# EFFICIENT USE OF FOSSIL FUELS IN PROCESS OPERATION

**Clark Gellings**
*Electric Power Research Institute, Palo Alto, California, USA*

**Kelly E. Parmenter and Patricia Hurtado**
*Global Energy Partners, Lafayette, California, USA*

**Keywords**: fossil fuels, thermal, industry, process, efficiency, energy-efficiency opportunities, combustion, boilers, steam, process heat

**Contents**





**Summary**

Fossil-fuel consumption dominates energy use in the industrial sector, and beyond. In fact, over 80% of primary energy consumption is in the form of fossil fuels. Because of the prevalence of fossil-fuel based systems, the efficient use of these systems presents an enormous potential for energy savings. This article presents a variety of energy-efficiency opportunities for four types of systems: combustion, boilers, steam, and process heat. Combustion is the foundation for the last three types of systems, and boilers and steam systems are directly related. Also presented in this article are case studies and future trends related to the efficient use of fossil fuels in industry.

## 1. Introduction

Fossil fuels are the dominant energy source for the world. In fact, in 1999 fossil fuels accounted for 85% of the world's primary energy consumption. The three major types of fossil fuels are petroleum, natural gas, and coal. Figure 1 is a comparison of international energy consumption of fossil fuels in 1990 and 1999. Since 1990, petroleum and natural gas have seen a steady rise, while coal has had ups and downs. Consumption of coal in 1999 was below 1990 values. Petroleum use leads world energy consumption, and currently accounts for ~47% of fossil-fuel use. Coal and natural gas use are very close in value, comprising 26 and 27% of total world fossil-fuel use.

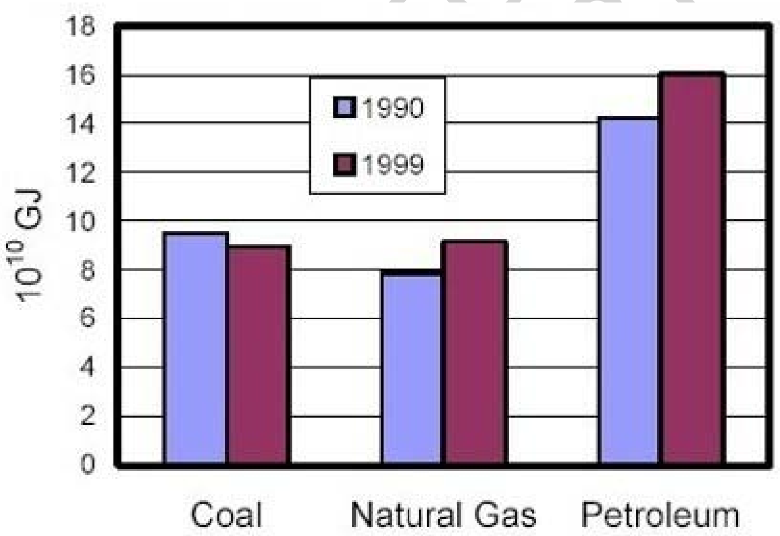


Figure 1. International consumption of fossil fuels in 1990 and 1999
Source: Data compiled from Energy Information Administration (EIA), US Department of Energy (US DOE), (2001), International Energy Annual, Table 1.8, available on-line at www.eia.doe.gov/iea/

Industry is the leading end-use sector for energy consumption, and accounts for ~37% of total energy consumption in the United States. Of that 37%, more than 80% is in the form of fossil fuels. Therefore, efficiency improvements in fossil-fuel-based process applications, present a substantial energy savings potential for industry. Figure 2 depicts the breakdown of primary fossil-fuel consumption in industry for the United States. Natural gas is the leading industrial fossil-fuel source (47%), followed closely by petroleum (43%), and then by coal (10%). Fossil fuels are used in industry both directly, and indirectly. Combustion processes and feedstock are direct applications, and electricity generation is an indirect application. Figure 3 shows the approximate direct end-uses of fossil fuels in the United States manufacturing sector (in 1985). The manufacturing sector does not include agriculture, forestry, fishing, mining, or construction.

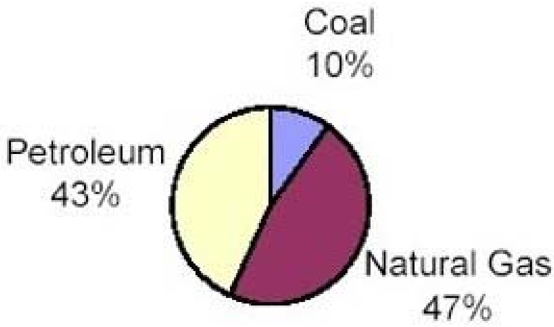


Figure 2. Primary industrial consumption of fossil fuels, 1999 (United States)
Source: Data compiled from Energy Information Administration (EIA), US Department of Energy (US DOE), (2001), International Energy Annual, Table 2.4, available on-line at www.eia.doe.gov/iea/

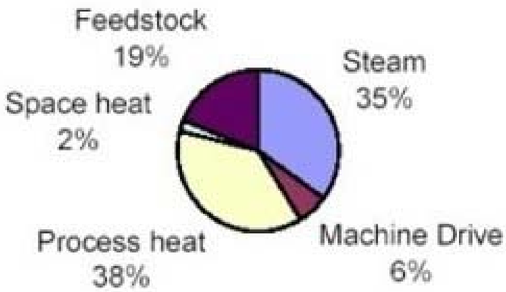


Figure 3. End-use of fossil fuels in manufacturing industries, 1985 (United States)
Source: Data compiled from *Industrial Energy Efficiency*, OTA-E-560, U.S. Congress, Office of Technology Assessment (OTA), Aug. 1993

As is illustrated in Figure 3, steam and process heat are the major industrial end-uses of fossil fuels. Each comprises more than one third of all fossil-fuel consumption. The next most significant end-use is feedstock at 19%. Machine drive and space heat follow with 6 and 2% of usage, respectively. Other industrial applications of fossil fuels include incineration and on-site vehicular transportation.

This article is concerned with the combustion of fossil fuels to create thermal energy. Thermal energy is also created with electricity, solar processes, biomass combustion, and heat recovery. In general, thermal energy is consumed in industry via the following main mechanisms:

- Sensible heat for heating products
- Latent heat for phase changes
- Heat of reaction for chemical changes

- Process and stack heat losses

The last mechanism—process and stack heat loss—presents the primary opportunity for energy savings. Sections 2 through 5 present measures to improve efficiency and reduce heat loss in four main types of fossil-fuel systems: combustion, boilers, steam, and process heat, respectively. Combustion is the foundation of boilers, steam, and process heat systems, and so combustion efficiency is discussed first. Boilers are discussed next, since they are the major source of steam. Steam and process heat discussion follow. Within each of these chapters efficiency measures are divided into two main categories: operation and maintenance, and equipment retrofit and replacement. Operation and maintenance measures are typically inexpensive, easy to implement, and can be implemented right away. Equipment retrofit and replacement measures consist of modifications to existing equipment and/or processes, and equipment replacement and system redesign. The measures in the second category usually require a more significant capital expenditure and are more difficult and time-consuming to implement, but generally result in larger energy savings. It should be noted that, before implementing any measure (especially equipment replacement and system redesign measures), it is important to verify that the measure meets financial criteria, such as an acceptable payback period, return on investments, and/or benefit-to-cost ratio. Sections 2 through 5 each end with a case study illustrating energy savings that can be achieved with by implementing specific efficiency measures. Section 6 describes a few of the trends pertaining to efficient fossil-fuel use. The trends are categorized by the system type (i.e., combustion, boilers and steam, and process heat).



## 2. Combustion

### 2.1. Perspective

Increasing fuel costs, regulatory issues, and competition are driving the need for more efficient combustion systems. Combustion systems are widely used in industrial processes such as boilers, furnaces, incinerators, and power generation. The main two end-uses of combustion systems are boilers and process heat. Boilers and process heat account for roughly 70% of fossil-fuel end-use in the manufacturing sector. Because of their prevalence in industry, the efficient use of combustion systems presents an enormous potential for energy savings. The next section of this chapter discusses the main energy-efficiency opportunities for combustion system; these opportunities are also summarized in Table 1. The final section of the chapter is a case study that demonstrates how the presence of excess oxygen reduces the combustion efficiency.

| **Operation and Maintenance** |
| --- |
| Adjust burners to yield the correct air-to-fuel ratio to optimize combustion efficiency |
| Check the combustion parameters regularly with analyzing equipment |
| Establish an adequate schedule for burner maintenance |
| Use the correct grade of fuel for maximum combustion efficiency |
| Consider alternate fuels to reduce costs and improve efficiency |

| |
|---|
| Insure that oil in oil-atomized systems is heated to the correct temperature for good atomization |
| **Equipment Retrofit and Replacement** |
| Install an advanced control system to analyze and regulate oxygen levels and other emissions |
| Replace inefficient burners with new efficient low-excess air burners |
| Preheat the combustion air with stack gas heat recovery to improve combustion efficiency |
| Consider switching to fluidized bed combustion if feasible |
| Install turbulators in the tubes of fire tube boilers to induce turbulent flow in the hot gas stream, and increase heat transfer |

Table 1. Summary of energy-efficiency opportunities for combustion systems

### 2.2. Energy-Efficiency Opportunities

The combustion process is the foundation of various thermal systems, including boilers, process heat systems, and incinerators. Therefore, combustion improvements present a considerable opportunity for energy efficiency. This section presents the main opportunities for the efficient combustion of fuels.

#### 2.2.1. Operation and Maintenance

Operation and maintenance improvements can yield significant energy savings for combustion systems, with relatively small costs. The most important efficiency measures include proper adjustment of the air-to-fuel ratio and burner maintenance. These and other opportunities are described below.

**Burner adjustment:** Adjust burners to yield the correct air-to-fuel ratio to optimize combustion efficiency. Too much or too little air can waste fuel. Too little air causes incomplete combustion of the fuel, and unburned fuel is emitted with exhaust. Excess air increases the temperature of the flue gas, and results in a considerable amount of wasted heat. A reduction in excess air of 10% can yield an efficiency improvement of ~1% when stack temperatures are near 315 °C (600 °F). The efficiency improvement will be about one-third of one percent when stack temperatures are near 140 °C (300 °F). The ratios of air-to-fuel vary depending on the fuel type and system, and a small percentage of excess air is necessary in general. For example, for pulverized coal the desired quantity of excess air is 15–20%, which equates to 3–3.5% excess oxygen. For a forced-draft gas boiler, the optimum amount of excess air is 5–10%, or 1–2% excess oxygen.

**Continuous monitoring:** Check the combustion parameters regularly with analyzing equipment. The air-to-fuel ratio varies with season, and needs to be periodically readjusted. A ratio that works well during the summer may result in excess air during the winter. Likewise, a good ratio during the winter may yield incomplete combustion during the summer. If installing continuous monitoring equipment with automatic trim control is not feasible, check periodically with a portable analyzer. The analyzer should measure the presence of excess air and carbon monoxide. (It may also be capable of monitoring other emissions for air quality purposes.) The presence of a high carbon monoxide content indicates that incomplete combustion is occurring. The incomplete combustion could be from a poor air-to-fuel ratio or from fouled burners.

**Burner maintenance:** Establish an adequate schedule for burner maintenance. Replace damaged burner tips, and remove soot and other deposits from the burners. The deposits will inhibit heat transfer, and reduce efficiency.

**Fuel selection:** Use the correct grade of fuel for maximum combustion efficiency. Consider alternate fuels to reduce costs and improve efficiency. Explore the use of wastes or by-products for fuel.

**Oil atomization:** Insure that oil in oil-atomized systems is heated to the correct temperature for good atomization. This will improve the efficiency of combustion.

### 2.2.2. Equipment Retrofit and Replacement

Equipment retrofit and replacement opportunities include adding advanced controls, converting to more efficient burners, and recovering heat. These measures generally require more capital expenditure than operation and maintenance measures, but often yield higher energy savings.

**Improved combustion controls:** Install an advanced control system to analyze and regulate oxygen levels and other emissions. Consider installing oil atomization and viscosity controls to improve efficiency. Better controls have the potential of reducing fuel use in boilers by ~2–12%.

**Burner replacement:** Replace inefficient burners with new efficient low-excess air burners. Consider converting to air or steam atomizing burners. Replace natural draft burners with forced draft burners. Burner replacement has the potential of reducing fuel use in boilers by several percent.

**Waste heat recovery:** Preheat the combustion air with stack gas heat recovery to improve combustion efficiency.

**Fluidized bed combustion:** Consider switching to fluidized bed combustion if feasible.

**Turbulator installation:** Install turbulators in the tubes of fire-tube boilers to induce turbulent flow in the hot-gas stream, and increase heat transfer. Turbulators are small baffles that are inserted into the tubes and cause the flow to become turbulent. Turbulence increases convective heat transfer to the surface of the tubes. This measure has the potential of reducing the stack gas temperature by 28%. For every 22 ºC (40 ºF) decrease in stack temperature, there is a 1% increase in combustion efficiency. After turbulator installation, it is often necessary to readjust the burner.

## 2.3. Case Study—Reduce Excess Air to Improve Efficiency

This example demonstrates the importance of proper burner adjustment for maximum energy efficiency. Assume that prior to the installation of an advanced control system to monitor oxygen levels, a gas-fired combustion system operated with a poor air-to-fuel ratio ($AFR_1$) that resulted in 25% excess air.

Under this adverse condition, the average stack gas temperature fluctuated between 310 and 325 °C (590 and 617 °F), and the process burned gas at a rate of $7.0 \times 10^5$ GJ ($6.6 \times 10^5$ MBtu) per year ($E_1$). After the new controls were installed, the excess air was reduced to 5% ($AFR_2$), which is a more acceptable level for the gas-fired system. The calculations in eqs. (1)–(3) show the yearly energy savings ($\Delta E$) of the combustion systems with new controls.

Fractional reduction in excess air (ΔAFR):

$$\Delta \text{AFR} = \text{AFR}_1 - \text{AFR}_2 = 0.25 - 0.05 = 0.20 \qquad (1)$$

Fractional energy savings for every 10% reduction in excess air with stack temperatures near 315 °C (ES):

$$\text{ES} = \frac{1\%}{10\%} = 0.1 \qquad (2)$$

Yearly energy savings ($\Delta E$):

$$\Delta E = E_1 \times \text{ES} \times \Delta\text{AFR} = (7.0 \times 10^5 \text{ GJ}) \times 0.1 \times 0.20 = 1.4 \times 10^4 \text{ GJ} \qquad (3)$$

For this combustion system, the yearly energy savings achieved by a 20% reduction in excess air is $1.4 \times 10^4$ GJ ($1.3 \times 10^4$ MBtu).

## 3. Boilers

### 3.1. Perspective

Boilers are very important energy-intensive systems that are used in a variety of sectors, including industrial, commercial, and residential. The function of a boiler is to generate steam or hot water for process applications, HVAC, and domestic hot water. In the industrial sector, process steam generated by boilers comprises more than one-third of the total industrial demand of primary resources.

This energy use is matched only by process heat applications. The majority of boilers are powered by combustion processes; however, there are a small percentage of electric systems in use. Nonelectric boilers are fueled primarily by coal, oil, and natural gas, but the use of biomass and low-grade fuels is increasing in popularity.

The typical efficiency of a boiler is on the order of 70–85%, although this value is quite variable depending on the particular system. Section 3.2 of this chapter presents the main energy-efficiency opportunities relevant to boilers. The opportunities are also summarized in Table 2. Section 3.3 demonstrates the importance of soot removal from fire-side boiler tubes.

| |
|---|
| **Operation and Maintenance** |
| Schedule regular boiler tune-ups to maintain the burners, clean the boiler tubes, adjust the air-to-fuel ratio, recalibrate the controls, measure the carbon monoxide and other emission levels, and monitor the temperature of stack gases |
| Analyze boiler efficiency on a daily basis to insure optimum performance |
| Clean the heat transfer surfaces within the boilers to eliminate fouling and scale and to maximize heat transfer efficiency |
| Maintain the stoker grate surfaces of coal-fired units for good air distribution, and improved efficiency |
| Load the most efficient boilers first, and then follow with boilers of decreasing efficiency |
| Operate boilers on high fire settings and at peak load for maximum efficiency |
| Turn off boilers during periods of no use to save fuel |
| Adjust the temperature of hot water boilers based on systems requirements |
| Repair or replace poor insulation on the boiler jacket and on condensate and feedwater tanks |
| Check the coal grinding mills to insure that the proper fineness of coal is achieved |
| Utilize better feedwater treatment to keep water cleaner, and boiler blow-down at a minimum |
| **Equipment Retrofit and Replacement** |
| Install wall and soot blowers on coal fired boilers to improve efficiency of heat transfer |
| Install equipment to re-inject fly ash from collectors in coal-fired boilers to reduce carbon losses |
| Return condensate to boiler to reduce consumption of energy, water, and chemicals |
| Use an economizer to preheat boiler feedwater with stack gas heat recovery |
| Preheat boiler feedwater with waste heat from boiler blowdown |
| Install blowdown controls to reduce energy losses from blowdown process |
| Recover heat with direct contact condensation heat transfer |
| Reduce heat loss by utilizing stack dampers |
| Size the boiler to meet system requirements |
| Evaluate the feasibility of installing a back pressure steam turbine for cogeneration |

Table 2. Summary of energy-efficiency opportunities for boilers

-
-
-



**Bibliography**

Chiogioji, M.H. (1979). *Industrial Energy Conservation*, 603 pp. New York: Marcel Dekker, Inc. [This book has a good discussion on improving boiler efficiency, and has useful information on process-specific efficiency measures.]

Cone, C. (1980). *Energy Management for Industrial Furnaces*, 201 pp. New York: John Wiley and Sons. [This book presents information on improved furnace application, design, construction, operation and maintenance.]

Dean N.L. Jr. (1981*). Energy Efficiency in Industry,* 444 pp. Cambridge, MA: Ballinger Publishing Company. [This is a valuable reference for general information on industrial energy efficiency.]

Gottschalk, C.M. (1995). *Industrial Energy Conservation,* 121 pp. New York: John Wiley and Sons. [This is a good source for information on energy management, financial considerations, and project implementation.]

Reay, D.A. (1977). *Industrial Energy Conservation—A Handbook for Engineers and Managers*, 358 pp. Oxford, UK: Pergamon Press. [This book contains valuable general information on industrial energy conservation.]

US DOE (1999). *Industrial Combustion Technological Roadmap—A Technology Roadmap by and for the Industrial Combustion Community*, 46 pp. Washington, DC: U.S. DOE. [This report presents the research and design priorities for meeting future goals in combustion systems.]

US EPA. (1998). *Climate Wise: Wise Rules for Industrial Efficiency*, EPA 231-R-98-014, 60 pp. Washington, DC: US EPA. [This presents results from audits of 4300 industrial facilities in the U.S.]

Winer M.J. and Jackson M. (eds.) (1991). *Energy and Environmental Strategies for the 1990s,* 636 pp. Lilburn, GA: The Fairmont Press, Inc. [This book is a compilation of papers presented at the 13th World Energy Engineering Congress. Chapter 77 has a very good discussion of boiler efficiency.]

**Biographical Sketches**

**Clark Gellings'** 30-year career in energy spans from hands-on wiring in factories and homes to the design of lighting and energy systems to his invention of "demand-side management" (DSM). Mr. Gellings coined the term DSM and developed the accompanying DSM framework, guidebooks, and models now in use throughout the world. He provides leadership in EPRI, an organization that is second in the world only to the Department of Energy (in dollars) in the development of energy-efficiency technologies. Mr. Gellings has demonstrated a unique ability to understand what energy customers want and need and then implement systems to develop and deliver a set of research and development programs to meet the challenge. Among Mr. Gellings' most significant accomplishments is his success in leading a team with an outstanding track record in forging tailored collaborations—alliances among utilities, industry associations, government agencies, and academia—to leverage research and development dollars for the maximum benefit. Mr. Gellings has published 10 books, more than 400 articles, and has presented papers at numerous conferences. Some of his many honors include seven awards in lighting design and the Bernard Price Memorial Lecture Award of the South African Institute of Electrical Engineers. He has been elected a fellow in the Institute of Electrical and Electronics Engineers and the Illuminating Engineering Society of North America. He won the 1992 DSM Achiever of the Year Award of the

Association of Energy Engineers for having invented DSM. He has served as an advisor to the U.S. Congress Office of Technical Assessment panel on energy efficiency, and currently serves as a member of the Board of Directors for the California Institute for Energy Efficiency.

**Kelly E. Parmenter**, PhD is a mechanical engineer with expertise in thermodynamics, heat transfer, fluid mechanics, and advanced materials. She has 14 years of experience in the energy sector as an engineering consultant. During that time, she has conducted energy audits and developed energy management programs for industrial, commercial, and educational facilities in the United States and in England. Recently, Dr. Parmenter has evaluated several new technologies for industrial applications, including methods to control microbial contamination in metalworking fluids, and air pollution control technologies. She also has 12 years of experience in the academic sector conducting experimental research projects in a variety of areas, such as mechanical and thermal properties of novel insulation and ablative materials, thermal contact resistance of pressed metal contacts, and drag reducing effects of dilute polymer solutions in pipeflow. Dr. Parmenter's areas of expertise include: energy efficiency, project management, research and analysis, heat transfer, and mechanical and thermal properties of materials.

**Patricia Hurtado**, P. E. is a mechanical engineer with a master in thermal sciences and over 20 years experience in the energy sector. She has worked as an energy planner for more than 10 years, conducting projects related to energy conservation, pollution reduction, building analysis, engineering modeling, strategic planning, market evaluation, program development and performance assessment, distribution and retail sector analysis, privatization evaluation in the electric utility sector, as well as energy sector restructuring, rate design and analysis. Her consulting assignments have included clients in the United States, Puerto Rico, Mexico, Colombia, and Thailand. Ms. Hurtado's areas of expertise include: energy system design and analysis, engineering simulation models, end-use data and engineering analysis, economic analysis, utility resource and strategic planning, forecasting, rate design and analysis, distribution and retail sector analysis, and technology and market assessments of new products and services.