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Project Summary

Energy Use Patterns and Environmental Implications of Direct-Fired Industrial Processes

Benjamin L. Blaney, Jay R. Hoover, James R. Blacksmith, and Paul W. Spaite

Energy consumption patterns and environmental impacts of direct-fired processes in the industrial sector were identified. The potential effects of fuel switching in several of these processes were determined.

Annual energy consumption in the United States has totalled approximately 75 quads (1 quad = 10^{15} Btu) in recent years. Direct-fired processes in the industrial sector consume 10 percent of this energy, or seven quads per year. Most of the direct-fired energy consumption occurs in the manufacture of chemicals, petroleum products, primary metals, and mineral products (cement, glass, brick, etc.).

An estimated 60 percent of all direct-fired fuel is burned in processes whose only emissions are products of combustion. However, the more important environmental impacts are associated with the firing of the remaining 40 percent of the fuel. This energy is consumed in processes that commingle combustion gases with materials being processed. These materials include volatile metals from blast furnaces, dust from cement kilns, and fine particulate from glass furnaces.

Switching of some direct-fired processes to coal has proven feasible. Fuel switching would have a more pronounced environmental impact on those processes emitting only products of combustion.

This Project Summary was developed by EPA's Industrial Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The Environmental Protection Agency is in the process of compiling a data base of energy consumption by industrial processes and of the associated pollutant emissions. The purpose of the study summarized here was to quantitatively characterize energy consumption and emissions of direct-fired* processes. These data will allow researchers to determine the environmental implications of future energy consumption trends in industry as well as the consequences of switching of process fuel.

*For the purposes of this study direct-fired industrial processes are defined as those which burn fossil-fuel based fuels to supply thermal energy from the flame and/or products of combustion. Steam generation was not included in this category for this study because it has been extensively investigated elsewhere

The study had three principal objectives.

1. Determine the amount of direct-fired energy consumed by individual industrial processes and associated equipment.
2. Evaluate the environmental impacts associated with these processes and equipment, and
3. Determine whether future alterations in present energy consumption patterns for direct firing would have significant environmental impact.

The study focused on six major industrial manufacturing groups: food; paper; chemicals; petroleum; stone, clay and glass; and primary metals. Seventy percent of the energy consumed by direct-fired processes in industrial manufacturing can be accounted for by specific processes within these six industries. This amounts to 4.8 quads (1 quad = 10^{15} Btu), or about seven percent of total United States energy consumption in 1974.

In addition to determining industrial energy consumption on a process-specific basis, the study estimated the total energy consumed in direct-fired processes in these six industries as well as in all other manufacturing industries. This was done indirectly by taking the difference between total manufacturing energy consumption and energy consumption in other than direct-fired end uses (i.e. electricity production, process steam, feedstocks and metallurgical reduction). By comparing the resulting, indirectly determined, overall direct-fired energy use for a given industry with a total consumed by all direct-fired processes identified for that industry, an independent check was obtained on whether all significant direct-fired processes had been identified for that industry.

The data points used for process-specific annual energy consumption spanned the period from 1971-1977; it was not possible to create a complete data set for one calendar year. However, with one exception, there was less than a 10 percent variation in the total energy consumed by the six major industries during this period, and therefore the data collected should be adequate for identifying the trends sought by this project. The one exception was the chemical industry where a 20 percent increase in total energy consumption and a 17 percent increase in direct-fired energy consumption occurred between 1971 and 1977. This increase in the chemical industry parallels the growth in products from this industry, especially in the organic chemicals segment. Therefore, the energy consumed per unit of product during the 1971-1977 period was assumed to remain fairly constant.

The pollution profiles for the direct-fired processes are only described qualitatively in the report. There are two reasons for this. First, the study was intended to emphasize the collection of energy consumption data. Secondly, as noted below, it was difficult to obtain quantitative factors for all the processes involved, frequently because these factors varied widely for a given process depending upon operating conditions. Therefore, only a qualitative discussion of emissions is provided. However, even this qualitative discussion concludes that changes in process fuel type will have little impact on emissions except in a very limited number of cases.

Results

Energy Consumption

Table 1 shows the amounts of energy consumed annually for various end uses within the six major manufacturing groups investigated, as well as for other manufacturing industries. Direct-fired processes account for 7 quads of consumed energy. This is 30 percent of all energy consumed by manufacturing industries and 10 percent of all energy consumed annually in the United States. It can be seen from the table that four of the major manufacturing industrial groups (SIC's 28, 29, 32 and 33) account for practically all of the direct-fired energy consumption. Also, direct firing supplies a large portion of all the process energy requirements for these four groups.

An energy analysis was also performed on the major processes within these six industrial groups. Table 2 presents the amounts of energy consumption which could be accounted for within each industry based on this process-specific analysis. The table shows that over 60 percent of the energy consumed in all manufacturing operations was accounted for by specific processes and that the energy accounted for in specific end-use categories ranged from 42 to 89 percent.

Of the greatest interest to this project was the association of 69 percent of the direct-fired energy consumption by all manufacturing industries with a specific process within the six major industrial groups. This amounts to 4.8 quads of annual energy consumption and is accounted for by 200 direct-fired processes. Further analysis showed that 27 of these processes accounted for 61 percent (4.3 quads) of all direct-fired energy consumption. These processes are listed in Table 3. Each consumes at least 0.03 quads of energy per year.

Pollutant Impacts

Approximately 60 percent of all industrial direct-fired fuel (4.2 quads) is fired in processes that emit only products of combustion. This amount is small compared to the 15 quads/year burned by utility boilers and the 10 quads/year burned in industrial and commercial boilers. In addition, direct-fired processes burn mostly gas or oil. Therefore, they do not appear to be serious contributors to the national burden of pollution from combustion products. However, actual emission data are limited, and local effects from operations such as refineries or other installations with large fuel consumption may be significant—either for the operations' generation of NO_x and SO_x or because the operations emit products of incomplete combustion.

The remaining 40 percent of direct-fired fuel (2.8 quads/year) is fired in processes, such as cement kilns and reverberatory furnaces, which permit commingling of the combustion products with dust and volatiles evolved by materials charged to the process. Discharges of these process contaminants do not appear to have been fully characterized.

For example, copper smelting operations discharge large quantities of dust and SO_x and other contaminants, such as volatile metals. Hydrocarbons, originating from ore flotation agents and introduced with the ore concentrate, are also believed to be present in the off-gases in significant amounts. While it is not known whether hydrocarbons or trace metals such as arsenic and cadmium are present in quantities that constitute an environmental threat, further investigation is felt to be necessary. Also, better knowledge of the content of raw materials being fed to direct-fired processes would be useful in understanding the potential for impacts from such processing.

Major environmental impacts result from direct firing of fuel in the primary metals industry group, especially in the

Table 1. *Fuel Use and Purchased Electricity for the Six Major Manufacturing Industry Groups, 10^{12} Btu/Yr*

Industry group	SIC	Year	Purchased electricity	Self-generated electricity	Steam	Direct-fired	Feed-stocks	Metallurgical reductant	Total
Food	20	1971	371.7	27.3	720.3	53.5	—	—	1,172.8
		1977	448.4	24.6	775.4	45.9	—	—	1,294.3
Paper	26	1971	367.5	266.5	1,631.1	54.5	—	—	2,319.6
		1977	454.7	287.4	1,602.2	51.1	—	—	2,395.4
Chemicals	28	1971	1,046.1	205.4	680.4	1,348.0	1,891.8	—	5,171.7
		1977	1,602.3	138.7	729.9	1,583.4	2,177.0	—	6,231.3
Petroleum	29	1971	248.8	56.7	758.6	2,169.4	—	—	3,233.5
		1977	324.6	46.5	667.6	1,943.6	—	—	2,982.3
Stone, clay, and glass	32	1971	260.9	9.4	110.9	1,029.1	—	—	1,410.3
		1977	336.9	4.6	100.7	1,051.7	—	—	1,493.9
Primary metals	33	1971	1,285.3	258.4	200.5	1,556.5	—	1,975.0	5,275.7
		1977	1,632.6	139.6	355.0	1,493.0	—	1,845.6	5,465.8
Other		1971	1,855.9	45.2	1,047.4	717.1	—	—	3,665.6
		1977	2,299.8	22.7	1,142.0	794.2	—	—	4,258.7
Total		1971	5,436.2	868.9	5,149.2	6,928.1	1,891.8	1.975.0	22,249.2
		1977	7,099.3	664.1	5,372.8	6,962.9	2,177.0	1,845.6	24,121.7

Table 2. *Summation of Process Energy Analysis for the Six Major Industry Groups[1] 10^{12} Btu/Yr*

Industry group	SIC	Electrical[2]	Process steam	Direct-fired	Feed-stocks	Metallurgical	Total[4]
Food	20	471.0	671.4	155.0	—	—	1,297.4
Paper	26	634.0	1,645.8	39.7	—	—	2,319.6
Chemicals	28	530.0	720.7	494.4	1,945.8	17.4[3]	3,708,3
Petroleum	29	175.4	486.5	2,010.1	—	—	2,672.0
Stone, clay, and glass	32	199.8	—	829.0	—	—	1,028.9
Primary metals	33	1,210.0	240.5	1,300.6	—	1,353.5	4,104.5
Total[4]		3,220.2	3,764.9	4,828.8	1,945.8	1,370.9	15,130.7
% of Total Manufacturing Energy Consumption[5]		42%	70%	69%	89%	74%	63%

[1]Methodology and sources are presented in Appendix B of project report.
[2]Estimate includes purchased and self-generated electricity converted at 10,500 Btu/kWh.
[3]Estimate includes coke used in the production of elemental phosphorus and sodium metal.
[4]Numbers may not add to exact totals due to independent rounding.
[5]Based on 1977 totals in Table 1.

iron and steel industry. One of the most significant sources of pollution in the iron and steel industry is the coke oven process. Emissions from this process include unburned hydrocarbons and SO_x. Other significant polluting processes in the iron and steel industry are blast furnace pig iron production, steelmaking, and sintering. The metal emissions from these processes include particulates, volatile metal fumes, CO and SO_x.

The most important pollutant resulting from direct-fired processes in the mineral processing industries is fine particulate from cement, lime, and glass production. These particulates are primarily from processed material and are affected only slightly by type of fuel used.

Finally, the impact of fuel change on emissions from direct-fired processes are likely to be small in most cases. There are several reasons for this. First, oil and gas will continue to be the principal fuels of choice because in many cases they are available as by-products from other processes, such as in the petroleum industry, or they are required because of their cleanliness. The use of gas for alumina calcining is an example of the latter situation. There is little likelihood of switching to coal in this process because the alumina product from the kiln must be fairly pure.

Second, the impact of fuel switching on emissions in the cases where the emissions from the fuel are commingled with those from the raw material being processed (e.g. in lime calcining) are expected to be minor because the

Table 3. *Summary of Major Energy Consuming Direct-Fired Processes*

Raw Material	SIC	Industry	Process/Operation	10^{12} Btu/yr
Oil and gas	2911	Petroleum refining	Atmospheric distillation	529.3
Iron ore	331/332	Iron and steel	Slabbing and blooming - reheat furnaces (271.5) - soaking pit (156.3)	427.8
Oil and gas	2911	Petroleum refining	Catalytic reforming	407.1
Limestone	3241	Hydraulic cement	Calcining	324.5
Oil and gas	2911	Petroleum refining	Vacuum distillation	296.5
Iron ore	331/332	Iron and steel	Blast furnace	267.3
Oil and gas	2911	Petroleum refining	Coking (delayed)	266.2
Oil and gas	2911	Petroleum refining	Fluid bed catalytic cracker	229.2
Sand and gravel	3211/3221 /3229	Glass	Melting	227.2
Oil and gas	2869	Organic chemicals	Ethylene/propylene (thermal cracking)	194.5
Limestone	3274	Lime	Calcining	145.9
Iron ore	331/332	Iron and steel	Coking	144.8
Oil and gas	2873	Agricultural chemicals	Ammonia steam reforming	139.0
Oil and gas	2911	Petroleum refining	Gas/oil hydrotreating	119.9
Iron ore	331/332	Iron and steel	Heat treatment	111.5
Iron ore	331/332	Iron and steel	Steelmaking - open hearth furnace (71.8) - basic oxygen furnace (14.4)	86.2
Oil and gas	2911	Petroleum refining	Naphtha hydrotreating	77.8
Clays	3251	Brick	Drying/firing	52.8
Oil and gas	2865	Organic chemicals	Benzene	44.8
Oil and gas	2911	Petroleum refining	Alkylation	42.8
Iron ore	331/332	Iron and steel	Cast iron melting - cupola furnace (21.7) - induction furnace (16.1)	37.8
Oil and gas	2895	Carbon black	Furnace process	35.7
Copper ore	3331	Primary nonferrous metals	Copper smelting	34.7
Bauxite	3334	Primary nonferrous metals	Alumina calcining	30.0
				4,273.3

principal pollutant is usually particulates from that material. Therefore a switch to coal in such a situation will not have a large impact on particulate emissions, although emissions of SO_x would increase.

There are several processes where future fuel switching could occur with significant impacts on process emissions. The furnaces used for heating of semi-finished steel in slabbing and blooming and in heat treatment processes have emissions which are solely products of combustion. Therefore, firing of fuels other than conventional fuels (natural gas, fuel oil, and coke oven gas) could have significant effect on type and amounts of emissions. The fact that these furnaces account for 0.54 quads of energy consumption makes their potential impact of particular concern. Similarly, a switch in fuel for copper reverberatory smelting from oil or gas to coal could result in significantly increased SO_x and NO_x emissions.

In at least one case, emissions may be decreased by a change in the process which results in fuel switching. At present there are two furnaces used for cast iron melting: cupola and induction furnaces. Cupola furnaces are controlled sources of trace and volatile metals. The recent trend toward increased electric induction melting has the effect of lowering emission levels at the facility, while improving product quality. While increased emissions will result at the electric power plant which powers the induction furnaces, these emissions can be controlled more cost-effectively than at the cast iron melting operation itself.

Benjamin L. Blaney is the EPA author and also the EPA Project Officer (see below); Jay R. Hoover and James R. Blacksmith are with Radian Corporation, Austin, TX 78766; Paul W. Spaite is a consultant, 6315 Grand Vista Avenue, Cincinnati, OH 45213.

The complete report, entitled "Energy Use Patterns and Environmental Implications of Direct-Fired Industrial Processes," (Order No. PB 81-234 221; Cost: $9.50, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650

The EPA Project Officer can be contacted at:

Industrial Environmental Research Laboratory
U.S. Environmental Protection Agency
Cincinnati, OH 45268

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