EFFICIENT USE AND CONSERVATION OF ENERGY IN THE INDUSTRIAL SECTOR

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Summary

Industry is the largest energy-consuming sector of the world. As a result, significant potential for energy efficiency and sustainability improvements exists. Considerable advances have been made in energy efficiency since 1970; however, there is still room for improvement. Current research and development are focused on sustainability through improved efficiency, reduced energy use, increased utilization of renewable resources, and maximized recovery of waste energy and materials. This topic addresses the primary and secondary energy resources for industry and provides a generalized approach to industrial energy management. In addition, industrial energy-efficiency opportunities are highlighted within the industrial energy management section. Future trends and progress toward increased industrial energy efficiency are also discussed for the categories of electricity use, fossil-fuel use, and specific process application. This topic serves as an introduction to the following four articles: *Efficient Use of Electricity in Process Operation, Efficient Use of Fossil Fuels in Process Operation, Energy Efficiency in Specific Industrial Segments, and Total Plant Energy Efficiency*.

1. Introduction

Energy is an essential part of life. Energy is not only vital for the survival of Earth and its inhabitants, but it is vital for the economies of the world. Aside from energy use for basic survival (i.e., food and shelter), energy is necessary to generate income for industrialized countries. Up until about the middle of the twentieth century, energy in the form of fossil fuels was readily available and inexpensive to obtain. As a result, energy resources were exploited, and little regard was given to efficient energy management. In the 1960s, concerns for resource depletion were beginning to increase. Studies were done in an attempt to predict the actual quantities and locations of energy resources. In the 1970s, the reality of limited resource availability hit hard. Two oil embargoes resulted in extreme increases in energy costs. The cost of crude oil increased by 10 times in less than a decade. Factors that contributed (and still contribute) to the energy crisis include uneven distribution of oil and other energy resources, exponential population growth, increased industrialization, and overall increased fuel consumption.

The lesson of the 1970s was that the rate of fossil fuel consumption had to decrease. This can be accomplished on the user side or the supply side. The three main ways to reduce fossil-fuel consumption on the user side are (a) increase energy management efforts and decrease fuel consumption for a given quantity of output, (b) redesign existing processes and switch to alternate fuel sources, and (c) reduce fuel consumption by “sacrificing” or eliminating energy-intensive processes. Of the three options, the first yields the fastest results without having to compromise much on the desired output. The use of alternate fuels is also a viable approach, but it can require more capital expenditure since many new technologies are still in the developmental stages. Sacrificing is another approach that may be suitable in some circumstances, such as by reducing light levels in areas that do not require high illumination; however, it is not economically practical for the national economy to shut down all energy-intensive processes. On the supply side, extracting harder-to-reach supplies and converting to alternative fuels can alleviate fossil-fuel limitations. But, when compared to user-side changes, supply-side changes take more time to have an impact. Energy management on the user side can buy time for future development of efficient processes and fuel substitutions. Efficient energy management on the user side is not only a very responsible approach in terms of fuel conservation and reduced environmental impacts, but it is also economically sound. Reduced fuel consumption results in reduced operating costs, reduced pollution control costs, and increased industry competitiveness. It also enables more independence from external energy supplies, and can thereby release international tensions.

Industry is the largest consumer of energy resources worldwide. In fact, in the United States, industry currently accounts for 37% of total energy consumption (see Figure 1). The next largest energy consumer is the transportation sector, comprising 27% of total consumption.

The residential and commercial sectors of the United States make up the balance of energy consumption, with 19% and 17% of total usage, respectively. In Japan, industry has an even larger share of energy consumption. Figure 2 shows that 50% of Japan's energy is consumed by industry. The high percentage results from the high-energy-intensive nature of Japan's industries and from the relatively small size and favorable climate conditions of the country.

The industrial sectors of Canada (Figure 3) and Germany (Figure 4) each comprise about one-third of total energy consumption. Because of industry's large share of energy utilization, the development and implementation of industrial energy-efficiency measures has a significant potential for global energy savings.

Industrial efficiency measures are aimed at increasing sustainability through reduced energy use, increased recovery of waste energy and materials, improved thermodynamic efficiencies, and increased utilization of renewable resources.

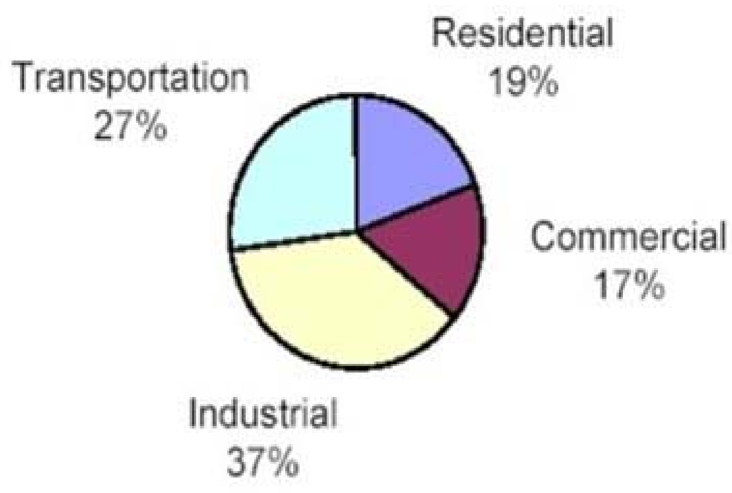

Figure 1. Total energy consumption by sector, 11-month total for 2000 (United States) Source: Data compiled from Energy Information Administration (EIA), US Department of Energy (US DOE), (2001), Monthly Energy Review, Table 2.4, available on-line at www.eia.doe.gov/emeu/mer/

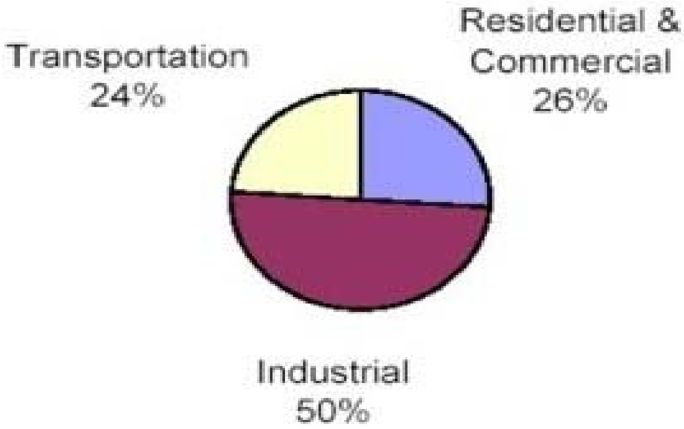

Figure 2. Total energy consumption by sector, 1992 (Japan).
Source: Data compiled from International Energy Agency. (1994). *Industrial Energy Efficiency: Policies and Programmes*, 335 pp. Paris, Organization for Economic Cooperation and Development (OECD), International Energy Agency (IEA), pg. 25 and Ministry of International Trade and Industry (MITI), Japan, 1992

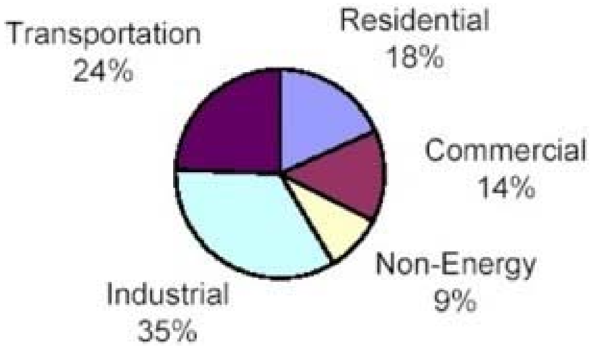

Figure 3. Total energy consumption by sector, 1992 (Canada)
Source: Data compiled from International Energy Agency. (1994). *Industrial Energy Efficiency: Policies and Programmes*, 335 pp. France: OECD/IEA, pg. 39

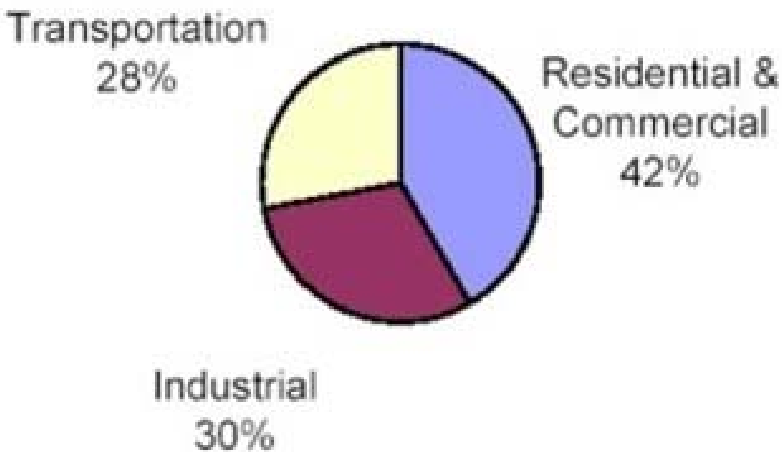

Figure 4. Total energy consumption by sector, 1990 (Germany)
Source: Data compiled from International Energy Agency. (1994). *Industrial Energy Efficiency: Policies and Programmes*, 335 pp. France: OECD/IEA, pg. 181

The industrial sector is comprised of a large variety of industries, such as the agricultural, forestry, fishing, mining, construction, and manufacturing industries. The quantity of energy consumed by specific industries within the sector ranges from moderate to quite high. The manufacturing industries have particularly high energy-use intensity. The industries of prevalence in each country vary with location. Each country has its own unique industry distribution. For example, Figure 5 shows the total energy consumption values by industry in the manufacturing subsector for the United States in 1998. The predominant energy consumers, in order of energy consumption, are (a) the petroleum and coal industry, (b) the chemical industry, (c) the paper industry, (d) the primary metals industry (including aluminum and stainless steel production), (e) the food industry, and (f) the nonmetallic mineral products industry (including glass production). Energy-efficiency opportunities for these six industries, with the exception of the food industry, are discussed in the chapter *Energy Efficiency in Specific Industrial Segments*. In Japan, the chemical industry and the iron and steel industry are the major energy consumers (Figure 6). In Canada, the pulp and paper industry dominates energy consumption (Figure 7).

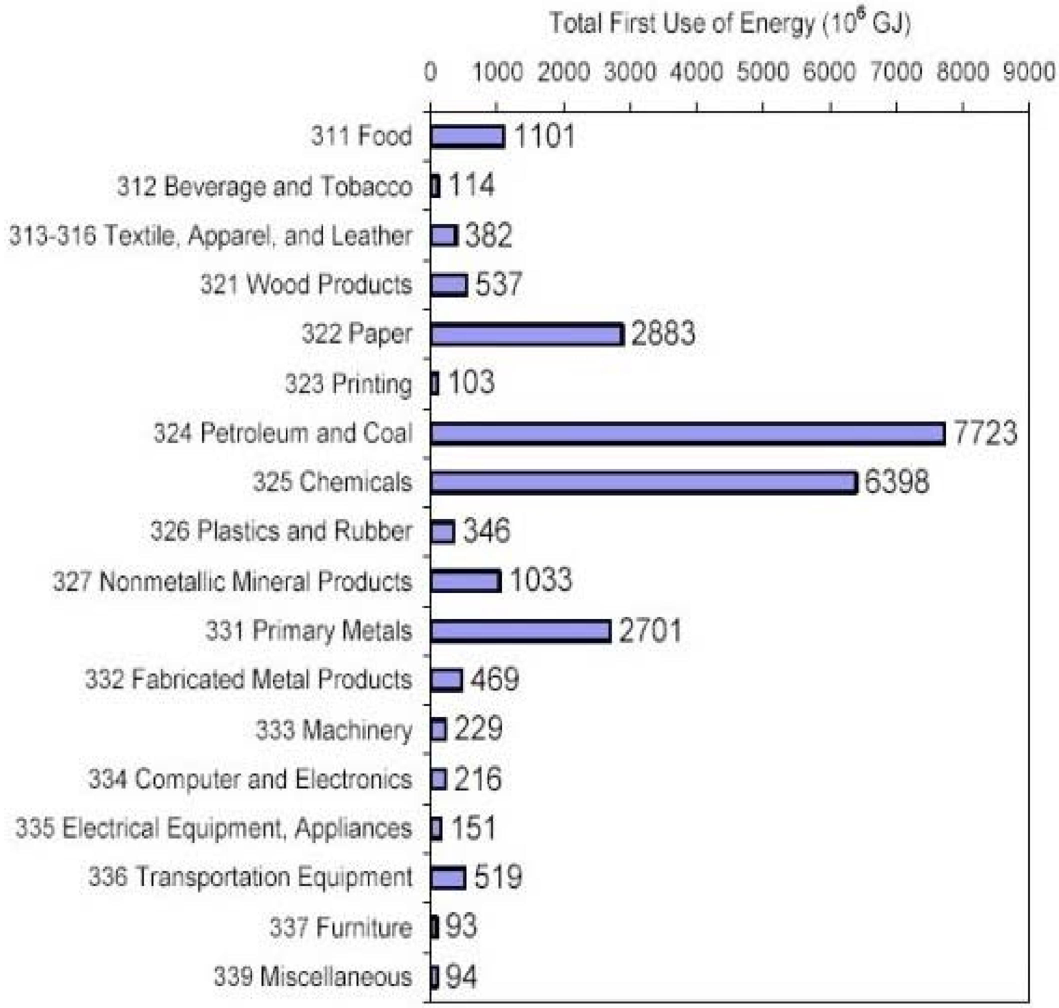

Figure 5. Total energy consumption by manufacturing industry, 1998 (United States)
Source: Data compiled from EIA, 1998 Manufacturing Energy Consumption Survey, Table N1.2

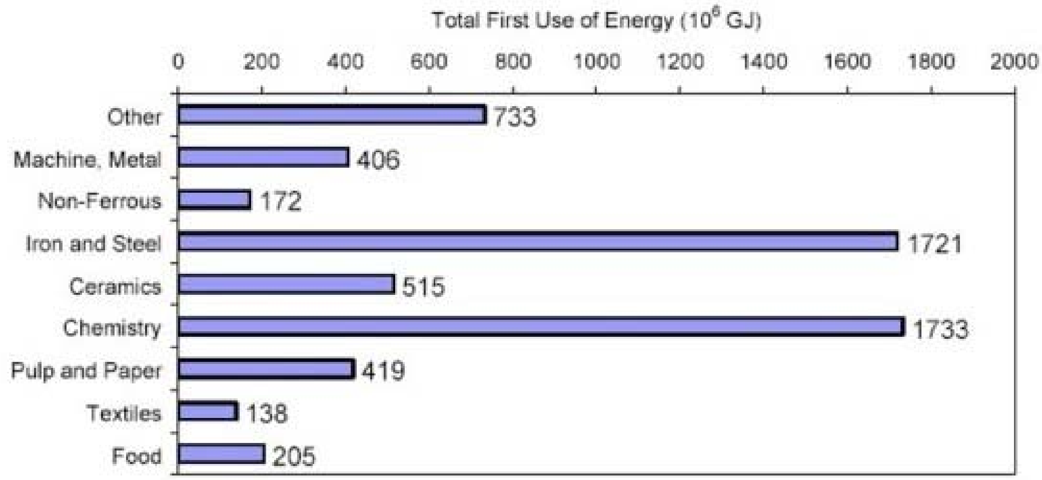

Figure 6. Total energy consumption by manufacturing industry, 1991 (Japan)
Source: Data compiled from International Energy Agency. (1994). *Industrial Energy Efficiency: Policies and Programmes*, 335 pp. France: OECD/IEA, pg. 27 and *Energy Balances in Japan*, Institute of Energy Economics, Japan

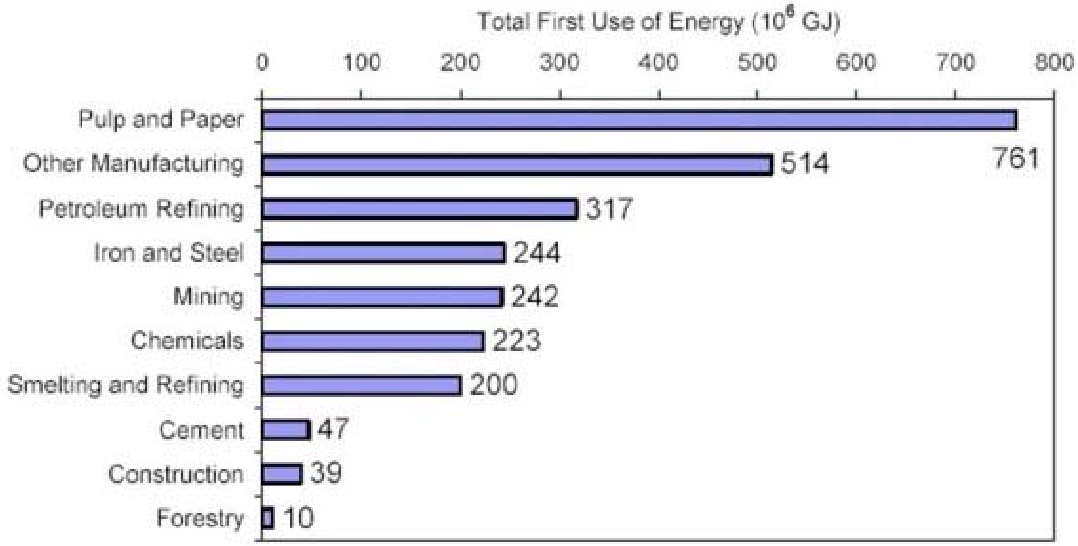

Figure 7. Total energy consumption by industry, 1992 (Canada)
Source: Data compiled from International Energy Agency. (1994). *Industrial Energy Efficiency: Policies and Programmes*, 335 pp. France: OECD/IEA, pg. 40

This topic addresses the efficient use and conservation of energy in the industrial sector. It should be mentioned that it is not thermodynamically correct to state that energy is "used" or "consumed" since energy is always conserved. Instead, it is more rigorously correct to state that energy "quality" or "exergy" is consumed. Exergy is a measure of the available work associated with an energy form. (See chapters under *Efficient Use and Conservation of Energy* for a more thorough discussion of exergy.) Energy forms with high quality, or exergy, include fossil fuels, electricity, and high-temperature and high-pressure thermal energy. Waste heat is a low-quality energy form. In this text and the articles that follow, the terms “energy use” and “energy consumption” are loosely used and are meant to imply the conversion of energy to a lower quality form. Similarly the terms “energy generation” and “energy production” imply the extraction, refinement, and/or conversion of one form of energy to another more useful form. Primary and secondary energy resources for industrial applications are discussed first in Section 2.

Primary energy resources consist of fossil fuels, nuclear fuels, and renewables. The main fossil fuels of interest are coal, oil, and natural gas. Nuclear fuels include uranium and thorium. Renewable resources arise from wind, wave, solar, wood, waste, geothermal, and hydropower energy. Secondary resources are useful energy forms that have been converted from primary sources. In the context of this discussion, they include recovered heat, on-site generation, and thermal energy storage.

These secondary resources are also discussed in greater detail in *Total Plant Energy Efficiency*. Section 3 describes the general procedures for establishing and maintaining an industrial energy management program. In particular, discussions regarding the organizational framework, historical data analysis, energy audits, and the evaluation, implementation, and monitoring of energy-efficiency opportunities are provided. Section 3 also includes extensive lists of energy-efficiency opportunities related to buildings, processes, grounds, and total plant energy use.

Section 4 discusses the progress and current trends of industrial energy-efficiency improvements. Energy-efficiency opportunities and trends for general and specific process operations are also presented in greater detail in the following articles within this topic: *Efficient Use of Electricity in Process Operation, Efficient Use of Fossil Fuels in Process Operation,* and *Energy Efficiency in Specific Industrial Segments.*

2. Energy Resources

The energy resources of the planet may be categorized as primary energy resources and secondary energy resources. Primary energy resources include fossil fuels, nuclear fuel, and renewable resources. The three main types of fossil fuels are oil, coal, and natural gas. There are also several other unconventional hydrocarbons (tar sands, oil shale, gas entrapped in sandstone and shale, geopressurized methane, and gas hydrates).

However, the unconventional forms are expensive and difficult to extract. The principle nuclear fuel used in reactors is uranium, although plutonium and thorium are also fissionable fuels. Renewable resources include solar, wind, wave, geothermal, wood, and waste-product energy, as well as the potential energy of dammed water (hydropower).

Figure 8 shows a breakdown of primary energy consumption for the world in 1999. Petroleum dominates worldwide consumption, comprising 40% of overall energy use. Natural gas and coal comprise 23% and 22% of total usage, respectively. Nuclear and hydropower each account for 7% of total consumption, and renewables represent the remaining 1%.

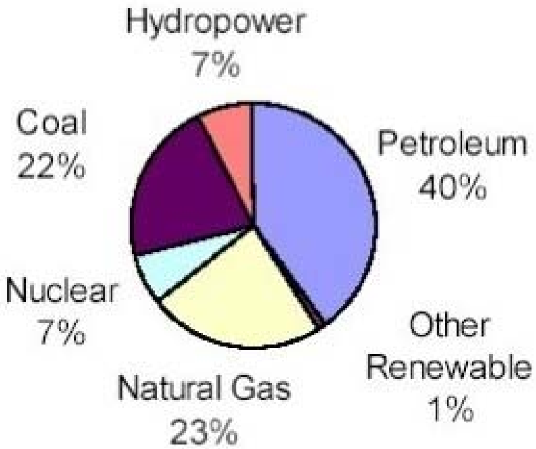

Figure 8. World consumption of primary energy by fuel type, 1999
Source: Data compiled from Energy Information Administration (EIA), US Department of Energy (US DOE), (2001), International Energy Annual, Table 1.8, available on-line at www.eia.doe.gov/iea/

A useful form of energy that arises from the conversion of a primary energy form is called a secondary energy resource. For worldwide consumption, electricity is considered a secondary energy source. Electricity is produced by the conversion of a primary energy form (i.e., fossil fuels, nuclear fuel, or renewables) to electrical energy with the use of generators, photovoltaic cells, and/or fuel cells. The majority of worldwide electricity is generated by the combustion of fossil fuels. In fact, in 1998, 63% of net electricity generation resulted from fossil-fuel combustion.

The remaining electricity is produced with renewable energy sources, such as hydroelectric power, solar energy, wind energy, wave energy, geothermal energy, or the combustion of wood or waste products. For industrial applications, electricity that is produced off-site and brought into the facility is considered a primary energy source for the industry.

In contrast, electricity produced on-site by the facility is typically considered a secondary energy. Section 2.1 discusses primary energy resources and their importance to industrial applications. Secondary energy sources are also important for industrial applications. Three of the main secondary sources arise from heat recovery, on-site generation, and thermal energy storage. Secondary resources are discussed in Section 2.2.

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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 U.S. 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 and 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's degree 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.