat exchangers. Although steam is used in applications with temperatures up to 700°F, the pressure requirements for this steam often make its generation and distribution impractical. Direct-fired furnaces can typically achieve higher temperatures than what steam can feasibly provide and are widely used in many chemical industry applications. Additionally, many chemical production processes involve exothermic reactions that provide opportunities for process heating with fluid-to-fluid heat exchangers.

Quenching

An important part of controlling chemical reactions is the regulation of the reaction temperature. In many applications, steam controls process temperature by quenching. Many chemical processes involve exothermic reactions and the heat released affects the temperature of the reaction. Steam is often directly injected to regulate such processes. Steam has a large latent heat capacity and can often be separated from process streams in subsequent steps, especially with chemicals that have low solubilities in water.

Dilution

In dilution, steam is often used to dilute a process gas to reduce coke formation on heat exchanger surfaces. Many chemical products, particularly hydrocarbons, tend to form deposits on high-temperature surfaces, which results in reduced heat transfer. Because these deposits are difficult to remove, steam is often injected with the process chemicals to minimize their surface formation. Steam helps by diluting these chemicals and by reducing localized hot spots.

Vacuum Draw

Steam ejectors are often used to produce a vacuum in certain process equipment. Steam ejectors use flow through a nozzle and a diffuser to create this vacuum. Other equipment that serves this purpose includes motor-driven vacuum pumps. The amount of steam used for this purpose varies from plant to plant.

Partial Pressure Control

Steam is often used to control the partial pressure of a reaction. When steam is injected with reactants in a fixed-volume vessel, it can increase the pressure and cause a desired shift in the reaction. This use of steam is particularly effective when the reactants have low solubility in water. An example of this use is found in ethylene production, where steam is injected into the pyrolysis furnace to inhibit unwanted reactions such as polymerization and cyclization.

Injection

Steam is often directly injected into a process to help transport products. Steam effectively serves in these applications by providing a source of pressure or by acting as an entrainment medium. A favorable characteristic in such applications is the ability to separate the water from the product in subsequent steps.

Source of Water

Steam is also a source of water as a solvent and a feedstock. As a solvent, steam provides both heat and solubility. As a feedstock, steam provides a source of pressure, temperature, and hydrogen (e.g., as in steam methane reforming).

Steam Use in the Chemical Industry by Product

To estimate the steam energy use in the chemical industry, the 20 most energy-intensive chemical products were evaluated. For these products, Table 3.2-1 shows the production amounts, the steam energy requirements per pound, and the total amount of steam needed to meet this production. Table 3.2-1 also indicates the total energy required to produce these products to indicate the amount of steam portion. The chemicals and the processes that account for their steam requirements are discussed below.

Ethylene Manufacture

Ethylene accounts for almost 25 percent of total chemical industry steam use. In 1994, over 22 million tons of ethylene were produced with about 343 trillion Btu of steam used to support this production, as shown in Table 3.2-2. Ethylene is one of the more important chemicals produced because of its use as a feedstock for a wide range of other products, including polyethylene, polyvinyl chloride, ethylene glycol, and various solvents and paints [1,3].

Ethylene is manufactured from the pyrolysis of a hydrocarbon feedstock. Common feedstocks include naphtha, ethane, and gas oil. Because ethylene production requires an abundant supply of hydrocarbon feedstock, ethylene plants are usually located near refineries. Although the pyrolysis reaction occurs in a direct-fired furnace, steam is also important to ethylene production. Steam is injected in the pyrolysis furnace both to dilute and to lower the partial pressure of the feedstock. Dilution helps inhibit the formation of coke on the furnace surfaces. Reducing the partial pressure of the feedstock helps drive the reaction toward ethylene production and away from undesired secondary reactions. Pyrolysis occurs at temperatures between 1,400° and 1,600°F, and unless reaction conditions are properly maintained, unwanted reactions such as polymerization and cyclization will result.

The amount of steam injected in the pyrolysis furnace depends on the feedstock. Where ethane is the dominant feedstock component, the amount of steam used is roughly 1/3 lb per lb of feedstock. However, with heavier feedstocks, there is an increased tendency for coke formation; feedstocks such as gas oil require a steam feed of about 3 lbs per lb of feedstock. Even within the same density of feedstock, the steam requirement varies depending on other factors that affect the pyrolysis reaction.

In ethylene production, steam is both provided to the process and recovered from the pyrolysis reaction, which is exothermic. Steam is also used in stripping and fractionating processes. Ethylene production uses a large amount of mechanical drive energy. According to MECS, about 68 trillion Btu of energy is used in machine drive applications for this industry segment and steam accounts for about 28 trillion Btu of this energy component.

Ammonia Manufacture

Ammonia is primarily manufactured by combining hydrogen with nitrogen in the presence of an iron catalyst. The nitrogen is supplied by air while the hydrogen is typically obtained from a process that combines high pressure steam with natural gas in the presence of a catalyst, a process known as steam methane reforming (SMR). Because natural gas is primarily methane (CH_4) it contains a large amount of hydrogen. Reforming releases much of the hydrogen in the steam. SMR often occurs in two stages that have different sets of temperatures, catalyst reactions and relative amounts of feedstock and steam. The SMR process is an important use of steam for other industries as well, including petroleum refining.

Other uses of steam in ammonia manufacturing include stripping unwanted gases from the product and facilitating ammonia conversion, as described in Table 3.2-3.

Urea

Urea is made primarily from ammonia. Combining ammonia with carbon dioxide at high pressures (between 2,000 and 3,700 psig) and high temperatures (350° to 450°F), generates a urea solution. Depending on the requirements of the final product, the urea can either be concentrated and formed into solid pellets or sold as a liquid solution. In urea production, steam is primarily used for process heating in the reaction vessel, as described in Table 3.2-4.

Styrene and Ethylbenzene Manufacture

Styrene and ethylbenzene are closely linked because ethylbenzene is a feedstock for the production of styrene. Approximately 99 percent of ethylbenzene is used to produce styrene. Ethylbenzene itself is made from ethylene and benzene through a series of catalytic reactions. Although ethylbenzene production is exothermic, steam is used to support several distillation tasks, as described in Table 3.2-5.

In contrast, styrene production is highly energy intensive. Although some styrene is manufactured as a byproduct of propylene oxide, most styrene is made by combining steam and ethylbenzene. Superheated steam is combined with ethylbenzene in the presence of a catalyst to remove hydrogen from (dehydrogenate) the ethylbenzene. The output of this process is sent to a distilling tower where additional steam facilitates the separation of styrene from the remaining ethylbenzene. The ethylbenzene is recycled back into the process, while the styrene is recovered.

Polystyrene

Polystyrene is the polymerized form of styrene. To begin the polymerization reaction, a feedstock of styrene is heated to approximately 230°F. After some of the styrene has polymerized, the solution is sent into a reaction tower, where the solution is agitated, mixed with additives, and maintained at a temperature usually between 230° and 350°F. Various desired properties of the final product, such as molecular weight, are achieved by controlling certain reaction parameters. The polymerized mixture is then sent to processing equipment that converts the polystyrene into pellets or strands. Steam use in polystyrene production is described in Table 3.2-6.

Chlorine and Sodium Hydroxide Manufacture

Chlorine and sodium hydroxide are manufactured as coproducts from the same process. These chemicals are primarily produced by the electrolysis of brine. In this process, the brine is introduced into an electric field with the negative and positive poles separated by a semipermeable diaphragm. The chlorine collects as a gas at the positive pole. At the negative pole, sodium ions collect and the solution becomes sodium hydroxide (caustic soda). Hydrogen is offgassed at the negative pole.

Steam use, as described in Table 3.2-7, has several applications during chlorine/ sodium hydroxide production:

- To increase the concentration of the caustic soda solution
- To preheat the brine prior to electrolysis
- To strip contaminants
- To provide thermal energy in the evaporator to achieve the appropriate concentration of caustic soda. (Concentrating the caustic solution is performed in either single or multiple effect evaporators.)

Ethylene Dichloride/PVC Manufacture

Ethylene dichloride is a feedstock for polyvinyl chloride (PVC). Approximately 98 percent of ethylene dichloride production is used to manufacture vinyl chloride monomer, which, in turn, is used to produce PVC. The production of ethylene dichloride combines ethylene and chlorine in the presence of a catalyst, creating a slightly exothermic reaction. In the production of ethylene dichloride, steam is primarily used to strip the waste products.

Ethylene dichloride is then sent on to produce vinyl chloride monomer. Ethylene dichloride is heated in a furnace through steam injection to initiate cracking, thus creating several products including vinyl chloride monomer and hydrochloric acid. Steam is injected into the furnace to facilitate the reaction. The products from the furnace are quenched, distilled, and separated. The hydrochloric acid is recovered and the vinyl chloride monomer is sent on as a feedstock for other processes, including PVC production.

PVC is manufactured by polymerizing the vinyl chloride monomer in a heated reaction vessel that has agitation devices to facilitate the process. Because the product from the reaction vessel contains unwanted components, such as unreacted vinyl chloride monomer, steam is used to strip the product. After stripping, the PVC is dewatered in a centrifuge and then dried further in a heat exchanger.

In the production of ethylene dichloride and PVC, steam is used in several process heating tasks and in stripping contaminants, as described in Table 3.2-8.

Phenol/Acetone Manufacture

Phenol is produced from a feedstock of cumene, which in turn is manufactured from propylene. To produce phenol, cumene is reacted with air at approximately 220°F to form an oxidized product, which is then sent through a separator and a concentrator. Steam is used in the concentrator to remove gases and other unwanted products.

The output of the concentrator is sent through a series of purification steps that isolate the phenol and acetone. Steam is used in this process to facilitate the separation of components in fractionating towers, as described in Table 3.2-9.

Benzene, Toluene, and Xylenes (BTXs)

Benzene, toluene, and xylenes are similar products that are frequently referred to collectively as BTXs. Benzene accounts for most BTX production. Approximately 80 percent of benzene is produced from reformed naphtha or pyrolysis gas. In the naphtha process, naphtha is exposed to a catalyst that converts it into a mixture of BTX compounds. Where pyrolysis gas is used, the feedstock already contains BTX compounds, but it is necessary to separate these components.

Separation processes start with solvent extraction to pull the BTX compounds out of the other components. The BTX-rich solvent is then sent to a fractionating column where the BTXs and the solvent are separated. The solvent is returned to the upstream separation process and the BTXs are sent to a series of towers that fractionate the individual benzene, toluene, and xylene components. Steam is used in the fractionating towers to facilitate component separation, as described in Table 3.2-10.

Caprolactum

About 80 percent of caprolactum production is used as a feedstock to produce nylons. The remaining 20 percent of caprolactum production is used in engineering resins and films. The feedstock for caprolactum is cyclohexanone, which itself is made from cyclohexane. Cyclohexanone undergoes a series of catalyst-based chemical reactions and the product is then combined with ammonia. Adding ammonia generates caprolactum and other byproducts such as ammonium nitrate and ammonium phosphate, commonly sold for fertilizer production. Steam use in caprolactum production is described in Table 3.2-11.

Sodium Carbonate

Sodium carbonate, also known as soda ash, is used in several applications including glass manufacturing and as a feedstock for several cleaning agents. In the United States soda ash is produced from trona ore, which is a complex of several components, including sodium and carbon. There are two principal ways in which trona ore is extracted from the ground that affect the way sodium carbonate is isolated. In one extraction method, sodium hydroxide is used to dissolve the trona ore. The resulting solution must be treated to precipitate out the sodium carbonate. Steam is primarily used to facilitate the precipitation processes. Because some of the precipitation processes are performed under vacuum, steam is used to pull this vacuum and to provide process heating, as described in Table 3.2-12.

Another ore extraction method uses blasting, which results in the recovery of solid trona that must be crushed, dissolved, filtered, and then processed to isolate the sodium carbonate. In both extraction methods, calcining is required. Calcining is a direct-fired process that is usually performed in a furnace.

Synthetic Rubbers

There are three principal synthetic rubber products: polybutadiene rubber, styrene butadiene rubber (SBR), and butyl rubber. Polybutadiene rubber (PBR) is used in tires, footwear, wire insulation, and conveyor belts. The production of PBR accounts for roughly 10 trillion Btu in steam energy. The steam requirements for PBR are shown in Table 3.2-13.

SBR is widely used in tires, carpet backing, flooring, wire and cable insulation, and footwear. SBR production accounts for about 7 trillion Btu in steam energy. The steam requirements for SBR are shown in Table 3.2-14.

Butyl rubber is also used in tires; however, because of its excellent air retention, it is the preferred material for inner tubes. It is also used in the inner liners of tubeless tires, and for many other automobile components, such as window strips, because of its resistance to oxidation. The steam requirements for butyl rubber production are shown in Table 3.2-15.

Cyclohexane

Cyclohexane is an important chemical in the production of adipic acid, which in turn is used to produce nylons and various adhesives, and as a flue gas desulfurization agent for coal-fired power plants. Cyclohexane is produced by combining benzene with hydrogen in the presence of heat and a catalyst. Steam is used to preheat the reactants and to stabilize the final products, as shown in Table 3.2-16.

Sources of Steam Generation

The primary sources of steam generation are boilers and process heat recovery heat exchangers. Boilers use the combustion of fossil fuels to produce the thermal energy that is used to generate steam. Heat recovery steam generators rely on heat transfer from a high-temperature process fluid to generate steam.

Heat Recovery

There are many sources of heat recovery in chemical manufacturing. Some reactions require high temperatures, allowing the use of process fluids to transfer heat to other processes and to generate steam. Additionally, many chemical processes are exothermic and heat recovery is used both to moderate the reaction temperature and to utilize useful energy within the plant.

The amount of steam generated from process heat recovery varies widely across the industry because of the diversity of chemical processes. Also, the amount of steam generated varies within industry segments and from plant to plant depending on facility size, age, level of manufacturing integration, and range of products produced at the plant.

Boilers

The estimated boiler capacity in the chemical manufacturing industry is about 500,000 MMBtu/hr. Figure 3.2-2 shows boiler capacity distribution according to boiler size. Over half of this capacity, about 280 MMBtu/hr, is accounted for by boilers above 100 MMBtu/hr. However, small boilers between 10 and 50 MMBtu/hr account for about 120,000 MMBtu/hr, illustrating the wide distribution of boiler size across the industry. This distribution is consistent with the range of diverse plant sizes and steam needs in the chemical industry.

Similarly, several different fuel types account for much of the boiler capacity. Figure 3.2-3 shows boiler capacity by fuel type. Natural gas, the dominant fuel type, accounts for about 205,000 MMBtu/hr of chemical industry boiler capacity, largely because it is used as a feedstock in many industry applications. As a result, many large chemical facilities are located close to natural gas supplies.

With respect to pressure, the largest amount of steam system capacity—over 300,000 MMBtu/hr—falls between 300 and 1,000 psig, as shown in Figure 3.2-4. Steam system pressures higher than 1,000 psig account for just over 25,000 MMBtu/hr, or 5 percent, of total steam system capacity.

Cogeneration

Steam is generated in cogeneration systems by two principal methods.

- Steam is generated by boilers then, depending on the system configuration, some or all of the steam is sent to drive steam turbines connected to electric generators. In some systems, the steam is exhausted from backpressure turbines into a header and used in other applications. In other systems, the steam is delivered to turbines, condensed, and sent into the condensate system, while the remaining boiler-generated steam is sent directly to process applications.
- Steam is generated by the waste heat recovered from reciprocating engines or gas turbines that are used to drive electric generators.

Many plants have both types of cogeneration capabilities. In fact, in the chemical industry, most of the electric energy—about 343 trillion Btu—is cogenerated from multiple technology systems. An example of this is the use of boiler-supplied steam to drive a steam turbine that is connected to an electric generator while also generating steam with heat recovery steam generators. These steam generators may recover heat from process fluids or from the exhaust gases of combustion turbines. These plants usually combine steam boilers, heat recovery heat exchangers, and, in many cases, combustion turbines. The relative balance between these sources depends on many plant characteristics, including fuel cost, electric energy prices, and the relation between thermal and electric energy requirements. Table 3.2-17 illustrates the amount of fuel used by the chemical industry in cogeneration applications.

References:

[1] *Energy and Environmental Profile of the U.S. Chemical Industry*, U.S. Department of Energy, Office of Industrial Technologies, May 2000.

[2] *Manufacturing Energy Consumption Survey 1994* (MECS), U.S. Department of Energy, Energy Information Administration, 1997.

[3] *U.S. Chemical Industry Statistical Handbook 1999*, Chemical Manufacturers Association, 1999.

[4] *Energy Analysis of 108 Industrial Processes, Drexel University Project Team*; Brown, H.; Hamel, B.; Fairmont Press, 1985.

[5] *1992 Industrial Process Heat Energy Analysis*, Final Report No. GRI 96/0353, Gas Research Institute, September 1996.

[6] Major Industrial Plant Database (MIPD^{TM}), IHS Energy, June 1999.

[7] *Analysis of the Industrial Boiler Population*, Final Report No. GRI-96/0200, Gas Technology Institute, June 1996.

Figure 3.2-1. Estimated Steam Energy Use for 20 Major Chemical Products

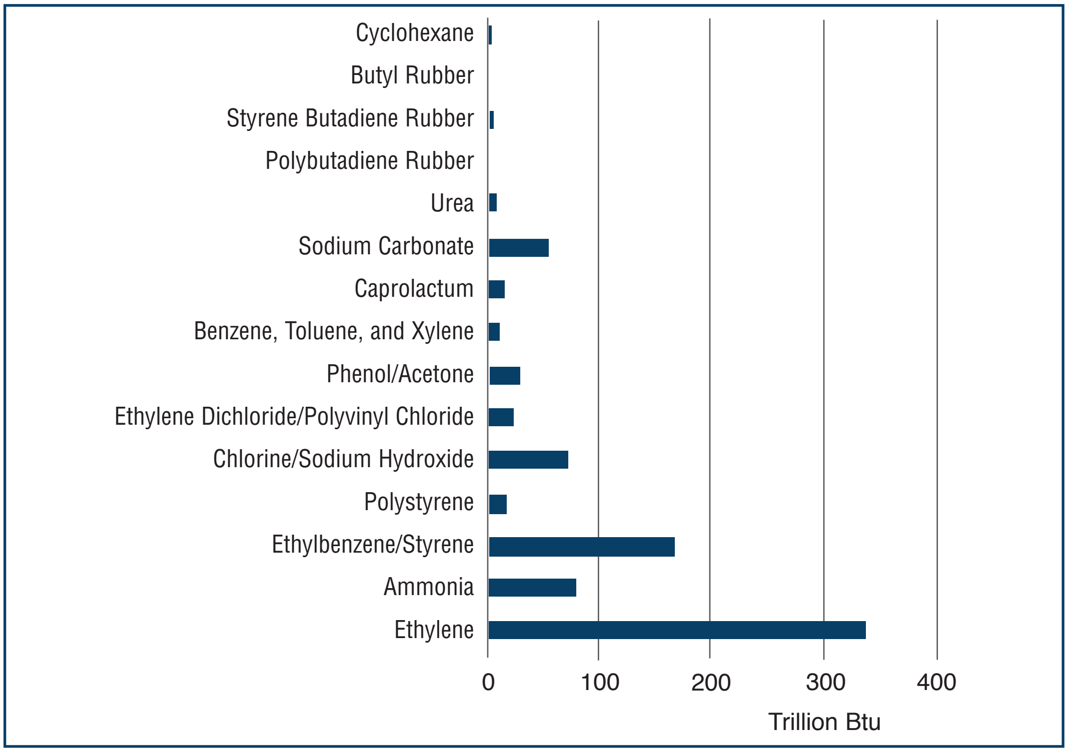


Table 3.2-1. Leading Energy-Intensive Chemicals [1,3,4]

Chemical	SIC	Production (Million lbs)	Unit Steam Energy (Btu/lb)	Total Steam Energy (Trillion Btu)	Total Energy (Trillion Btu)
Ethylene	2869	44,534	7,695	343	406
Ammonia	2873	15,788	5,062	80	274
Ethylbenzene/Styrene	2865	11,270	15,000	169	190
Polystyrene	2821	7,620	2,123	16	17
Chlorine/Sodium Hydroxide	2812	25,078	2,909	73	197
Ethylene Dichloride/Polyvinyl Chloride	2821	14,818	1,648	24	34
Phenol/Acetone	2865	4,054	7,459	30	32
Benzene, Toluene, and Xylene	2865	28,118	342	10	12
Caprolactum	2824	1,508	9,691	15	18
Sodium Carbonate	2812	20,552	2,683	55	79
Urea	2873	16,720	483	8	18
Polybutadiene Rubber	2822	550	1,584	0.9	10
Styrene Butadiene Rubber	2822	2,497	2,049	5	7
Butyl Rubber	2822	431	638	0.3	7
Cyclohexane	2865	2,108	1,593	3	4
			Totals	**832**	**1,305**

Table 3.2-2. Energy Use in Ethylene Production [1,3,4,5]

Process	Steam Pressure (psig)	Steam Temperature (°F)	Unit Steam Use (Btu/lb)	Production (Million lbs)	Total Steam Energy (Trillion Btu)	Total Energy (Trillion Btu)	Steam Energy as a % of Total
Dilution	120	350	2,467				
Acetylene Removal (Stripping)	15	250	253				
Fractionation	50	300	675				
Mechanical Drive (Process Steam)	1,000	600	629				
Mechanical Drive (Recovered Steam)	1,000	600	3,671				
		Total	**7,695**	**44,534**	**343**	**406**	**85%**

Table 3.2-3. Energy Use in Ammonia Production [1,3,4,5]

Process	Steam Pressure (psig)	Steam Temperature (°F)	Unit Steam Use (Btu/lb)	Production (Million lbs)	Total Steam Energy (Trillion Btu)	Total Energy (Trillion Btu)	Steam Energy as a % of Total
Steam Reformer	650	475	2,665				
Other Processes (Stripping, Additional Conversion Steps)	Various	Various	2,397				
		Total	**5,062**	**15,738**	**80**	**274**	**29%**

Table 3.2-4. Energy Use in Urea Production [1,3,4,5]

Process	Steam Pressure (psig)	Steam Temperature (°F)	Unit Steam Use (Btu/lb)	Production (Million lbs)	Total Steam Energy (Trillion Btu)	Total Energy (Trillion Btu)	Steam Energy as a % of Total
Synthesis Reaction	170	375	**483**	**16,720**	**8**	**18**	**45%**

Table 3.2-5. Energy Use in Ethylbenzene/Styrene Production [1,3,4,5]

Process	Steam Pressure (psig)	Steam Temperature (°F)	Unit Steam Use (Btu/lb)	Production (Million lbs)	Total Steam Energy (Trillion Btu)	Total Energy (Trillion Btu)	Steam Energy as a % of Total
Benzene Distillation	75	320	265				
Benzene Drying	120	350	182				
Ethylbenzene Distillation	235	400	338				
Ethylbenzene Preheating	120	350	370				
Dehydrogenation Reactor	Vacuum	1,200	4,922				
Superheater	Various	750	4,037				
Steam Preheat	180	380	3,433				
Separation	5	230	234				
Fractionation	50	300	73				
Ethylbenzene Distillation	5	230	755				
Styrene Distillation	5	230	390				
		Total	**15,000**	**11,270**	**169**	**190**	**89%**

Table 3.2-6. Energy Use in Polystyrene Production [1,3,4,5]

Process	Steam Pressure (psig)	Steam Temperature (°F)	Unit Steam Use (Btu/lb)	Production (Million lbs)	Total Steam Energy (Trillion Btu)	Total Energy (Trillion Btu)	Steam Energy as a % of Total
Condenser	15	250	118				
Blending	15	250	391				
Melt Compounding	850	525	1,212				
Drying	160	370	402				
		Total	**2,123**	**7,620**	**16**	**17**	**94%**

Table 3.2-7. Energy Use in Chlorine/Sodium Hydroxide Production [1,3,4,5]

Process	Steam Pressure (psig)	Steam Temperature (°F)	Unit Steam Use (Btu/lb)	Production (Million lbs)	Total Steam Energy (Trillion Btu)	Total Energy (Trillion Btu)	Steam Energy as a % of Total
First Brine Heater	120	350	375				
Second Brine Heater	120	350	225				
Cooler/Stripper	120	350	62				
Multiple Evaporator	120	350	1,748				
Evaporator	120	350	499				
		Total	**2,909**	**25,078**	**73**	**197**	**37%**

Table 3.2-8. Energy Use in Ethylene Dichloride/PVC Production [1,3,4,5]

Process	Steam Pressure (psig)	Steam Temperature (°F)	Unit Steam Use (Btu/lb)	Production (Million lbs)	Total Steam Energy (Trillion Btu)	Total Energy (Trillion Btu)	Steam Energy as a % of Total
Vinyl Chloride Production	15	250	658				
Reactor	15	250	292				
Dumping Tank	15	250	65				
Distillation	15	250	5				
Drying	160	370	333				
Blending	15	250	65				
Melt Compounding	50	295	164				
Drying	160	370	67				
		Total	**1,648**	**14,818**	**24**	**34**	**71%**

Table 3.2-9. Energy Use in Phenol/Acetone Production [1,3,4,5]

Process	Steam Pressure (psig)	Steam Temperature (°F)	Unit Steam Use (Btu/lb)	Production (Million lbs)	Total Steam Energy (Trillion Btu)	Total Energy (Trillion Btu)	Steam Energy as a % of Total
Depropanizer	10	240	152				
Benzene Column	450	460	1,371				
Cumene Column	665	500	189				
Concentrator	15	250	696				
Acetone Column	15	250	889				
Vacuum Column	15	250	3,124				
Phenol Column	15	250	1,038				
		Total	**7,459**	**4,054**	**30**	**32**	**95%**

Table 3.2-10. Energy Use in Benzene, Toluene, and Xylene Production [1,3,4,5]

Process	Steam Pressure (psig)	Steam Temperature (°F)	Unit Steam Use (Btu/lb)	Production (Million lbs)	Total Steam Energy (Trillion Btu)	Total Energy (Trillion Btu)	Steam Energy as a % of Total
Solvent Recovery	20	250	171				
Fractionation	20	250	171				
		Total	**342**	**28,118**	**10**	**12**	**81%**

Table 3.2-11. Energy Use in Caprolactum Production [1,3,4,5]

Process	Steam Pressure (psig)	Steam Temperature (°F)	Unit Steam Use (Btu/lb)	Production (Million lbs)	Total Steam Energy (Trillion Btu)	Total Energy (Trillion Btu)	Steam Energy as a % of Total
Various Reactions	**Various**	**Various**	**9,691**	**1,508**	**14.6**	**18**	**81%**

Table 3.2-12. Energy Use in Sodium Carbonate Production [1,3,4,5]

Process	Steam Pressure (psig)	Steam Temperature (°F)	Unit Steam Use (Btu/lb)	Production (Million lbs)	Total Steam Energy (Trillion Btu)	Total Energy (Trillion Btu)	Steam Energy as a % of Total
Vacuum Crystalizer	**15**	**250**	**2,683**	**20,552**	**55**	**79**	**70%**

Table 3.2-13. Energy Use in Polybutadiene Rubber Production [1,3,4,5]

Process	Steam Pressure (psig)	Steam Temperature (°F)	Unit Steam Use (Btu/lb)	Production (Million lbs)	Total Steam Energy (Trillion Btu)	Total Energy (Trillion Btu)	Steam Energy as a % of Total
Mixer	15	250	478				
Blowdown Tank	15	250	1,106				
		Total	**1,584**	**550**	**0.9**	**10**	**9%**

Table 3.2-14. Energy Use in Styrene Butadiene Rubber Production [1,3,4,5]

Process	Steam Pressure (psig)	Steam Temperature (°F)	Unit Steam Use (Btu/lb)	Production (Million lbs)	Total Steam Energy (Trillion Btu)	Total Energy (Trillion Btu)	Steam Energy as a % of Total
Bulk Storage	15	250	54				
Monomer and Solvent Stripper	15	250	121				
Monomer and Solvent Separator	15	250	30				
Hot Emulsion Reactor	15	250	472				
Latex Stripper	15	250	605				
Latex Concentrator	15	250	242				
Thermal Drying	15	250	525				
		Total	**2,049**	**2,497**	**5**	**7**	**73%**

Table 3.2-15. Energy Use in Butyl Rubber Production [1,3,4,5]

Process	Steam Pressure (psig)	Steam Temperature (°F)	Unit Steam Use (Btu/lb)	Production (Million lbs)	Total Steam Energy (Trillion Btu)	Total Energy (Trillion Btu)	Steam Energy as a % of Total
Distillation Tower	15	250	150				
Distillation Tower	15	250	100				
Extruder	15	250	388				
		Total	**638**	**431**	**0.3**	**7**	**4%**

Table 3.2-16. Energy Use in Cyclohexane Production [1,3,4,5]

Process	Steam Pressure (psig)	Steam Temperature (°F)	Unit Steam Use (Btu/lb)	Production (Million lbs)	Total Steam Energy (Trillion Btu)	Total Energy (Trillion Btu)	Steam Energy as a % of Total
Preheater	600	489	1,247				
Stabilizer	600	489	346				
		Total	**1,593**	**2,108**	**3.4**	**4**	**91%**

Figure 3.2-2. Chemical Industry Boiler Capacity by Boiler Size [7]

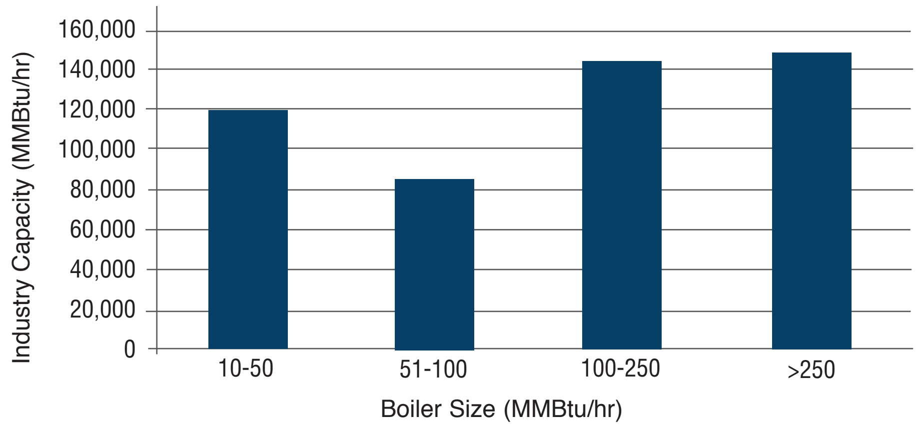


Figure 3.2-3. Chemical Industry Boiler Capacity by Fuel Type [7]

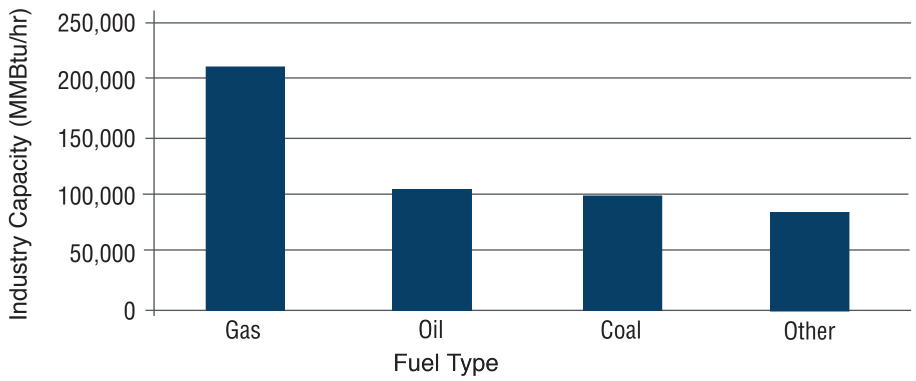


Figure 3.2-4. Chemical Industry Steam System Capacity by Pressure [6,7]

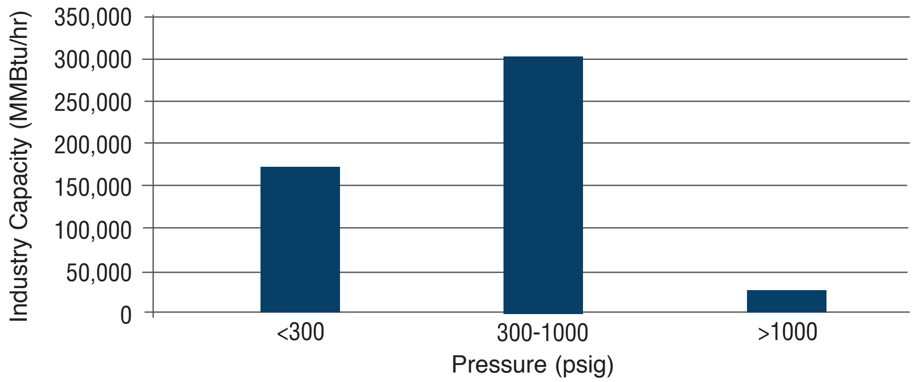


Table 3.2-17. Cogeneration Fuel Use in the Chemical Industry [2]

		Cogeneration Technology					
		Steam Turbines					
Industry	**SIC**	**Steam Supplied by Boilers**	**Steam Supplied by Heat Recovery Heat Exchangers**	**Combustion Turbines**	**Multiple Technologies**	**Other**	**Total**
Chemicals and Allied Products	**28**	**46**	**17**	**29**	**343**	**6**	**442**
Alkalies	2812	18	0	0	84	0	102
Inorganic Pigments	2816	0	0	0	0	0	0
Industrial Inorganic Chemicals, nec.*	2819	10	8	4	0	4	26
Plastics Materials & Resins	2821	2	0	14	30	0	46
Synthetic Rubber	2822	2	0	0	0	0	2
Organic Fibers, Noncellulosic	2824	7	0	0	7	0	14
Cyclic Crudes and Intermediates	2865	0	0	0	7	0	8
Industrial Organic Chemicals, nec.*	2869	7	9	9	211	0	235
Nitrogenous Fertilizers	2873	0	0	2	4	0	7

*Not elsewhere classified

Units are Trillion Btu

3.3 Assessing Steam Use in the Petroleum Refining Industry

Figures and Tables referenced in this section begin on page 62 in the order they are mentioned in the text.

Introduction

The petroleum refining industry uses energy to convert crude oil into many different products, some of which are used directly by consumers, while others are feedstocks for other industries. Production data for these petroleum refining processes can be combined with process energy data to estimate overall industry energy use. Additionally, the component energy types, including direct-fired, electric, and steam, can be disaggregated from the energy data for each refining process. This allocation allows the total steam use within the industry to be estimated. This steam use estimate can then be compared to the amount of fuel used to generate steam, as indicated by the *Manufacturing Energy Consumption Survey 1994* (MECS) [1].

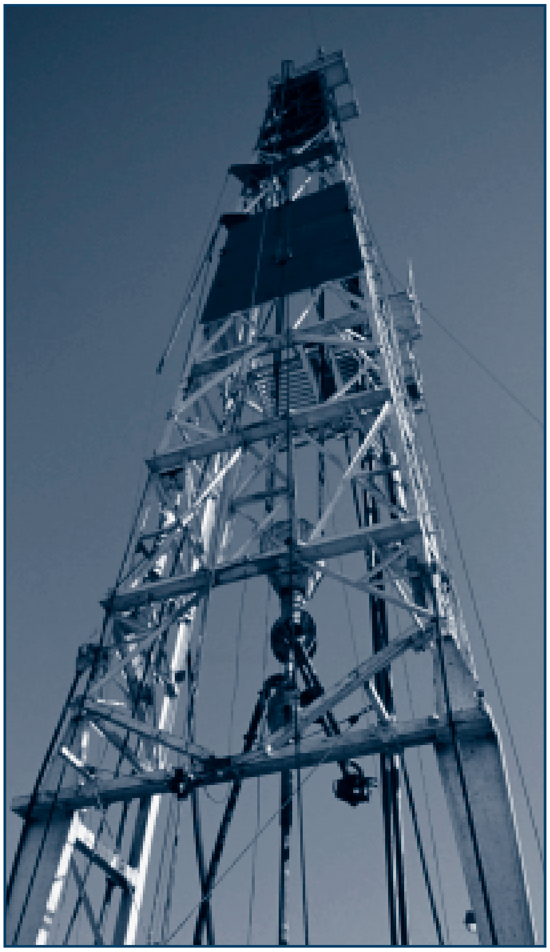
This section describes energy data for steam use by key end-use processes. This section also describes how steam is used by the major refining processes and discusses sources of steam generation.

Key Results

There are 11 major refining processes that represent the principal end uses of steam in the petroleum refining industry. The estimated steam energy requirements for major petroleum refining processes are presented in Figure 3.3-1. Process steam energy-use requirements vary between 12.4 and 261.4 trillion Btu. Note that visbreaking and coking operations are net steam producers.

The sum of the energy use for these 11 process is 900 trillion Btu. If a steam system efficiency of 75 percent is assumed, the total fuel used to generate steam based on the process data becomes 1,200 (= 900/0.75) trillion Btu. Section 2 of this report estimated that the petroleum industry used 1,675 trillion Btu for steam generation. These two estimates of fuel used to generate steam in the petroleum refining industry compare favorably.

The major sources of steam generation in the petroleum refining industry are boilers and heat recovery steam generators. The estimated boiler capacity in the refining industry is about 210,000 MMBtu/hr. Boilers that generate more than 250 MMBtu/hr account for about 100,000 MMBtu/hr, or roughly 48 percent of the industry's total boiler capacity. Most of the boiler capacity in the petroleum refining industry is fired by byproduct fuels, such as refinery gas and coke. In terms of steam system pressure, about 60 percent of the total



There are 11 major processes that represent steam end use in the petroleum refining industry. Steam generation for these processes account for more than 1,675 trillion Btu in fuel use.

industry boiler capacity is at 300 psig or less. Most of the remaining boiler capacity is between 300 and 1,000 psig.

Steam Use in the Petroleum Refining Industry by Major Processes

Combining the energy used by each process and the amount of product produced by each process provides an estimate of the total amount of energy used by the industry. This energy use can be disaggregated into components of electric, direct-fired, and steam energy. Table 3.3-1 describes the average energy requirements of these processes by technology and combines production estimates to calculate overall industry energy use. In 1994, total energy used by the processes in the petroleum refining industry is estimated as 2,333 trillion Btu, of which steam represents 900 trillion Btu.

The data in Table 3.3-1 represents an end use perspective. The fuel use that corresponds to this end-use energy data must be determined using a reasonable conversion factor that essentially accounts for the losses associated with converting the fuel to useful energy and delivering it. If a steam system efficiency of 75 percent is assumed, the total fuel used to generate steam based on the process data becomes 1,200 (= 900/0.75) trillion Btu.

Section 2 of this report estimated that the petroleum industry used 1,675 trillion Btu for steam generation. These two estimates of fuel used to generate steam in the petroleum refining industry compare favorably.

Similarly, in relative terms, the end-use perspective indicates that steam represents 39 percent (= 900/2,333) of the total energy use, while MECS indicates that the fuel used to generate steam represents 51 percent of the total industry fuel use.

General Applications of Steam in Petroleum Refining

Refineries use steam for several purposes:

- Stripping
- Fractionation
- Power generation
- Mechanical drive
- Quenching
- Dilution
- Process heating
- Vacuum draw.

Stripping

Steam is commonly used in petroleum refining to facilitate the separation of components. In stripping towers, steam is injected with hot crude oil and carries out contaminants such as sulfur and ammonia in a waste effluent. The steam used in stripping is usually not recovered; however, the wastewater effluent may undergo a concentration process that often uses steam for process heating to reduce the volume of waste.

Fractionation

In fractionating towers, steam is used to assist in the separation of hydrocarbon components. Steam is injected in the bottom of the tower. When steam is introduced with a hydrocarbon mixture, it reduces the partial pressure of the hydrocarbon components, which facilitates the separation and removal of the volatile components. The steam helps separate the lighter hydrocarbon products, which then rise up the tower where they condense on horizontal trays. These trays are increasingly cooler higher up the tower. Consequently, the heavier hydrocarbons collect on the lower trays while the lighter products collect on the higher trays. Steam also helps to prevent coke deposition on hot surfaces.

Power Generation

Fuel use data for this report is supplied by the MECS. In MECS, there are two principal categories of on-site power generation: conventional and cogeneration. Conventional generation uses fossil-fuel-fired engines or combustion turbines to drive electrical generators. Cogeneration refers to several technologies that combine electric power generation and thermal power use. Cogeneration includes the use of steam turbines, which along with other steam services, use boiler generated steam to generate electric power. Another common type of cogeneration uses heat recovered from the exhaust gases of an engine or a combustion turbine that drives an electric generator. MECS provides data for conventional electric power generation in terms of fuel use and cogenerated power generation in terms of kWh.

MECS indicates that the petroleum industry used about 74 trillion Btu of fuel to generate electric power. All of this fuel was reported as natural gas. In terms of cogeneration, about 137 trillion Btu of fuel was used by the petroleum industry to cogenerate electric and thermal power. Additional discussion of cogeneration is provided in Section 2 of this report.

The amount of steam used in power generation applications varies widely by plant. Refining plants will usually meet their electric power needs with a mixture of purchased power and on-site generation. The ratio between purchased power and self-generated power depends on several factors, including cost of electricity, capacity for on-site power generation, and on-site demand for steam.

Mechanical Drive

In the petroleum refining industry, about 108 trillion Btu of energy is used in mechanical drive applications. Of this total, about 12 trillion Btu is provided by natural gas [1]. Natural gas can be used in direct-drive applications and in firing boilers that provide steam for steam turbine-driven loads.

Steam turbines account for a large amount of energy used in machine-drive applications. Steam is used because of its reliability (especially if the electric power supply is prone to outage risks), and because steam turbine drives often provide favorable economic advantages. Common examples of equipment driven by steam turbines include pumps and compressors. Electric motors can usually be substituted for steam turbines; however, the specific characteristics of the plant determine whether a steam turbine or a motor is more feasible for certain drive applications.

Process Heating

Steam is used in many refining process heating applications; however, the amount of steam used in these applications varies. Many refining processes require temperatures that exceed what can be reasonably met by steam. Consequently, refineries use significant amounts of fuel for direct-fired applications, generating this heat in furnaces and in the regenerator sections of fluid catalytic crackers.

Refineries generate significant amounts of combustible byproducts, such as refinery gas and petroleum coke, which are usually burned in either a furnace or a boiler. Refinery gas accounts for approximately 44 percent of a refinery’s energy use while coke comprises about 16 percent [1].

Additionally, there are many exothermic processes that are inherent to refinery operation. These hot process streams provide many opportunities for heating needs to be served using process-to-process heat exchangers.

Quenching

Another application for refinery steam is to quench hot process gases. Quenching is one method of controlling a chemical reaction. Because many refining processes involve exothermic reactions, the heat released during these reactions affects the temperature of the reaction. Steam is often injected to regulate these process temperatures. Steam has a large latent heat capacity and can often be separated comparatively easily from hydrocarbon streams.

Dilution

Steam is often used to dilute a process gas to reduce coke formation on heat exchanger surfaces. Hydrocarbon deposits on high temperature surfaces tend to form coke, which interferes with heat transfer. Because these deposits are difficult to remove, steam is often injected along with the oil to minimize their formation.

Pressure Control

Steam ejectors are often used to produce a vacuum in certain process equipment. Steam ejectors use flow through a nozzle and a diffuser to create this vacuum. Other equipment, such as motor-driven vacuum pumps can serve the same purpose. Consequently, the amount of steam used for this purpose varies from plant to plant.

Steam can also regulate the pressure of the process by being injected with a process fluid. Steam is useful in such applications because it has limited solubility with many hydrocarbon products and can be separated out at later stages.

Description of Petroleum Refining Processes

The following discussion describes the principal process steps in petroleum refining. Where applicable, the use of steam to support the process is described. Figure 3.3-2 provides a basic description of the process flow at a petroleum refinery.

Desalting

Desalting is the first step in the refining process. Desalting is necessary to remove metals, salts, and other contaminants that lead to equipment fouling and corrosion and catalyst deactivation. Desalting temperatures range from 200° to 300°F. Desalting is usually electric energy intensive, relying on electric fields to attract and remove salt contaminants. Chemicals are often added to the oil to facilitate this process. The energy used to heat the oil is usually provided through a process heat exchange with oil from the atmospheric distillation tower.

Atmospheric Distillation

Crude oil contains a wide range of hydrocarbons. Separating hydrocarbon components by their respective boiling points produces products, such as fuel gases, liquefied petroleum gas (LPG), gasoline, naphtha, solvents, fuel oils, coke, and petrochemical feedstocks. Atmospheric distillation is the initial separation process and is performed at roughly atmospheric pressure in fractionating towers. The temperature of this process is kept below 725°F because at higher temperatures the hydrocarbons have enough energy to initiate a reaction known as cracking, which results in breakdown of long molecules into shorter ones.

In atmospheric distillation, crude oil is heated in a furnace and then sent into the flash zone of a fractionating tower. As the heated components rise within the tower they pass through openings in horizontal fractionating trays. These trays collect the hydrocarbons that condense on them. Controlling the vapor/liquid contact in the trays optimizes separation of the components. Light hydrocarbon gases are pulled from the top of the tower. Products such as gasoline, kerosene, and naphtha are drawn from trays in the middle of the tower. At the bottom of the tower, heavy hydrocarbon components are drawn off and sent into another distillation process.

In most fractionating towers, sidestreams are drawn off and sent to small distillation columns for further separation. These fractionating towers use an additional set of trays to separate the hydrocarbon products. The recovered steam and light end gases are vented back into the atmospheric tower above the sidedraw tray.

Many fractionating towers use reboilers to increase the quality of the hydrocarbon separation. Reboilers vaporize liquid hydrocarbon product using thermal energy from steam or another high-temperature process stream.

Steam Use. In atmospheric distillation, steam is injected in the bottom of the tower to strip any remaining gas oil from the liquid descending to the bottom of the tower. Steam is also introduced below the bottom trays of the sidestream strippers. The steam helps remove contaminants from the oil, forming a wastewater effluent. Steam is used in the sidedraw fractionating towers to perform the same function. Steam is also often used to provide heat for the reboilers.

Vacuum Distillation

Vacuum distillation is performed to separate the hydrocarbon components from the heavy products drawn from the bottom of the atmospheric distillation tower. Distillation under vacuum conditions is necessary to avoid exceeding temperatures above 725°F, which is close to the temperature that cracking begins. Vacuum distillation produces light hydrocarbon gases, high quality fuel, and coke, which is used in many industrial applications. Vacuum distillation towers also use reboilers to improve the separation of hydrocarbon components.

Heavy crude products from the bottom of the atmospheric tower are further separated in a vacuum distillation tower at low pressure. Atmospheric tower bottoms are heated in a vacuum furnace to temperatures in the range of 730° to 850°F. The pressure in the vacuum tower is reduced and maintained using mechanical pumps, steam ejectors, and surface condensers. At lower pressure the boiling points are lowered and further separation is achieved at lower temperatures without the concern of hydrocarbon cracking and excessive coke formation.

Vacuum gas oil is recovered from the top of the column. Sidestreams can be routed to stripping towers to increase yields of intermediate products. The bottom products from vacuum towers can be used as fuel or further processed to produce coke and refinery gases.

Steam Use. To improve vaporization in the vacuum distillation tower, steam is introduced to the furnace inlet and below the bottom tray of the tower. Adding steam to the furnace inlet increases tube velocity and minimizes coke formation and improves separation in the tower by decreasing hydrocarbon partial pressure. Similar to its use in atmospheric distillation, steam is introduced to the strippers to strip lighter hydrocarbons from the heavier ones. Steam also provides heat for certain reboilers and is used in steam ejectors to maintain vacuum conditions in the tower. These ejectors use steam flow through a nozzle and a diffuser to create this vacuum.

Cracking

The gasoline that is produced directly from atmospheric and vacuum distillation is called straight run gasoline, which represents about 10 to 25 percent of the crude oil input. However, gasoline accounts for about 45 percent of total refinery output [2]. Cracking heavy hydrocarbons into lighter hydrocarbons accounts for most of this difference. Cracking processes are either thermal or catalytic and convert the heavy residual products from the bottoms of the atmospheric and vacuum distillation units into lighter products, such as gasoline, kerosene, and naphtha. Thermal cracking uses heat to break down large hydrocarbon molecules, while catalytic processes use a catalyst in addition to heat—though at a lower temperature—to promote the reaction.

Fluid Catalytic Cracking

Fluid catalytic cracking (FCC) is the most widely used cracking process. FCC uses a catalyst and heat to convert heavy oil products into lighter hydrocarbons. The cracking process is conducted at temperatures around 900° to 1,000°F and uses a powdered catalyst that takes on the properties of a fluid when mixed with the vaporized feed. The catalyst is introduced to the feed in the feed line, or riser. The hot catalyst vaporizes the feed and the vapors carry the catalyst upward through the riser to the reactor. Most of the cracking reactions take place in the riser. When the mixture enters the reactor, cracked hydrocarbon vapors are mechanically separated using cyclones. Oil remaining on the catalyst in the reactor is removed by steam stripping. The hydrocarbon product from the reactor is sent to a fractionating tower where the components are separated. The spent catalyst flows to the regenerator and is reactivated by burning off the coke deposits.

The catalyst in some units is steam-stripped as it leaves the regenerator to remove adsorbed oxygen. Regeneration is necessary to reactivate the catalyst for reuse because the catalyst is continuously circulated between the reactor and regenerator. After the catalyst has passed through the reaction vessel having reacted with residual oil, it is typically coated with coke. The regenerator essentially burns this coke off, allowing the catalyst to be returned to the reaction vessel feed line. The release of this coke from the catalyst is highly exothermic, so the regenerator is a large source of heat, which is typically recovered as steam or power through the use of a waste heat boiler, gas expander turbine, or steam turbine.

Steam Use. Steam is introduced to the reaction vessel to strip the remaining oil from the catalyst. Steam may also be used in the regenerator to remove adsorbed oxygen and in the fractionating tower to help separate the hydrocarbons that were cracked from the heavy oil. The amount of steam injected with the feedstock ranges from 2 to 7 percent by weight [2]. Although large amounts of steam are used in injection tasks, the heat released during cracking provides enough energy to enable FCC to make and export some steam.

Visbreaking

Visbreaking is a thermal cracking process in which a furnace heats a feedstock, which is then pressurized to complete the cracking reaction. There are two principal types of visbreaking processes that use different pressurizing designs. In the coil process, the feedstock is pressurized in a coil located in the furnace. The coil process has favorable temperature control and tube decoking characteristics. In the soaker process, the feedstock is sent to a separate reaction vessel where the effluent is held for a period of time while the cracking is achieved. Although this separate vessel is more difficult to decoke, the soaker process is more energy efficient.

Visbreaking processes can be maintained over a range of temperatures and pressures depending on the desired product characteristics. Common temperatures range from 700° to 1,000°F while the pressures range from 50 to 250 psig.

Steam Use. The use of steam in visbreaking is similar to that in the other cracking processes. Steam is used to strip lighter hydrocarbons in the fractionating tower.

Catalytic Hydrocracking

Catalytic hydrocracking is a cracking process that uses hydrogen and a catalyst to produce blending stocks for gasoline. Hydrogen, which is a byproduct of catalytic reforming, is pressurized and injected into a reaction vessel with the residual oil feedstock. The presence of hydrogen promotes the cracking reaction. There are several process configurations that depend on the catalyst and the desired products.

Hydrocracking occurs at lower temperatures than catalytic cracking, but requires high pressures (between 1,200 and 2,000 psig).

Steam Use. Steam is used as a mass transfer medium to facilitate the removal of lighter hydrocarbon products. Steam is also used in cracking processes to moderate the reaction by quenching. The release of energy from the catalyst regeneration process is often recovered through a heat exchanger to generate steam.

Coking

Coking is a process that produces useful forms of coke from heavy residue products that are generated from other refining processes such as vacuum distillation. The coke produced from this process can be used to generate on-site power and is often sold to other industries. Saleable products include petroleum coke for power generation applications and steel production, and anodes for the aluminum industry.

The different coking processes include delayed coking, fluid coking, and proprietary processes such as Flexicoking[1]. Delayed coking is a semi-batch process that uses a furnace to heat a feedstream of residual oil and sends this stream into one of two or more coke drums. After the coke drum is filled, the feedstream is alternated to a parallel empty coke drum. The filled coke drum is held at a certain temperature to complete the cracking reaction. At the completion of the coking process, steam is injected to help remove the light hydrocarbons from the chamber. The light hydrocarbons are then sent through a fractionator to separate the products. The remaining coke in the chamber is quenched with either another process flow or water. The coke solidifies at the bottom of the vessel, where it is cut with high pressure water jets and removed. A coke drum blowdown system is typically used to recover hydrocarbon and steam vapors generated during the quenching and steaming process.

Fluid coking is a continuous process that uses a single reaction chamber to produce coke, avoiding the need for alternating coke drums. Flexicoking is similar to fluid coking, except a gasification process is used to treat the final coke product.

Steam Use. Steam is used in coking processes to separate hydrocarbon products in fractionating towers. Steam is also used in the delayed coking process to remove hydrocarbon vapors from the coke drum after the reaction is complete.

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[1] Tradename for a process developed by Exxon Research and Engineering [2].

Hydrogen Production

Refineries use hydrogen for several different processes, including catalytic hydrocracking, hydrotreating, alkylation, isomerization, and other treatment processes that achieve certain properties in the refined products. Hydrogen is also sent into the refinery fuel gas header.

Although some hydrogen is produced by catalytic reforming, refineries often need to supplement this supply. The most common method of hydrogen production is steam/methane reforming (SMR). Because natural gas is primarily methane (CH_4) it contains a large amount of hydrogen. Additionally, reforming releases much of the hydrogen in the steam. In this process, steam is combined with methane at a high temperature and pressure in the presence of a catalyst to generate hydrogen, carbon monoxide, and carbon dioxide.

Steam Use. SMR is energy intensive, requiring large amounts of steam. SMR often occurs in two stages, which have different sets of temperatures, catalyst reactions, and relative amounts of feedstock and steam.

Hydrotreating/Hydrofinishing

Hydrotreating, also called hydrofinishing, removes contaminants, such as sulfur, ammonia, and unwanted hydrocarbons, such as saturated olefins. There is a range of hydrotreating options that depend on the desired characteristics of final product and the types and levels of unwanted compounds. Most hydrotreatment processes use a catalyst. In fact, the process flow for hydrotreatment is similar to that for catalytic hydrocracking. The type of catalyst depends on the nature of the contaminant that is targeted for removal.

Hydrotreatment is commonly performed upstream of catalyst processes to prevent accelerated degradation of the catalyst. The equipment used in hydrotreating includes reaction vessels, absorbers, and separators.

Steam Use. Steam is used in hydrotreatment primarily to strip and fractionate the treated hydrocarbons. Steam strips much of the sulfur, forming a wastewater effluent. Steam also improves the separation of the hydrocarbons into different streams depending on subsequent process requirements.

Alkylation

Alkylation is a process that converts light gas products from the cracking processes into alkylates. Alkylates have high octane numbers and relatively low vapor pressures. They are important blending components for gasoline and jet fuel. Other useful alkylation products include butane and propane. Alkylation uses cooling, compression, and a catalyst-based reaction to reform light gases (ethane and propane) into heavier hydrocarbons. There are two principal alkylation processes, sulfuric acid and hydrofluoric acid, that vary based on the type of acid that is used to promote the alkylation reaction.

Steam Use. Steam is used in alkylation primarily to strip products, such as propane and butane from the alkylate.

Catalytic Reforming

Catalytic reforming is a process that converts the molecular structure of certain hydrocarbon products into more useful forms. The purpose of reforming is to increase the octane level of gasoline. Reforming processes primarily upgrade gasoline and naphtha drawn from the atmospheric and vacuum distillation towers and from cracking processes.

The reforming process uses heat and catalysts to generate high-octane gasoline. This process also generates light hydrocarbon gases, which are often used in other refining processes. For example, catalytic reforming is a primary source of hydrogen. The hydrogen generated from this process is sent into the hydrocracking processes to facilitate the conversion of residual oils into gasoline.

Steam Use. In catalytic reforming, steam is used primarily in stripping towers to separate the light hydrocarbon gases from the high-octane product.

Isomerization

Isomerization reforms the structure of a hydrocarbon without changing the number of carbons or hydrogens. Because a hydrocarbon can exhibit different properties depending on how the molecule is structured, isomerization is used to create a product with certain favorable characteristics. The reactions required in isomerization are typically assisted with catalysts. Isomerization is typically used to convert butane, pentane, and hexane into their respective isomers, which are then used in blending processes to improve the properties of gasoline. Isobutane is a particularly valuable product that is used in many refining and petrochemical processes.

Isomerization typically uses a furnace to heat a feedstock, which is then sent into a reaction vessel. The products of the reaction vessel are typically cooled, then injected with steam into a stabilizer column. The steam removes some of the contaminants, such as sulfur and ammonia, and forms a wastewater effluent. The light hydrocarbons pulled from the separator also require some cleaning. The isomerized product is then used or sold.

Steam Use. Steam is used in isomerization primarily to separate the various hydrocarbon components downstream of the reaction vessel.

Sources of Steam Generation

The primary sources of steam generation in the petroleum industry are boilers and heat recovery steam generators. Boilers use combustion of fossil fuels to produce the thermal energy that is used to generate steam. Heat recovery steam generators rely on heat transfer from a high-temperature process fluid to generate steam.

Boilers

The estimated boiler capacity in the refining industry is about 210,000 MMBtu/hr [7]. Boiler capacity in this industry is concentrated in large boilers, as shown in Figure 3.3-3. Boilers that generate more than 250 MMBtu/hr account for about 100,000 MMBtu/hr of the industry capacity or roughly 48 percent of the industry's total capacity. This distribution reflects the large plant size that characterizes the petroleum industry. There are only 160 petroleum refining plants in the United States, primarily because of the economics of manufacturing that characterize the refining industry. As a result, the plants and their steam systems tend to be large.

Most of the boiler capacity in the petroleum refining industry is fired by byproduct fuels, such as refinery gas and coke. This is primarily because of the availability of these byproducts from various refining processes. Figure 3.3-4 shows the distribution of boiler capacity by fuel type.

With respect to steam system pressure, about 130,000 MMBtu/hr of steam system capacity, or 62 percent of industry's total capacity, is less than 300 psig steam. The distribution of steam system capacity by pressure is shown in Figure 3.3-5. Much of the steam use in the refining industry is for stripping and fractionating, which typically do not require high pressures.

Heat Recovery Steam Generators

Heat Recovery Steam Generators (HRSGs) generate steam by transferring energy from high-temperature processes, such as from the exhaust gases from a combustion turbine or a catalytic cracker.

Many of the processes at refineries require high temperatures. Consequently, there are many heat recovery opportunities at these plants. Heat can be recovered with process fluids or with steam generation and the particular characteristics of a plant determine which heat recovery option is more feasible. Cogeneration is widely used at refineries because of their large demands for both thermal and electrical energy.

Cogeneration

The total amount of steam that is cogenerated in the petroleum refining industry is roughly 10,600 MMBtu/hr, as shown in Table 3.3-2. This compares to a boiler capacity of roughly 210,000 MMBtu/hr. An important consideration in comparing these numbers is how they were calculated. The industry boiler capacity is based on an estimate of the boiler population. The cogenerated steam is calculated using MECS data, which provide the amount of electricity generated by cogeneration technologies. The amount of steam that corresponds to this electricity generation is found by calculating the amount of fuel used to generate this electricity then calculating the amount of steam that corresponds to this fuel use. There are several assumptions that are required for these calculations. These assumptions and a sample calculation are included in the Discussion section in Appendix B.

References:

[1] *Manufacturing Energy Consumption Survey 1994*, U.S. Department of Energy, Energy Information Administration, December 1997.

[2] *Energy and Environmental Profile of the U.S. Petroleum Refining Industry*, December 1998, U.S. Department of Energy Office of Industrial Technologies.

[3] *Energy Analysis of 108 Industrial Processes*, Drexel University Project Team; Brown, H.; Hamel, B.; Fairmont Press, 1985.

[4] *1992 Industrial Process Heat Energy Analysis*, Final Report No. GRI 96/0353, Gas Research Institute, September 1996.

[5] *Oil and Gas Journal Online*, http://ogj.pennnett.com, U.S. Refineries—State Capacities for 1995–2000.

[6] *Industry Brief, Petroleum Refining*, EPRI, 1993.

[7] *Analysis of the Industrial Boiler Population*, Final Report No. GRI-96/0200, Gas Technology Institute, June 1996.

[8] Major Industrial Plant Database (MIPD^{TM}), IHS Energy, June 1999.

Figure 3.3-1. Estimated Steam Energy Use for Major Petroleum Refining Processes

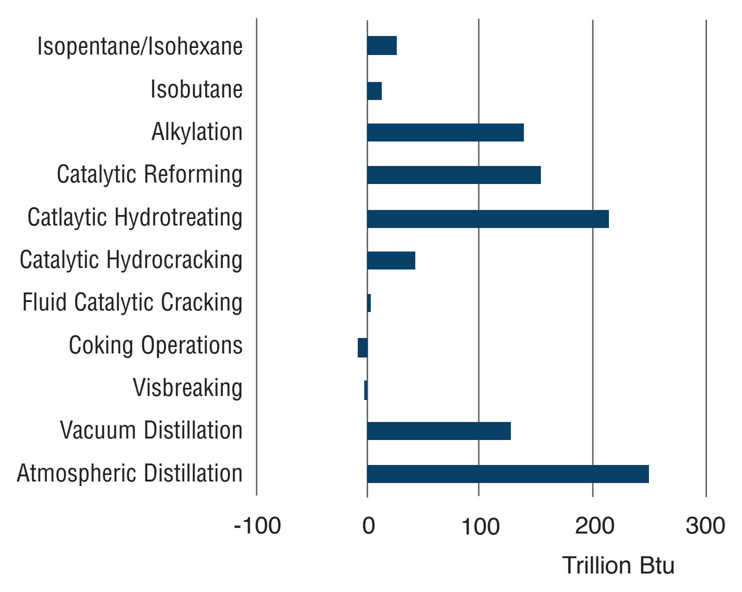

Table 3.3-1. Energy Requirements of Common Refinery Processes [2,3,4,5,6]

Process	Avg. Unit Energy Use (Thousand Btu/barrel)	Production (Thousand barrels/day)	Energy Use by Technology (Trillion Btu)			
			Direct Fired	Electric	Steam	Total
Atmospheric Distillation	114	14,584	383.3	12.3	246.1	641.7
Vacuum Distillation	92	6,433	112.7	2.8	123.3	238.8
Visbreaking	87	65	3.3	0.0	(1.3)	2.1
Coking Operations	170	1,771	110.5	14.1	(9.4)	115.1
Fluid Catalytic Cracking	100	5,051	105.9	23.4	0.5	189.8
Catalytic Hydrocracking	240	1,261	62.2	18.2	33.6	113.9
Catalytic Hydrotreating	120	7,912	202.1	54.6	212.0	468.7
Catalytic Reforming	284	3,692	242.6	13.5	117.2	373.2
Alkylation	375	1,157	-	10.9	139.5	150.4
Isomerization	-	-	-	-	-	-
Isobutane	359	101	-	0.4	12.4	12.8
Isopentane/Isohexane	175	434	-	0.9	25.9	26.8
Total	-	-	**1,283**	**151**	**900**	**2,333**

Figure 3.3-2. Basic Process Flow of a Petroleum Refinery

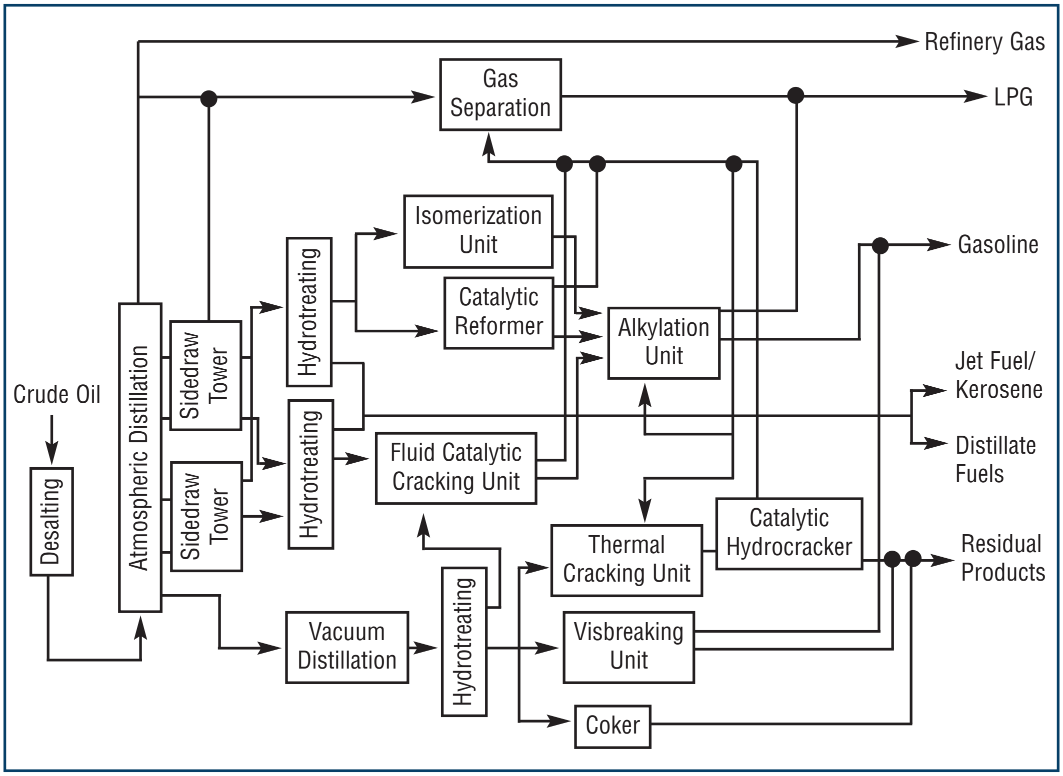

Figure 3.3-3. Boiler Capacity in the Petroleum Industry by Boiler Size [7]

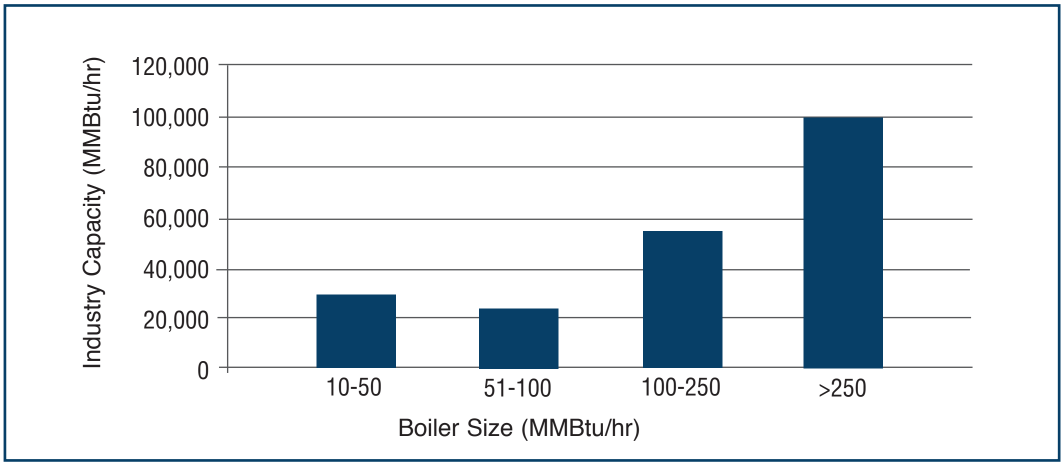

Figure 3.3-4. Petroleum Industry Boiler Capacity by Fuel Type [7]

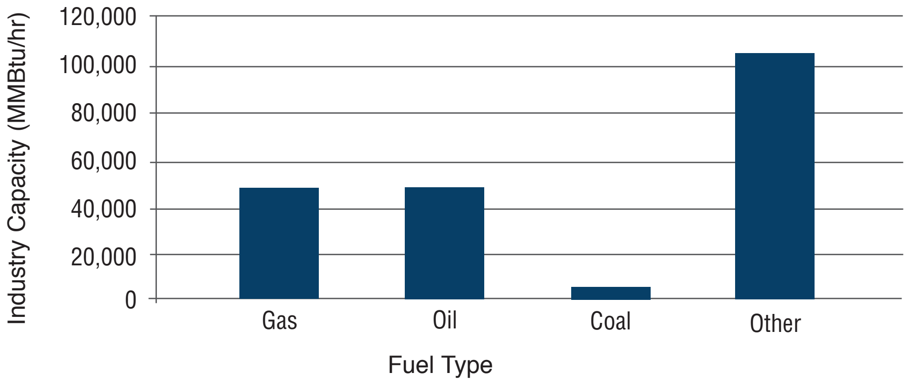

Figure 3.3-5. Petroleum Industry Steam System Capacity by Pressure [7,8]

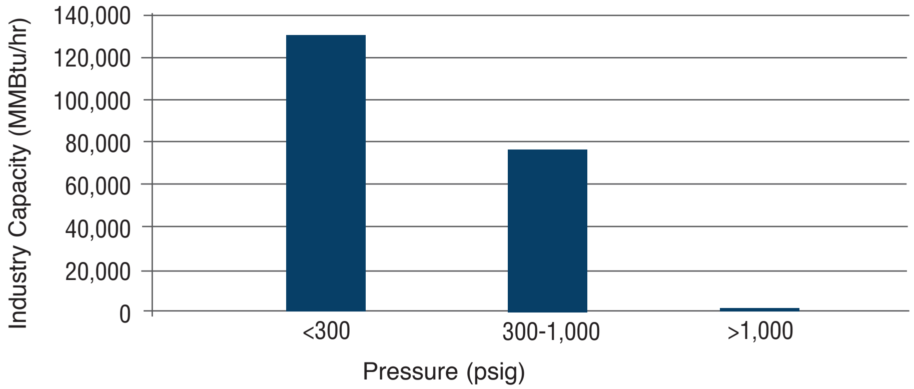

Table 3.3-2. Estimated Steam Generation Capacity by Cogeneration in the Petroleum Industry (MMBtu/hr) [1]

		Cogeneration Technology					
		Steam Turbines		Combustion Turbines	Multiple Technologies	Other	Total
Industry	**SIC**	**Steam Supplied by Boilers**	**Steam Supplied by Heat Recovery Heat Exchangers**				
Petroleum Refining	2911	96	96	509	9,451	469	10,621

Steam System Performance Improvement Opportunities

Figures and Tables referenced in this section begin on page 77, in the order they are mentioned in the text.

Introduction

This section estimates the potential savings available from implementing steam system improvements in the pulp and paper, chemical manufacturing, and petroleum refining industries. To develop these savings estimates, 30 performance improvement opportunities were identified that cover the most significant ways to improve steam system performance and efficiency in these target industries.

To assess the energy savings available from implementing steam system improvements, it was determined that expert elicitation would be the most effective approach. Expert judgment was elicited by sending questionnaires to qualified experts. The major types of data that were requested were:

- Fuel savings
- Percentage of facilities for which each opportunity is feasible
- Payback period
- Reasons for implementing the improvement.

This section presents data gathered from this approach.

Key Results

The results of this effort indicate that fuel savings from individual steam system improvements range from 0.6 percent to 5.2 percent. The payback periods for these steam system improvements range from 2 to 34 months; the majority are less than 24 months. The percentages of facilities for which these improvements are feasible range from 3.4 to 29.4 percent.

Overall industry fuel savings, which are the combination of estimates for fuel savings and the percentage of facilities for which an opportunity is feasible, for each of the 30 opportunities range from 0.02 percent to 3.0 percent. The data showing overall fuel savings for the major areas of a steam system are shown in Figure 4-1.

When combined, the total potential fuel savings from these steam system improvement opportunities totaled over 12 percent for each industry. Table 4-1 indicates that the total energy savings potential for these 30 steam system improvement opportunities is 674 trillion Btu.

This data illustrates several key results.

- Individual fuel saving opportunities can be significant, especially because facilities can often implement several steam system improvements.
- Because most payback periods are less than 2 years, these improvements are generally worth considering.

- Total potential energy savings associated with steam improvements is significant, amounting to over 12 percent for each target industry.

Methodology

Experts with experience in the steam systems at multiple industrial facilities are able to provide data that is representative of industry conditions. An optional approach would be to survey a representative sample of industrial facilities in the subject industries. However, gathering enough data to assess each system adequately—even in a representative sample of facilities—would be cost prohibitive.

Effective expert elicitation requires asking the right people the right questions. To find the right people, we sought a set of qualified experts. These contacts were made through:

- The BestPractices Steam program
- Referrals by other industry stakeholders
- Industry research.

Prospective participants were contacted to determine their level of knowledge and experience in the steam systems of the subject industries. After describing the objectives of this project and assessing the qualifications of the prospective participants, we requested qualified experts to provide estimates of steam system energy savings.

To ask the right questions regarding these savings, a list of 30 performance improvement opportunities was developed and is shown below[1]:

1. Minimize Boiler Combustion Loss by Optimizing Excess Air
2. Improve Boiler Operating Practices
3. Repair or Replace Burner Parts
4. Install Feedwater Economizers
5. Install Combustion Air Preheaters
6. Improve Water Treatment
7. Clean Boiler Heat Transfer Surfaces
8. Improve Blowdown Practices
9. Install Continuous Blowdown Heat Recovery
10. Add/Restore Boiler Refractory
11. Establish the Correct Vent Rate for Deaerator
12. Reduce Steam System Generating Pressure
13. Improve Quality of Delivered Steam
14. Implement an Effective Steam Trap Maintenance Program
15. Ensure Steam System Piping, Valves, Fittings, and Vessels are Well Insulated
16. Minimize Vented Steam
17. Repair Steam Leaks
18. Isolate Steam from Unused Lines
19. Improve System Balance
20. Improve Plant-Wide Testing and Maintenance Practices
21. Optimize Steam Use in Pulp and Paper Drying Applications
22. Optimize Steam Use in Pulp and Paper Air Heating Applications
23. Optimize Steam Use in Pulp and Paper Water Heating Applications
24. Optimize Steam Use in Chemical Product Heating Applications
25. Optimize Steam Use in Chemical Vacuum Production Applications

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[1] Refer to Appendix C for a more detailed description of these opportunities.

26. Optimize Steam Use in Petroleum Refining Distillation Applications
27. Optimize Steam Use in Petroleum Refining Vacuum Production Applications
28. Improved Condensate Recovery
29. Use High-Pressure Condensate to Generate Low-Pressure Steam
30. Implement a Combined Heat and Power (Cogeneration) Project

To simplify references to and descriptions of these opportunities, we defined five categories. Four of these categories refer to parts of the steam system: generation, distribution, end-use, and recovery. A fifth category is combined heat and power (CHP), also known as cogeneration. Because a CHP project has significant implications for all four parts of the system, it was considered separately.

The principal data gathered for each improvement opportunity were:

Fuel savings. This benefit is the measure of the efficiency gain available to the entire system from implementing the improvement opportunity. Fuel savings, rather than efficiency, was used because efficiency gain can be used in reference to a particular device, such as a turbine, as well as a system. To avoid potential misinterpretation, we selected a measurement that could be used to compare against all other opportunities.

Percentage of facilities for which each opportunity is feasible. This measure requests how many facilities can feasibly implement this improvement. Because "feasibility" can have different quantitative meanings to different industries and facilities, it was not explicitly defined; instead, the experts were requested to use their judgment.

Payback period. The payback period is the time required for the benefits generated by the improvement to return the implementation costs.

Reasons for implementing the improvement. This response provides insight into why the improvement opportunity is usually implemented. Often, several reasons are used to justify an improvement project. We requested the experts to rank the reasons in order of importance. If the reasons provided in the list did not sufficiently describe why the improvement is usually implemented, the experts were requested to discuss other reasons. The questionnaires listed the following candidate reasons:

- Energy savings
- Performance improvement
- Increased capacity
- Improved reliability
- Reduced maintenance
- Safety/environmental.

We also encouraged the experts to provide additional insights that could further qualify and/or explain their responses. In many cases, experts provided answers that were different than the available responses and often they provided rationale for these answers.

We determined that the best tool to elicit expert knowledge regarding these opportunities was a hardcopy questionnaire. A hardcopy questionnaire provides several advantages, including flexibility in devoting time to complete it, allowing research, and permitting write-in comments. A detailed discussion of the questionnaire can be found in Appendix D.

Before sending the questionnaire out to the experts, it was reviewed by a separate group of industry stakeholders. The questionnaire was reviewed and modified until it met three important objectives.

Is it user friendly? Although the questionnaire addressed a broad range of steam system considerations, its length and format were designed to encourage participation.

Are the questions unambiguously worded? It is essential that the different experts reading the same question would arrive at a common understanding with respect to what was being asked.

Do the responses gather accurate and representative data? Experts should find a reasonable set of choices to select their answers, and should have an opportunity to qualify and/or amplify their answers.

The questionnaire was sent to 34 participants who agreed to participate. Of those, 19 participants returned the questionnaire with useful data.

Industry Considerations

There were also several approaches considered in presenting the data. One way is to group the data by industry. Most of the experts indicated that they have more experience in some industries than others. Categorizing the experts based on their responses to the end-use-specific improvement opportunities allows the data from these expert responses to be assigned to the respective industries. However, there was a significant amount of overlap among the experts, resulting in little distinction among the results of each industry. The fuel savings, feasibility percentages, and paybacks are roughly the same for opportunities in each industry.

Alternatively, data can be presented to indicate opportunities across all three industries. Although there are some differences, the level of agreement between the experts from different industries promotes grouping the results. An important exception to this approach is the set of end-use opportunities, because these are specific to each industry.

Statistical Considerations

After the questionnaires were returned and the data from them extracted, several different approaches were considered to statistically evaluate the collected data.

In terms of statistical description of the results, we selected geometric mean as the most appropriate way to present the data. Other statistical options include arithmetic mean, which is the average value among all the responses, and median, which is the 50th percentile value, meaning half the answers are higher and half are lower. The fundamental difference between arithmetic mean, geometric mean, and median is the way they treat the extreme values. Because the mean approach weighs the value of all data, outliers have a strong effect. In the median approach, the values of outliers do not affect the median value as much because the data is ranked; whether a value is a little higher or a lot higher than the next one in the ranking is not a factor. Alternatively, the geometric mean uses a logarithmic calculation that weighs the value of the outliers, but not as strongly as the arithmetic mean. To present the uncertainty data, lower and upper uncertainties of 2.5 and 97.5 percentile, respectively, were selected. The difference between these uncertainties indicates the level of agreement between the experts.

Discussion of alternative statistical analyses is presented in Appendix F. Additionally, the statistical results for all three approaches are provided in Appendix E.

Grouping the Opportunities

To present the results, we grouped the opportunities into three categories: general opportunities, end-use opportunities, and special opportunities. Assigning the data into these categories promotes better discussion of the methods used to acquire data and the implications that can be drawn from the results.

General Opportunities

General opportunities can be applied to facilities in all three industries. The principal characteristics among these opportunities are that they can generally be considered for a wide range of steam systems and that implementing them usually results in fuel savings. An exception to this characteristic is CHP, which, although able to improve the overall energy efficiency of a facility, does not necessarily reduce fuel use. CHP projects can be implemented at many industrial facilities; however, they generally require assessment of many factors, including electric power needs, rate structure, thermal requirements, and fuel prices.

End-Use Opportunities

End-use opportunities apply to the services or tasks that convert the steam's energy into useful work. The experts were requested to consider all the ways that the efficiency of a steam end-use process can be improved. These opportunities encompass a broad range of measures, ranging from correcting deferred maintenance to making a configuration more efficient to replacing a component with a more efficient model. Because end-use opportunities are process specific, the data for these opportunities are presented by each industry.

Special Opportunities

Several of the opportunities were evaluated with a special set of responses because obtaining energy saving data for these opportunities requires a different set of queries. (See Appendices C and D.) Water treatment, steam trap maintenance, plant-wide maintenance, and insulation improvements were evaluated on a facility-wide basis rather than on an individual project basis. As a result, this group of opportunities is presented separately.

Water Treatment. Systems with poor water treatment practices tend to experience more problems, such as boiler tube failure, foaming (which, in turn, causes boiler water carryover and poor steam quality), and fouled heat transfer surfaces. Conversely, in general, a facility that follows a formal water treatment program will operate more efficiently than a facility that does not. As a result, the experts were requested to separate plants into three categories, determine the percentage of plants that fall in these categories, and estimate the representative efficiency differences between the steam systems in these categories.

Steam Traps. Steam trap performance can have a wide range of effects on the steam system, including improved end-use equipment performance, better steam quality, and decreased risk of water hammer. Although system efficiency increases when the number of failed traps in the system is reduced, there are other benefits as well.

Additionally, the efficiency losses caused by failed traps vary widely depending on the types of traps and their applications. The wide range of trap types and sizes complicates the question of asking how much energy can be saved by repairing traps at a representative facility. Some traps fail closed. Although such failures impair system performance, they do not translate directly into an energy loss. Other traps fail open, allowing steam to escape or to pass into the condensate system. However, the consequences of these failures depends on steam pressure, trap size, and other operating conditions.

To provide a quantifiable measure of the efficiency gain available from this improvement, we requested that the experts estimate the percentage of plants that belong in each of three categories based on steam trap management practices. We then requested estimates of the fuel savings associated with improving the trap maintenance program to an effective level. The experts were asked to use their judgement with respect to what constitutes "effective."

Insulation. Quantifying the savings associated with improving insulation at an entire facility is difficult. Although the costs and benefits of a particular insulating task, such as insulating a valve or replacing insulation on a known length of pipe, can be calculated, the number of these opportunities that exists at a large facility is difficult to determine. To simplify the efficiency gains associated with this opportunity, we requested that the experts separate the population of plants into four categories. The experts were requested to assign population estimates to these categories.

Plant-Wide Maintenance. Plant-wide maintenance refers to general system management practices. Proactive system management often allows the discovery and resolution of problems before they worsen and cause damage or avoidably high operating costs. In general, plants that promote employee awareness regarding the indications of trouble and the costs of problems operate more efficiently and more reliably. The experts were requested to classify facilities into three categories based on their management practices.

Results

The results of the data analyses are presented in the following sets of tables and graphs. The results presented in these tables and graphs represent the geometric mean. Upper and lower uncertainty values provide meaningful indications regarding the level of agreement among the expert for each opportunity and are available in Appendix E.

Individual Opportunity Fuel Savings Can be Significant

The fuel savings that are available to a representative industrial facility are listed in Table 4-2 and shown graphically in Figure 4-2. These fuel savings generally fall between 0.6 percent and 2.9 percent; however, the estimate for combined heat and power projects is 5.2 percent. A CHP project may or may not reduce actual fuel purchased by a plant—in fact, on-site fuel use may increase. The fuel savings in this case represents a reduction in total facility energy use, including fuel and electricity that are purchased from utility sources.

Because many facilities are able to implement several of these opportunities, the total fuel savings available to a typical facility can be significant. As with many plant utility systems, improving steam system performance with multiple projects can result in interactive effects, which can increase or decrease the available savings. To illustrate, assume that a facility implements three improvements: (1) the amount of vented steam is minimized, (2) feedwater economizers are installed, and

(3) excess combustion air is minimized. Assuming that there are no interactive effects, the sum of these fuel savings is 7.8 percent, which is a very significant energy and cost benefit.

Significant Percentages of Target Industry Facilities Can Implement These Improvement Opportunities

The percentages of facilities for which these improvements are feasible are listed in Table 4-3 and shown graphically in Figure 4-3. These percentages range from 3.4 to 29.4 percent. An important implication of this data is it is highly practical for many facilities to implement one or more steam system improvements. In many cases, these opportunities exist because a facility is not aware of the cost savings associated with implementing the improvement.

Payback Periods are Generally Less Than 2 Years

The payback period represents how long it takes for the economic benefits from an improvement to return the costs of implementing it. The payback periods for general improvement opportunities are listed in Table 4-4 and shown graphically in Figure 4-4. Competing demands for limited resources mean that projects requiring investment must produce a reasonable return. Eight improvement opportunities produce paybacks that are less than 6 months, which is generally considered an attractive payback period. Eleven opportunities have estimated paybacks of less than 1 year.

Total Industry Fuel Savings

The total available industry savings is the combination of the individual fuel savings estimate and the feasibility percentage estimate. Total industry savings were calculated using each expert's response. For example, assume that for optimized condensate recovery a reviewer indicates that the representative fuel savings is 2 percent and that 24 percent of the industrial facilities can feasibly implement this improvement. These two values result in a total industry savings estimate of 0.48 percent. This result is slightly different than combining the separate averages of all estimates for fuel savings and for percentage of facilities. The results of this approach are listed in Table 4-5 and shown graphically in Figure 4-5.

Industry fuel savings estimates range from 0.02 to 0.85 percent. Although these percentage values seem low, they represent a portion of the total fuel used by these industries to generate steam. When these percentages are applied against trillions of Btu, both the energy and the cost savings are significant. The size of these savings becomes more impressive when the sum of the general opportunities fuel savings is calculated.

End-Use Opportunities

End-use improvements are specific to particular industries. The fuel savings, percentage of facilities, total savings available, and the payback period for the end-use improvement opportunities are all shown in Table 4-6. These opportunities have similar savings and payback data as the other opportunities.

Special Opportunities

Another group of opportunities is discussed separately because different types of queries were used to obtain the data. Unlike the categories of general opportunities and end-use opportunities, the data in this group address facility-wide practices and conditions. As a result, rather than gathering data about specific projects, for this group of opportunities, experts were requested to estimate data regarding a facility's overall approach to water treatment, insulation, steam trap management, and plant-wide testing and maintenance.

Many Facilities Can Improve Their Water Treatment Practices

The results of improving the water treatment practices at the facility level and across the three industries are reported in Table 4-7. A steam system with an effective water treatment program will operate between 1.6 and 3 percent more efficiently than one with an ineffective treatment program. Although higher operating efficiency is one benefit, an effective water treatment program will in general extend equipment life, improve system performance, and reduce the risk of operating problems, such as poor steam quality.

The Efficiency Gains Available From an Effective Steam Trap Management Program are Significant

The results for improving steam trap management practices at a facility are shown in Table 4-8. The estimated fuel savings available from improving a facility's steam trap management program are 7.2 percent. This significant savings potential is available in over one-fourth of the facilities in the three targeted industries. Altogether, about 70 percent of the industrial facilities can improve their steam trap management programs.

The representative payback period for improving steam trap management programs was reported to be 8 months. Generally, an 8-month payback period is attractive.

Insulation Improvements Can be Implemented at Almost 40 Percent of the Industrial Facilities

The results for improving the steam system insulation at individual facilities and across all three industries are shown in Table 4-9.

The representative payback period for improving steam system insulation was estimated to be about 14 months. Insulation projects can involve a wide range of difficulty. Some insulation improvements can be simple such as installing removable insulation over a previously uninsulated fitting, equipment, or pipe. Other cases require replacing the insulation on a poorly insulated line that is difficult to access.

Plant-Wide Testing and Maintenance Practices Can be Improved in Over 70 Percent of the Industrial Facilities

The results of the plant wide testing and maintenance opportunity are shown in Table 4-10. The representative payback period for improving plant-wide testing and maintenance programs was reported to be about 6 months, which is generally an attractive payback.

Fuel Savings Opportunities are Available Across All Areas of a Steam System

The results of assigning fuel-saving opportunities to certain areas of a steam system are listed in Table 4-11 and shown graphically in Figure 4-6. Categories of generation, distribution, end use, recovery, and combined heat and power were selected. Because the end-use opportunities are industry specific, we presented them by their respective industries.

Note that the Generation area of a steam system contains fuel savings of over 15 percent. Because 10 of the 30 improvement opportunities are related to the generation part of the system, it is not surprising to find that this area involves a large portion of the fuel savings. However, other areas of the system also offer significant fuel savings, indicating that when looking to improve steam system performance and efficiency, a comprehensive systems approach should be used.

Similarly, to view how industry savings are distributed among the area of the steam system, total savings data were grouped into the same categories that were used in Table 4-11 and were presented in Table 4-12 and shown graphically in Figure 4-7. Recall that industry fuel savings for an opportunity is determined by combining estimates for typical fuel savings and the percentage of plants for which that opportunity is feasible. However, in this case, we included the special opportunities categories, which on an industry-wide basis account for a relatively large amount of savings.

Steam trap management and plant-wide maintenance are the largest sources of total industry savings. The primary reason for the large impacts of steam trap management and plant-wide maintenance on industry-wide savings is the percentage of facilities that can achieve significant savings by improving these programs.

Reasons for Implementing Improvements

The experts were requested to provide reasons why steam system improvements are implemented. Six candidate reasons were provided and are described below; however, the experts were allowed to enter other reasons as well.

Energy Savings

Improving system efficiency reduces energy needs and energy costs in industrial processes.

Performance Improvement

Often, an upgrade or modification to a steam system is made to improve its performance. Aspects of improved performance include higher steam quality, quicker and improved response to load changes, and fewer unwanted fluctuations in steam pressure.

Increased Capacity

This reason includes the ability to deliver more steam or steam at higher pressure.

Improved Reliability

This reason addresses factors that reduce the risk of unexpected downtime. Steam systems are often critical to plant operation; consequently, factors that reduce the risk of loss of steam are important.

Reduced Maintenance

This reason addresses ways to limit wear and tear on the system, for example, by correcting a problem that previously resulted in damaged valve seats.

Safety/Environmental

This reason combines the benefits of reducing employee risk while improving the environmental performance of the plant. Examples of safety benefits include reduced burn risks and reduced risk of exposure to hazardous chemicals. An example of environmental benefits includes reduced emissions.

Results: Energy Savings is Reported as the Most Important Reason

Not surprisingly, energy savings is cited as the leading reason for implementing a steam system improvement. However, usually more than one reason is recommended, indicating that non-energy benefits are a significant factor in improving steam system efficiency and performance.

Although the experts largely agreed that energy savings was usually the most significant implementation reason, there was variation in their estimates of the significance of the other reasons. The questionnaire requested the experts to rank the reasons in order of significance. To combine the input of these experts, we assigned weights to the rankings, then summed the results for each opportunity to indicate which reasons are the most significant. The top three reasons for each of the improvement opportunities are provided in Appendix G.

Conclusions

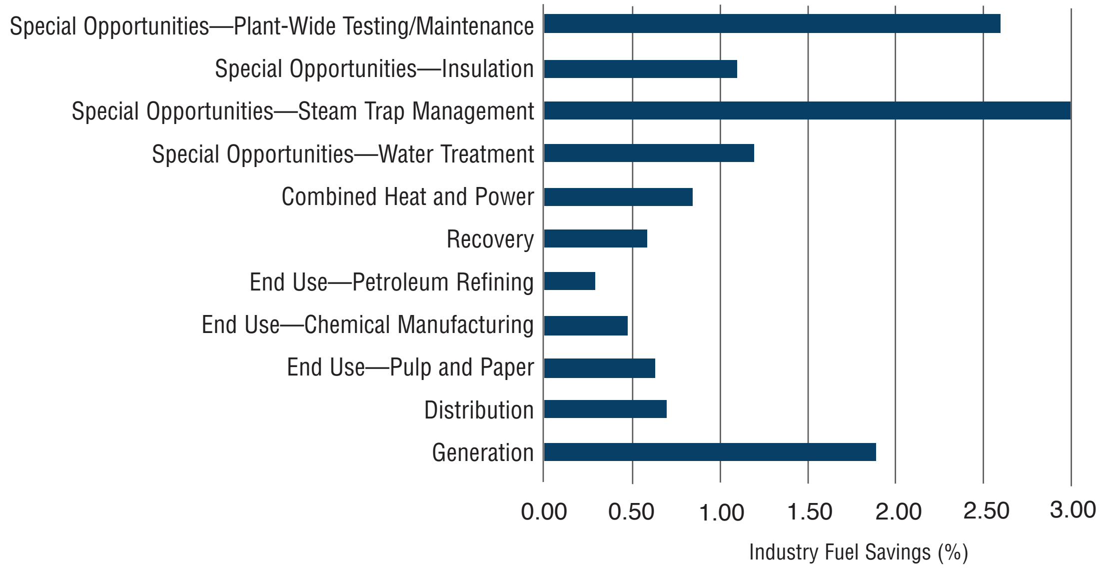
Combining the savings estimates with the total amount of energy used to generate steam for the three subject industries provides an estimate of the total energy savings. The results of this combination are shown in Table 4-13.

Translating the total saving potential, along with the uncertainty data, into a total energy savings estimate requires combining total energy use for each industry with the percentage savings. Data for the amount of energy used to generate steam in the three industries was presented in Section 2. The resulting total energy savings are shown in Table 4-14.

The principal reason that the industry fuel savings estimates for each of the three industries are so close is that there was little difference between the estimated total industry savings among the end-use opportunities. For each industry, the total savings estimates for the end-use opportunities ranged between 0.3 and 0.6 percent.

The data in Table 4-14 illustrate that the total potential energy savings for each target industry is significant. Because the total fuel savings for each industry exceeds 12 percent, the overall savings potential for the three target industries is 674 trillion Btu.

Figure 4-1. Total Industry Fuel Savings for Each Part of the Steam System



Note that the Recovery, all of the End Use, Distribution, and Generation categories included multiple opportunities.

Table 4-1. Total Potential Steam System Energy Savings by Industry

Industry	Industry Fuel Savings (%)	Fuel Used to Generate Steam (Trillion Btu)	Savings Potential (Trillion Btu)
Pulp and Paper	12.5	2,221	278
Chemical Manufacturing	12.4	1,540	191
Petroleum Refining	12.2	1,675	205
Total			**674**

Table 4-2. General Opportunity Fuel Savings

Opportunity	Typical Fuel Savings (%)
Implement Combined Heat and Power (Cogeneration) Project	5.2
Minimize Vented Steam	2.9
Install Feedwater Economizers	2.7
Minimize Boiler Combustion Loss by Optimizing Excess Air	2.2
Optimize Condensate Recovery	2.1
Install Combustion Air Preheaters	1.7
Improve Boiler Operating Practices	1.5
Use High-Pressure Condensate to Make Low-Pressure Steam	1.5
Repair or Replace Burner Parts	1.5
Improve System Balance	1.4
Clean Boiler Heat Transfer Surfaces	1.4
Repair Steam Leaks	1.4
Reduce Steam System Generating Pressure	1.3
Improve Quality of Delivered Steam	1.0
Isolate Steam from Unused Lines	0.9
Install Continuous Blowdown Heat Recovery	0.8
Improve Blowdown Practices	0.8
Establish the Correct Vent Rate for the Deaerator	0.6
Add/Restore Boiler Refractory	0.6

Figure 4-2. The Majority of General Opportunity Fuel Savings Were Greater Than 1 Percent

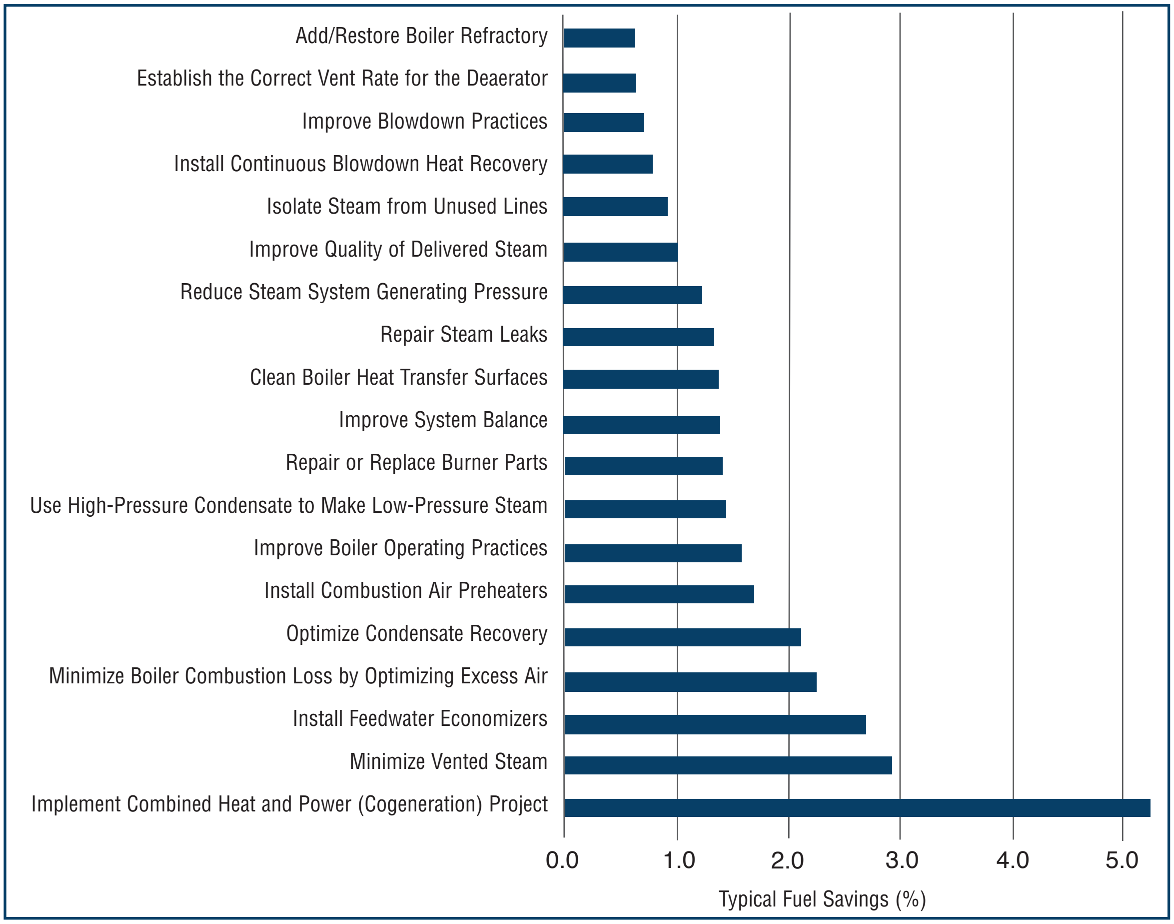


Table 4-3. Percentage of Facilities Where the General Opportunities are Feasible

Opportunity	Percent of Facilities (%)
Minimize Boiler Combustion Loss by Optimizing Excess Air	29.4
Optimize Condensate Recovery	24.2
Repair Steam Leaks	15.7
Implement Combined Heat and Power (Cogeneration) Project	14.7
Improve Blowdown Practices	14.0
Install Feedwater Economizers	13.0
Install Continuous Blowdown Heat Recovery	12.0
Improve Boiler Operating Practices	11.2
Repair or Replace Burner Parts	9.8
Improve Quality of Delivered Steam	9.7
Reduce Steam System Generating Pressure	8.9
Establish the Correct Vent Rate for the Deaerator	8.6
Use High-Pressure Condensate to Make Low-Pressure Steam	8.2
Isolate Steam from Unused Lines	7.8
Improve System Balance	7.2
Minimize Vented Steam	6.5
Clean Boiler Heat Transfer Surfaces	6.4
Add/Restore Boiler Refractory	3.7
Install Combustion Air Preheaters	3.4

Figure 4-3. Facilities Where General Opportunities are Feasible Ranged from 3 to 29 Percent

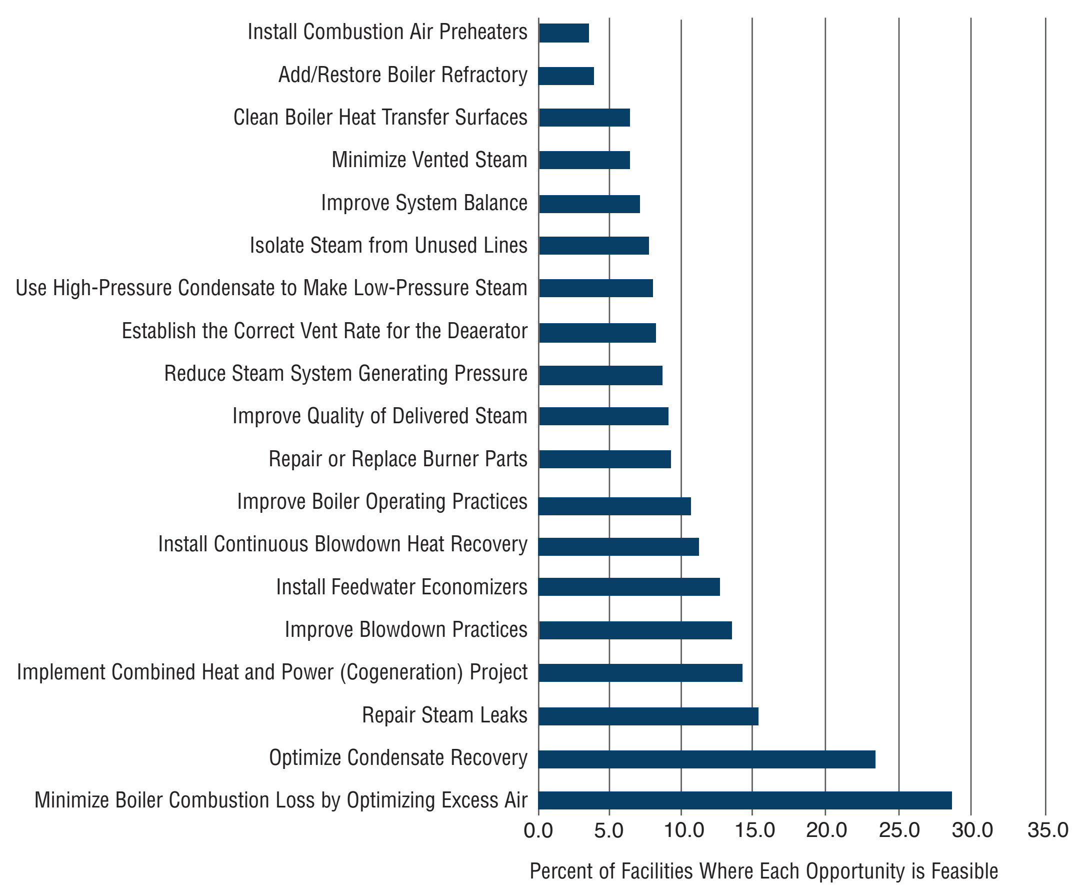


Table 4-4. Payback Period by Opportunity

Opportunity	Payback Period (Months)
Reduce Steam System Generating Pressure	2
Isolate Steam from Unused Lines	2
Improve Blowdown Practices	3
Establish the Correct Vent Rate for the Deaerator	3
Improve Boiler Operating Practices	4
Minimize Vented Steam	5
Minimize Boiler Combustion Loss by Optimizing Excess Air	6
Repair Steam Leaks	6
Improve System Balance	7
Clean Boiler Heat Transfer Surfaces	7
Repair or Replace Burner Parts	12
Add/Restore Boiler Refractory	13
Optimize Condensate Recovery	14
Improve Quality of Delivered Steam	14
Use High-Pressure Condensate to Make Low-Pressure Steam	15
Install Feedwater Economizers	20
Install Continuous Blowdown Heat Recovery	20
Install Combustion Air Preheaters	27
Implement Combined Heat and Power (Cogeneration) Project	34

Figure 4-4. Simple Paybacks for Steam System Improvements Were Reported to be Typically Less Than 2 Years

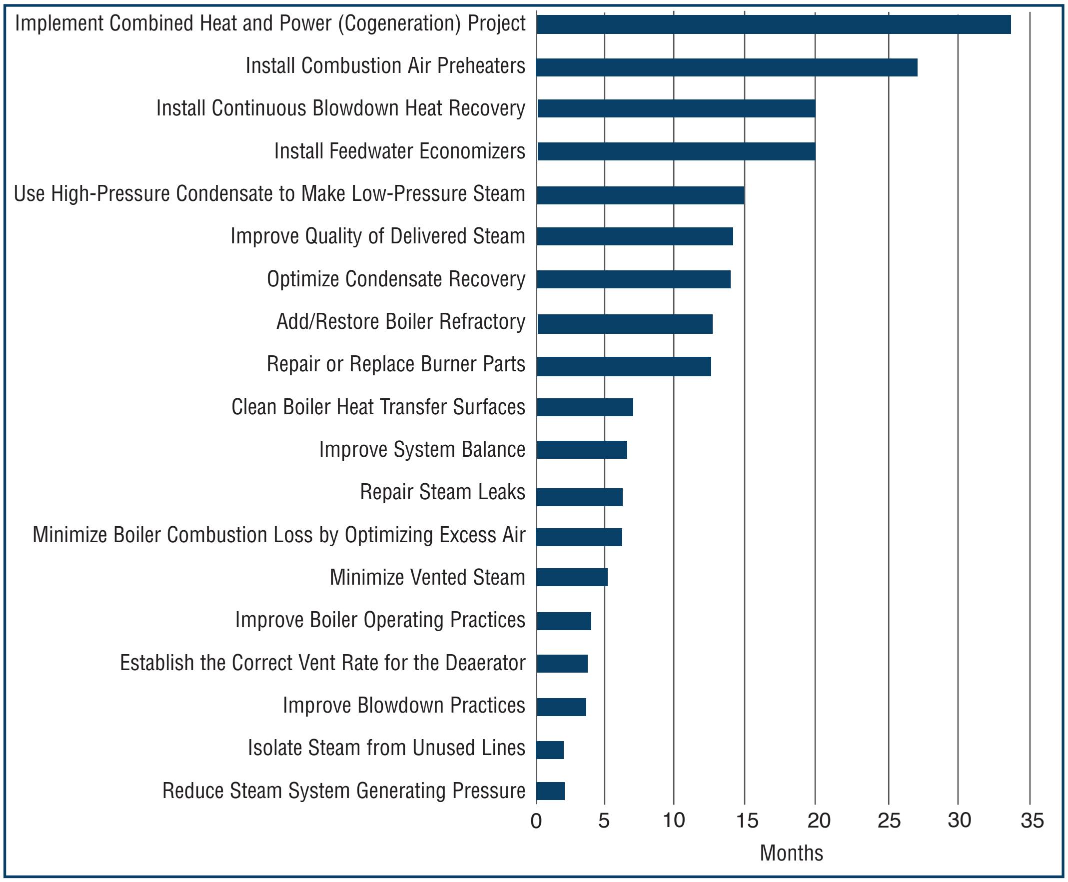
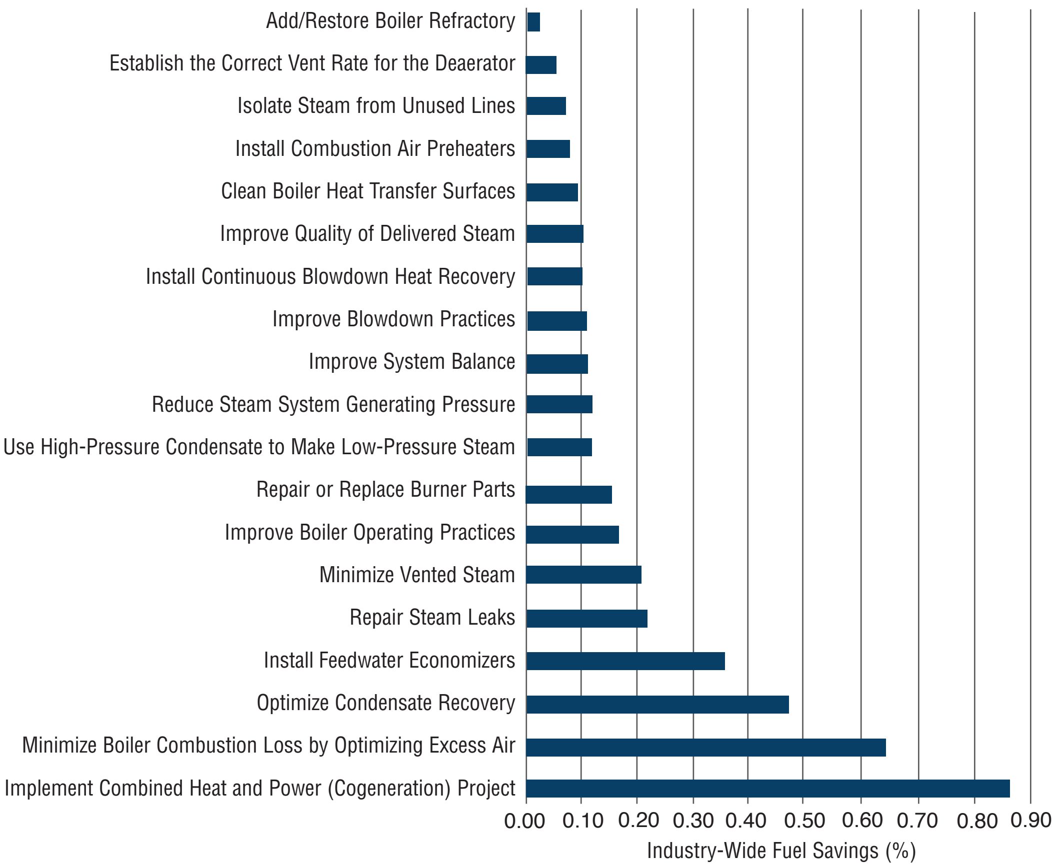


Table 4-5. Industry Fuel Savings by General Opportunity*

Opportunity	Industry Fuel Savings (%)
Implement Combined Heat and Power (Cogeneration) Project	0.85
Minimize Boiler Combustion Loss by Optimizing Excess Air	0.64
Optimize Condensate Recovery	0.48
Install Feedwater Economizers	0.36
Repair Steam Leaks	0.22
Minimize Vented Steam	0.20
Improve Boiler Operating Practices	0.17
Repair or Replace Burner Parts	0.15
Use High-Pressure Condensate to Make Low-Pressure Steam	0.11
Reduce Steam System Generating Pressure	0.11
Improve System Balance	0.11
Improve Blowdown Practices	0.11
Install Continuous Blowdown Heat Recovery	0.10
Improve Quality of Delivered Steam	0.10
Clean Boiler Heat Transfer Surfaces	0.09
Install Combustion Air Preheaters	0.08
Isolate Steam from Unused Lines	0.07
Establish the Correct Vent Rate for the Deaerator	0.05
Add/Restore Boiler Refractory	0.02
Total Savings (%)	**4.04**

*This set of improvements addresses “general” opportunities.

Figure 4-5. Total Fuel Savings for General Steam Improvement is About 4 Percent*



*This set of improvements addresses "general" opportunities.

Table 4-6. Results for the End-Use Opportunities

Opportunity	Typical Fuel Savings (%)	Percentage of Facilities (%)	Industry Fuel Savings (%)	Payback Period (Months)
Pulp and Paper Optimize Steam Use in Pulp and Paper Drying Applications	5.0	9.4	0.46	26
Optimize Steam Use in Pulp and Paper Air Heating Applications	1.1	7.5	0.08	19
Optimize Steam Use in Pulp and Paper Water Heating Applications	1.2	7.9	0.09	16
Chemical Manufacturing Optimize Steam Use in Chemical Product Heating Applications	2.0	17.6	0.34	17
Optimize Steam Use in Chemical Vacuum Production Applications	2.1	6.5	0.13	18
Petroleum Refining Optimize Steam Use in Petroleum Refining Distillation Applications	1.9	11.7	0.19	18
Optimize Steam Use in Petroleum Refining Vacuum Production Applications	1.7	6.5	0.11	23

Table 4-7. Data for Improving Water Treatment Practices*

Correct Problems from Improper Water Treatment

Condition	Percentage of Facilities (%)	Improvement	Typical Fuel Savings (%)	Industry Fuel Savings (%)
Excellent, No Improvement	23.5	-	-	-
Good, Improvement Possible	30.8	Moving from “good” to “excellent”	1.6	0.5
Inadequate	14.9	Moving from “inadequate” to “excellent”	2.9	0.7
Total				**1.2**

*The Percentage of Facilities totals do not add up to 100 percent because of the statistical approach used.

Table 4-8. Data for Improving Steam Trap Management*

Implement an Effective Steam Trap Management Program

Condition	Percentage of Facilities (%)	Improvement	Typical Fuel Savings (%)	Industry Fuel Savings (%)
Has Effective Trap Management Program	12.9	-	-	-
Traps Managed Informally, Improvement Possible	40.1	Moving from “improvement possible” to “effective”	3.0	1.3
Does Not Manage Traps	25.5	Moving from “does not maintain” to “effective”	7.2	1.7
Total				**3.0**

*The Percentage of Facilities totals do not add up to 100 percent because of the statistical approach used.

Table 4-9. Data for Improving Steam System Insulation*

Ensure that Steam System Piping, Valves, Fittings, and Vessels are Well Insulated

Condition	Percentage of Facilities (%)	Improvement	Typical Fuel Savings (%)	Industry Fuel Savings (%)
Insulation Excellent, No Improvement	6.9	-	-	-
Insulation is Good, Does Not Exceed Hurdle Rate	29.7	-	-	-
Insulation Inadequate, Exceeds Hurdle Rate	37.8	Moving from “inadequate” to “excellent”	2.5	0.9
System is Uninsulated	1.1	Moving from “essentially uninsulated” to “excellent”	1.6**	0.2
Total				**1.1**

*The percentage of facilities total does not add up to 100 percent because of the statistical approach used.

**The data in this table reflects several zero data entries that tend to underestimate the potential savings available from uninsulated systems.

Table 4-10. Data for Improving Plant-Wide Testing and Maintenance*

Improve Plant-Wide Testing and Maintenance Practices

Condition	Percentage of Facilities (%)	Improvement	Typical Fuel Savings (%)	Industry Fuel Savings (%)
Practices Excellent, No Improvement	3.0	-	-	-
Practices Good, Improvement Possible but Benefit is Small	36.5	Moving from “inadequate” to “excellent”	2.2	0.8
Practices are Inadequate	34.4	Moving from “essentially uninsulated” to “excellent”	5.3	1.7
Total				**2.6**

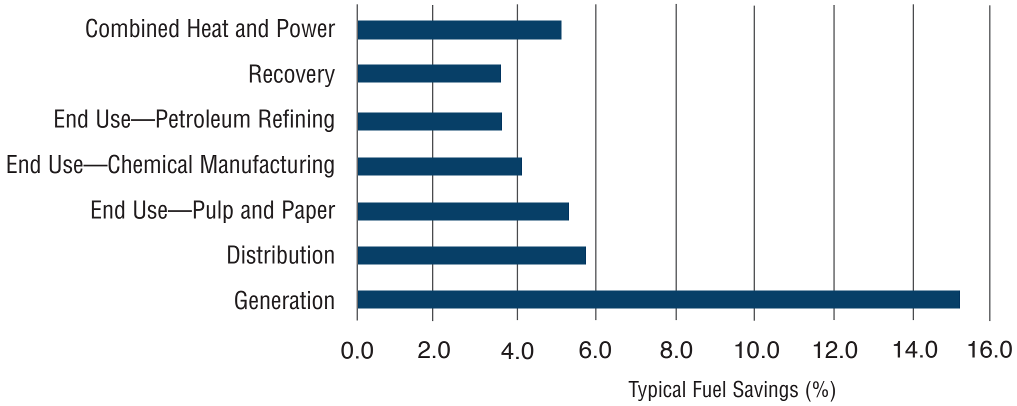
*The percentage of facilities total does not add up to 100 percent because of the statistical approach used.

Table 4-11. Typical* Fuel Savings for Each Major Area of the Steam System*

Category	Typical Fuel Savings (%)
Generation	15.2
Distribution	7.7
End Use	
Pulp and Paper	7.2
Chemical Manufacturing	4.1
Petroleum Refining	3.6
Recovery	3.6
Combined Heat and Power	5.2

*Typical fuel savings data represents the savings available to a representative plant. There are four key opportunities that are not included in Table 4-11 and Figure 4-6: water treatment, steam trap management, insulation, and plant-wide testing and maintenance. The method used to gather data for these opportunities does not allow the fuel savings for a representative facility to be determined. However, these opportunities are included in a subsequent section that discusses industry-wide fuel savings.

Figure 4-6. Typical Industry Fuel Savings for Each Major Area of the Steam System



*Typical fuel savings data represents the savings available to a representative plant. There are four key opportunities that are not included in Table 4-11 and Figure 4-6: water treatment, steam trap management, insulation, and plant-wide testing and maintenance. The method used to gather data for these opportunities does not allow the fuel savings for a representative facility to be determined. However, these opportunities are included in a subsequent section that discusses industry-wide fuel savings.

Table 4-12. Total Industry Fuel Savings for Each Part of the Steam System

Category	Total Industry Fuel Savings (%)
Generation	1.9
Distribution	0.7
End Use	
Pulp and Paper	0.6
Chemical Manufacturing	0.5
Petroleum Refining	0.3
Recovery	0.6
Combined Heat and Power	0.9
Special Opportunities	
Water Treatment	1.2
Steam Trap Management	3.0
Insulation	1.1
Plant-Wide Testing and Maintenance	2.6

Figure 4-7. Total Industry Fuel Savings for Each Part of the Steam System

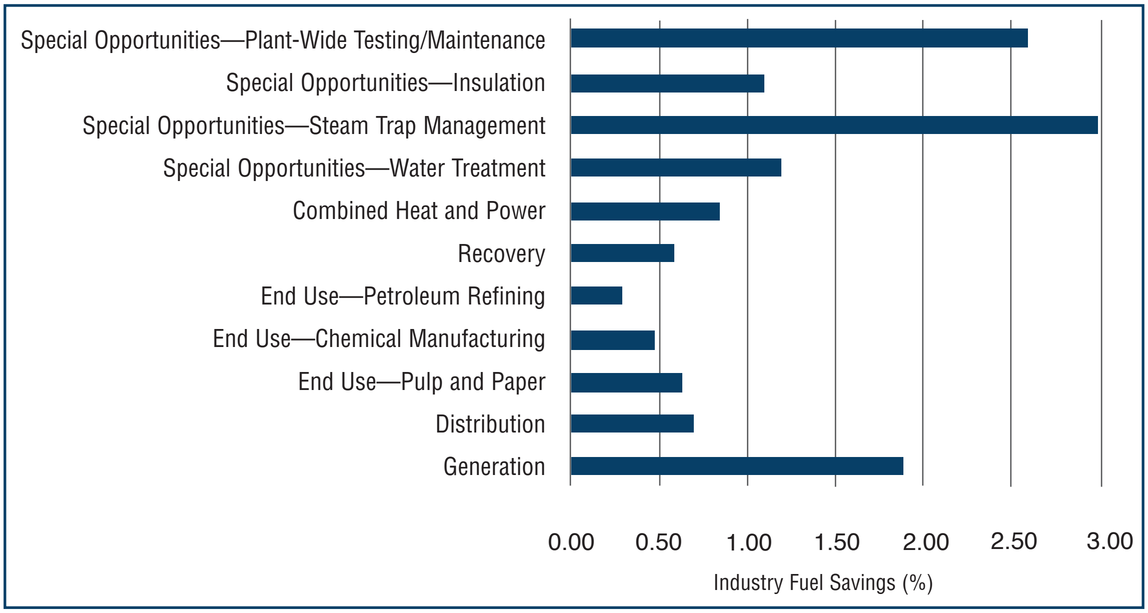


Table 4-13. Total Percentage Fuel Savings by Industry

Opportunities	Industry Steam System Fuel Saving Potential (%)	Total
General Opportunities	4.0	-
Special Opportunities	7.9	-
Industry-Specific Opportunities		
Pulp and Paper	0.6	12.5
Chemical Manufacturing	0.5	12.4
Petroleum Refining	0.3	12.2

Table 4-14. Total Potential Steam System Energy Savings by Industry

Industry	Industry Fuel Savings (%)	Fuel Used to Generate Steam (Trillion Btu)	Savings Potential (Trillion Btu)
Pulp and Paper	12.5	2,221	278
Chemical Manufacturing	12.4	1,540	191
Petroleum Refining	12.2	1,675	205
Total			**674**

Notes

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