Industrial Energy Efficient Technology Guide 2007

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PRODUCT DESCRIPTION

This report updates the *Industrial Energy Efficient Technology Reference Guide*, previously known as the *Electrotechnology Reference Guide*. The last version of the *Electrotechnology Reference Guide* was published in 1992. This 2007 edition specifically updates information on industrial-sector energy consumption and the status of energy efficient technologies.

Results & Findings

The Guide outlines energy consumption for 21 manufacturing segments and provides detailed information on electricity and natural gas use for each segment. Electric utility competition from the natural gas industry is examined, including an analysis of gas-fired cogeneration. End-use applications of both electricity and natural gas within U.S. industrial sectors are analyzed. Details are provided on electricity consumption for motor drives, electrolytics, process heating, and lighting for all 21 sectors, with a major emphasis on motor drives and process heating. Current and emerging efficient electric technologies are identified and categorized into one of the following: process heating, electrolytic, or machining and welding.

Challenges & Objective(s)

The U.S. manufacturing sector continues to face international competition, especially from China. There also is increasing environmental pressure to reduce criteria pollutants and greenhouse gases. Faced with growing international competition, U.S.-based industry needs to continue improving by reducing production costs while maintaining production levels and improving product quality. To help retain its competitiveness, U.S. industry needs to become more innovative and apply newer manufacturing technologies that improve productivity.

The electric industry needs to maintain a strong industrial customer base despite increasing competition from cogeneration, non-utility electricity suppliers, “green power” from renewables, and the natural gas industry. Competition from these energy sources has grown significantly over the past twenty years, as have environmental issues such as greenhouse gas concerns and renewable portfolio standards. To maintain market share, the electric industry needs to become more customer-oriented by developing competitively priced electric services that help their industrial customers improve their productivity, which will improve their value to those customers. Implementation of electrotechnologies can improve productivity in the manufacturing sector.

Applications, Values & Use

This document will assist utility analysts in identifying industrial markets that can benefit from energy efficient technologies and in understanding their potential within such markets. With these insights, utilities can better coordinate working relationships with their industrial customers, manage their loads more effectively, market new service and power options, develop a competitive advantage over competing energy sources, and help stimulate their local economy. This guide’s format also provides a framework that utilities can use to assess electrotechnology applications within their own service territories.

EPRI Perspective

The U.S. manufacturing sector electricity has been and continues to be an important consumer of energy. One of the main trends from 1994 to 2002 was the growth in electricity consumption. The growth in the manufacturing sector's relative share of electricity consumption may have been influenced by the amount of electricity purchased from non-utility suppliers, which grew significantly over this period. The decline in electricity prices during much of the 1990s coupled with the increase in the costs of other fuels also made electricity an attractive alternative. As the number of electric-based technologies continues to grow, the importance of electricity to the manufacturing sector will continue to grow.

Approach

Most of the source data in Sections 2 and 3 of the Guide come from the Energy Information Administration's (IEA's) Manufacturing Energy Consumption Survey (MECS). MECS is performed every five years, with a three-year gap between the survey and the report. Many of the Guide's descriptions of process heating electrotechnologies are based on work done to develop *Improving Process Heating Performance: A Sourcebook for Industry, 2nd Edition*, U.S. Department of Energy, Industrial Technologies Program, 2007.

Keywords

Industrial energy efficiency
Cogeneration
Combined heat and power
Manufacturing
Electrolytics
Processing

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SUMMARY

Introduction

This Report is an update of Industrial Energy Efficiency Reference Guide. The prior editions were called Electrotechnology Reference Guide, and were based on the premise that:

> *American industry faces a major challenge in restoring its competitive position in world markets; the critical need to simultaneously improve product quality and reduce production costs. To meet this challenge, American industry must apply the same technological innovations that previously made the United States the world's leading industrial nation.*
>
> *A similar challenge faces the electric industry today; the challenge to maintain a strong industrial base in the face of increase competition from cogeneration, independent power producers, and the natural gas industry. This competition has forced electric utilities to become more market oriented and to develop competitively-priced electric services which help to improve their customer's productivity. These services differ from the traditional provision of electricity as an end-product in itself in that they are targeted to meet specific and well-defined customer application needs. Many of these needs are best met through electrotechnologies.*

Many of these challenges have been met by U.S. industry and the electric utility sector over the past 20 years, but new challenges have arisen. The current premise has changed to meet these new challenges:

> *The U.S. manufacturing sector continues to face international competition, especially from China. There is also increasing environmental pressure to reduce criteria pollutants and greenhouse gases. Faced with growing international competition, U.S.-based industry needs to continue improving by reducing production costs while maintaining production levels and improving product quality. To help retain its competitiveness, U.S. industry needs to become more innovative and apply newer manufacturing technologies that improve productivity.*
>
> *The electric industry faces needs to maintain a strong industrial customer base notwithstanding increasing competition from cogeneration, non-utility electricity suppliers, "green power" from renewables, and the natural gas industry. Competition from these energy sources has grown significantly over the past twenty years, as have environmental issues such as greenhouse gas concerns and renewable portfolio standards. To maintain market share, the electric industry needs to become more customer-oriented by developing competitively priced electric services that help their industrial customers improve their productivity, which will improve their value to those customers. The implementation of electrotechnologies can improve productivity in the manufacturing sector.*

Electrotechnologies are technologies that consume electricity to manufacture or transform a raw material into a finished product. Electrotechnologies can be used in a wide variety of industrial processes. In most electrotechnologies electromagnetic, electrochemical, and/or electrothermal effects are inherent parts of the process. In many applications electricity offers some advantages over other energy sources (known as 'form value') based on its unique characteristics such as on-demand availability, work-site efficiency, precise control, cleanliness, reliability and security of supply. Electrotechnologies are able to capitalize on electricity's high form value.

Electrotechnologies may compete against fossil fuel technologies, renewables or sometimes against other electrotechnologies. Some electrotechnologies face stiff competition and others have little or no effective competition. The terms of competition for electrotechnologies are dictated by manufacturing (production) requirements, industry economics, and the cost and performance characteristics of the electrotechnologies themselves as well as the competing technologies.

Objectives

The last version of the Electrotechnology Reference Guide was published in 1992. This effort is not a true revision of that document, but rather an update on industrial sector energy consumption and the status of electrotechnologies.

This document will assist utility analysts in identifying the industrial markets that can benefit from the application of electrotechnologies and to understand their potential within such markets. With these insights utilities can better coordinate working relationships with their industrial customers, manage their loads more effectively, market new service and power options, develop a competitive advantage over competing energy sources, and help stimulate their local economy. In addition, this guide's format (industrial analysis, end-use applications analysis and electrotechnology descriptions) provides a framework that utilities can use to assess electrotechnology applications within their own service territories.

The objectives of this document are to provide an overview of industrial energy use with a detailed examination of electricity and natural gas consumption so individual utilities can develop an understanding of their industrial customers' parameters and energy needs and assess electric utility competition from customer self-generation, non-utility electricity suppliers, and the natural gas industry; provide a disaggregation of industrial energy use by sector and application, and give an introduction to electric-based solutions.

Overview of this Document

Section 2, Industry Analysis, outlines the energy consumption for each of the four industry categories and twenty-one manufacturing segments. Detail is provided on electricity and natural gas use for each segment. Electric utility competition from the natural gas industry is examined, including an analysis of gas-fired cogeneration.

Section 3, End-Use Application Analysis, examines end-use applications of electricity and natural gas within U.S. industrial sectors. Details on electricity consumption for motor drives, electrolytics, process heating and lighting are analyzed for all 21 sectors. Particular emphasis is given to motor drives since this is currently the largest industrial electricity-consuming application, and process heating since it is the end-use application that has the greatest potential for new uses of electricity. Industrial use of natural gas is categorized according to its application to process heating, cogeneration, space heating, and use as a feedstock. Major process heating uses of natural gas are also examined.

Most of the source data in Sections 2 and 3 came from the Energy Information Administration's (IEA) Manufacturing Energy Consumption Survey (MECS). The MECS is performed every 5 years, with a 3 year gap between the survey and the report. The data in Section 2-3 is for 2002, which was published by IEA in 2005. 2007 data will not be published until 2010.

Section 4, Energy Efficient Technologies, identifies current and emerging efficient electric technologies and categorizes them into the following categories: process heating, electrolytic, and machining & welding. While some electrotechnologies are cross-cutting (can be used in more than one category), some are specific to certain types of industrial processes and those are categorized according to their industry suitability. Portions of many of the descriptions of the process heating electrotechnologies in this document are based on work done to develop *Improving Process Heating Performance: A Sourcebook for Industry, 2nd Edition*, U.S. Department of Energy, Industrial Technologies Program, 2007.

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INDUSTRY ANALYSIS

The U.S. manufacturing sector electricity has been and continues to be an important consumer of energy. One of the main trends in the 1994 to 2002 period is the growth in electricity consumption. In 1994, industrial electricity consumption was 791 billion kWh, representing 12.5% of the net end-use share of energy used in manufacturing. By 2002, manufacturing electricity consumption had risen to 844 billion kWh and accounted for 12.7% of the sector's net end-use share of energy consumption. The growth in the relative share of electricity consumption may have been influenced by the amount of electricity purchased from non-utility suppliers, which grew significantly over this period – from 22 billion kWh in 1994 to 104 billion kWh in 2002. In addition, the decline in electricity prices during much of the 1990s coupled with the increase in the costs of other fuels, made electricity an attractive alternative. This is seen in Figure 2-1 and supported in the section on trends below. As the amount of electric based technologies continues to grow, the importance of electricity to the manufacturing sector will continue to grow.

Trends in Industrial Electricity Consumption, 1994 to 1998

- Industrial electricity consumption in 1998 was 3.7 percent higher than in 1994.
- Coal use as a feedstock falls as the electric arc process for the production of raw steel rises by 24% between 1994 and 1998 and the basic oxygen process falls by 2% during this timeframe.
- Onsite electricity generation in 1998 was slightly lower than in 1994.
- Average industrial electricity prices in 1998 were 6 percent lower than in 1994 and continued to fall until 2000 and 2001.

Trends in Industrial Electricity Consumption, 1998 to 2002

- Industrial electricity consumption in 2002 was 2.9 percent higher than in 1998, but 2.3 percent lower from 2000.
- Coal use as a feedstock rises by 3.4% between 2002 and 1998 while the use of natural gas, coke & breeze and residual oil fall by 12.8%, 12.1%, and 40.9% respectively over this timeframe.
- Onsite electricity generation in 2002 was 3.4% lower than in 1998.
- Average industrial electricity prices in 2002 were approximately 9% higher than in 1998.

Post-2002 Trends

Although not shown in any of the tables in Sections 2-3, a number of post-2002 trends are noted below:

- Natural gas costs have increased significantly from 2002-2007. The average industrial natural gas price in 2002 was around $4/MMBtu while current prices are closer to $8/MMBtu. This trend favors electrification and electrotechnologies.
- Electricity price changes have varied across the county. During deregulation, some states had rate freezes, and after the freeze, prices rose significantly (Maryland is a good example, which went from 4.0 cents per kilowatt hour in 2002 to over 10 cents per kilowatthour in 2006). Some states have had slight increases (North Carolina was 4.7 cents per kilowatthour in 2002 and only increased to 5.2 cents per kilowatthour by 2006). Average U.S. industrial electricity prices were approximately 4.9 cents per kilowatthour in 2002 and rose to 6.1 cents per kilowatthour in 2006. The average U.S. industrial increase, percentage-wise, is much less than that of natural gas, which again favoring electrotechnologies.

- Increased emphasis on greenhouse gases emissions. Many industrial companies in the U.S. are measuring and accounting for their greenhouse gas emissions and trying to reduce them. In many cases, a switch from a fossil-fueled application to an electrotechnology will reduce the overall carbon output from a process.

Because of these post-2002 trends, the current the condition for electrotechnologies relative to other technologies has never been better, especially in regions in the U.S. with low electricity prices.

Estimates of manufacturing energy consumption for 2002 are displayed in Table 2-1 by industrial category and energy use. The industrial categories include process industries, materials production, metals fabrication and non-metals fabrication. The energy uses include total purchased fuels, by-product fuels, heat and power usage, feedstock fuels and electricity. Table 2-2 lists the industrial sectors found under each of the industrial categories. By examining manufacturing energy use within the four major industrial categories (process industries, materials production, metals fabrication and non-metals fabrication) this section shows the degree and manner in which U.S. manufacturing is highly dependent on electricity.

The estimates of energy use reflect the increase in energy consumption, particularly electricity, due to fuel switching (using electricity in place of a fossil fuel) and greater electricity purchases from non-utility suppliers in the wake of the electric power industry restructuring.

Several aspects of the electric power industry make possible the increase in electricity consumption:

- **Interconnected transmission grid**. As a result of transmission access to different regions, integrated utilities are able to sell to more customers and to customers in areas outside of their traditional service territories.
- **Merchant power plants.** These are power plants that are built or established with much of their output not already committed to specific customers. Merchant plants seek the most profitable markets they can reach over the transmission grid wherever they may be found, even across state borders.
- **Power marketing.** Sales of electricity by power marketing companies have risen significantly in the past 15 years. These companies' ability and willingness to resell electricity at lower prices increases the quantities of power that are traded.
- **Wholesale power price volatility.** Severe price fluctuations in wholesale power markets can occur from hour to hour and day-to-day depending on the time of year, meteorological events, reserve margin levels, transmission constraints, plant outages and fuel supply problems. These price swings create basis differentials across regions that power marketing companies and merchant generators seek to exploit. As an example, during the month of June 2006 in California, average, real-time dispatch prices exceeded $250/MWh 176 times while in August 2006, the average, real-time dispatch prices exceeded $250/MWh just 46 times.

Electric Energy Use in the Manufacturing Sector

This section describes the eight-year trend of manufacturing energy use. In 1994, manufacturing accounted for 37.6% of electricity consumption in the U.S. By 2002, manufacturing electricity consumption still represented 33.4% of the U.S. total. While the 2002 figure shows a decline over 1994 manufacturing electricity consumption, the pattern of annual consumption varied substantially between industrial sectors. Table 2-2 shows the declines and increases in electricity consumption for the U.S. manufacturing segments at the 3-digit level. The most notable declines in electricity consumption were recorded for industrial sectors whose activity has been shrinking such as textile mills, machinery, and printing and related support. However, important increases were found in sectors whose activity has been expanding such as food, beverages, fabricated metal products, computer and electronic products, transportation equipment and plastics and rubber products. In addition, for many of these industries, the share of electricity within total energy use increased. This suggests that these sectors are either using more electric-based equipment or that they may be using more electricity as part of a fuel switching strategy.

Of the four industrial categories, none posted a decline in electricity consumption over the eight-year period. Metals fabrication experienced the largest growth at 2.15%, followed by non-metals fabrication at 1.29%, materials production at 0.42%, and process industries with 0.34%. Table 2-2 also shows the portion that electricity represents of total energy consumed for each industrial category and sector. The largest increase in electricity consumption is recorded by the metals fabrication category, which jumps from 40.4% to 43.7%, while process industries had a small decline from 7.7% to 7.3%.

One of the more striking aspects of the period's electricity use is the pattern of consumption between 1994 and 1998, and between 1998 and 2002. In 1998, manufacturing electricity consumption totaled 906 billion kWh, which shows that electricity use rose 16.5% in the first half of the eight-year period. However, between 1998 and 2002 manufacturing electricity consumption fell to 844 billion kWh, a decline of approximately 7%.

The descriptions of electricity use by industrial category and sector do not explicitly consider the electric-based technologies discussed in Section 3 or the end use applications discussed in Section 4 that are responsible for electricity consumption. While such perspectives are important in analyzing electricity use and identifying opportunities for new technologies, these relative shares of manufacturing electricity consumption provide a good initial way to understand the importance of electricity in manufacturing.

Trends in Electric Intensity

Electric intensity defined as the ratio or electricity consumption to total energy use, provides important insight into possible substitution or fuel switching of electricity for other energy sources. While Table 2-3 shows that electric intensity was fairly stable for aggregate manufacturing, certain sectors experienced important swings in their electric intensity. In some cases, these large swings are due to the change from the SIC to the NAICS classification i.e., SIC code 21 was for tobacco and allied products whereas its NAICS equivalent also include beverage production. However, in many other sectors such as food, textile mills, primary metals, fabricated metal products, computer and electronic products, machinery, transportation equipment and wood products, electricity intensity increased by more than 3%. In some cases, this increase in intensity is consistent with an increase in sector's energy consumption such as food or transportation equipment. For some sectors however, electricity intensity increased as the sector's energy use declined i.e., textile mills and machinery, which could be an indication of fuel switching within those sectors.

Role of Electricity in Manufacturing

The cost of purchased electricity is important for understanding the share of electricity in production costs. This can be seen with the ratio of electricity costs to the value of shipments. Between 1994 and 2002 the ratios of electricity costs to values of shipments were pretty stable for most industrial sectors. As a whole, manufacturing recorded a very slight decrease in the cost of electricity as a percentage of value of shipments from 1.12% to 0.99%. The ratio did rise perceptibly for a few sectors such as beverage and tobacco products, apparel and textile products, and printing. However, most sectors recorded declines, with petroleum and coal products and computer and electronics products showing the greatest declines.

Manufacturing Energy Use Components

While purchased fuels make up the majority of the energy used in manufacturing, byproduct fuels and energy sources that are used as feedstocks can represent important portions of energy consumption for many industrial sectors. This is seen in Table 2-4 where byproduct and feedstock energy use is displayed by industrial sector. Byproduct and feedstock fuel use represents over 12 trillion BTU and 35% of the primary energy consumption in manufacturing. The sectors that depend the greatest on byproduct and feedstock energy include wood products (36.2%), paper (32.9%), petroleum and coal products (45.4%), chemicals (39.7%), primary metals (31%) and electrical equipment, appliances and components (28.6%).

In 2002, the estimated amount of self-generated less sold electricity was more than 104 billion kWh, more than 12% of total manufacturing electricity consumption. This figure is slightly higher than in 1994 when it approximated 100 billion kWh and accounted for over 13% of total manufacturing electricity consumption. Two sectors account for approximately 66 billion kWh or 63% of self generated less sold electricity – primary metals and chemicals.

Natural Gas Use in Manufacturing

Of all the purchased fuels that account for non-electric manufacturing energy consumption, natural gas was the preferred fuel source as it accounted for over 60% of total non-electric manufacturing energy consumption in 2002. However, as manufacturing's use of electricity rose between 1994 and 2002, its use of natural gas declined as both a percentage of total energy consumption and in aggregate terms as seen in Table 2-5. Natural gas consumption declined by 343 trillion BTU or 5% over this period while the portion of natural gas to total energy consumption declined by 3.1% overall. The decline in natural gas consumption may be a result of the increase in natural gas costs.

Of the four industrial categories, only non-metals fabrication recorded an increase in natural gas use as a percent of total energy consumption while process industries, materials production and metals fabrication registered declines. One industrial sector in which the decline was particularly noteworthy is the chemicals sector in which natural gas use as a percent of total energy consumption fell by 12.4%. Some sectors that registered strong increases in natural gas use as a percent of total energy consumption were transportation equipment, electrical equipment, appliances and components, printing and related support, and furniture and related products.

Comparison of Growth in Use of Electricity vs. Natural Gas

As natural gas use by manufacturing declined over the 1994 to 2002 period, electricity consumption by manufacturing rose by 7.2% overall. Table 2-6 shows that there is wide variation of natural gas and electricity use growth rates within the industrial sectors. The sectors with the greatest increase in natural gas consumption include transportation equipment (3.68%), electrical equipment, appliances and components (10.71%), plastics and rubber products (2.1%), wood products (2.78%), textile product mills (16.67%) and apparel (2.88%). The sectors for which natural gas consumption declined significantly were textile mills (-4.42%), computer and electronic products (-3.09%), and machinery (-3.24%).

By comparison, electricity use increased for the majority of manufacturing sectors, resulting in an average annual rate of growth of 0.83% for all of manufacturing. The most notable increase in electricity consumption by any sector was for beverage and tobacco products at 64.4%. This is due to the fact that beverage production was not part of the SIC code for tobacco products in 1994, while in 2002 both sectors were under the same NAICS code. Other notable sector increases in electricity consumption include food (1.91%), transportation equipment (3.85%), fabricated metal products (4.78%), plastics and rubber products (2.56%), and textile product mills (3.13%). Only two sectors showed important declines in electricity consumption over the period: textile mills (-3.03%) and machinery (-2.73%).

Table 2-1: 1994 Industrial Energy Use Summary

		2002 Total Energy Use (trillion BTU)					Electricity Consumption (billion kWh)		
NAICS codes	Categories	Total Purchased Fuels & Electric Use	By-Product Fuel Use	Energy Used for Heat & Power	Energy Used for Feedstocks	Primary Energy Use	Electricity Purchases	Electric Self-Generated Less Sold	Electricity Total
311, 312, 313, 322, 324, 325	Process Industries	17,062	3,635	20,697	7450	28,147	321	47	368
327, 331	Materials Production	3,179	402	3,581	653	4,234	147	39	186
332, 333, 334, 335, 336, 339	Metals Fabrication	1,438	3	1,441	78	1,519	173	12	185
315, 316, 321, 323, 326, 337	Non Metals Fabrication	987	220	1,207	4	1,211	99	6	105
	Total	22,666	4,260	26,926	8,185	35,111	740	104	844

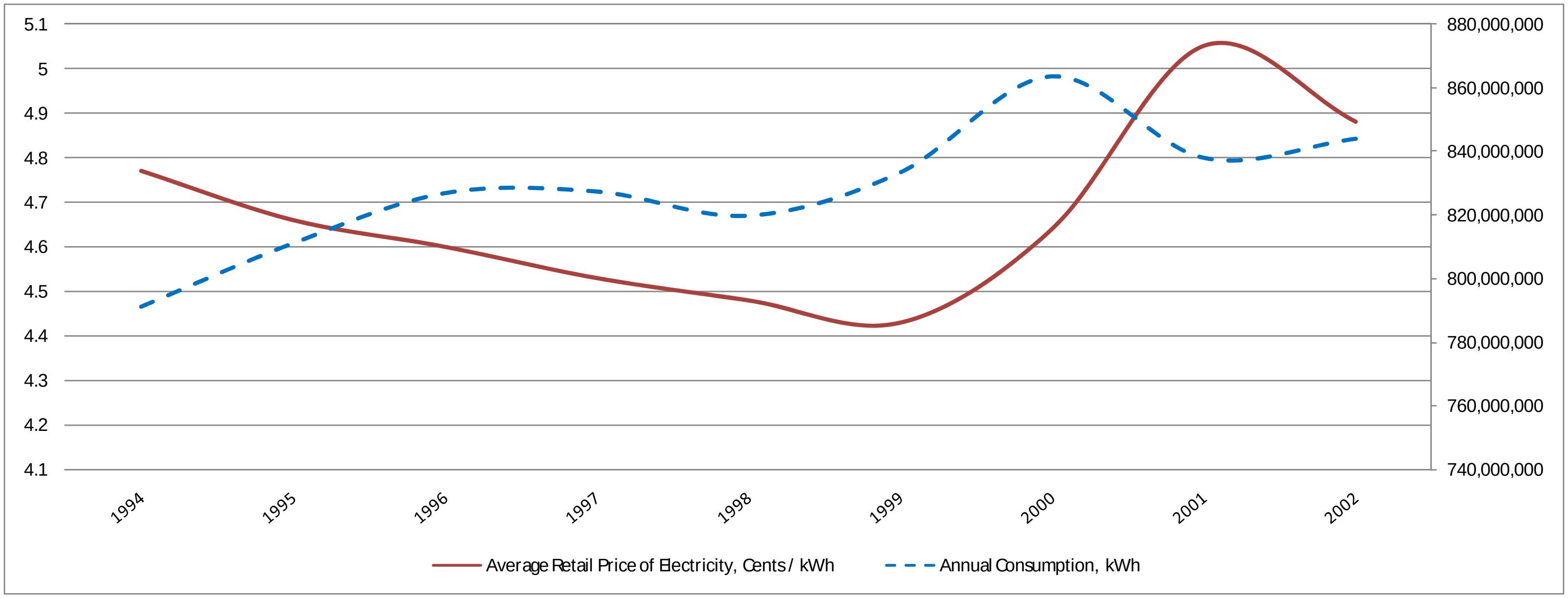

Figure 2-1: Trends in Electricity Prices and Consumption, 1994-2002

Table 2-2: Manufacturing Purchased Fuels and Electric Use by Category and Sector Ranked by Total Electric Use

NAICS code	SIC code equivalent	Industrial Sectors	Total Purchased Fuels and Electric Use						
			Trillion BTU		Billion kWh		Percent Annual Growth	Percent Electricity	
		Process Industries	1994	2002	1994	2002	1994-2002	1994	2002
325	28	Chemicals	5,328	6,465	156	160	0.32%	10.0%	8.4%
311	20	Food	1,142	1,123	59	68	1.91%	17.6%	20.7%
322	26	Paper	2,665	2,363	72	65	-1.22%	9.2%	9.4%
324	29	Petroleum & Coal Products	6,339	6,799	36	41	1.74%	1.9%	2.1%
313	22	Textile Mills	310	207	33	25	-3.03%	36.3%	41.2%
312	21	Beverage & Tobacco	51	105	1	8	64.42%	8.7%	26.0%
		Total Process Industries	15,835	17,062	357	367	0.34%	7.7%	7.3%
		Materials Production							
331	33	Primary Metals	2,464	2,120	144	145	0.09%	19.9%	23.3%
327	32	Non Metallic Mineral Products	944	1,059	36	41	1.74%	13.0%	13.2%
		Total Materials Production	3,408	3,179	180	186	0.42%	18.0%	20.0%
		Materials Fabrication							
		Metals Fabrication							
336	37	Transportation Equipment	363	429	39	51	3.85%	36.7%	40.6%
332	34	Fabricated Metal Products	367	388	34	47	4.78%	31.6%	41.3%
334	36	Computer & Electronic Products	243	201	33	38	1.89%	46.3%	64.5%
333	35	Machinery	246	177	32	24	-3.13%	44.4%	46.3%
335	38	Electrical Equip., Appliances, and Components	107	172	13	14	0.96%	41.5%	27.8%
339	39	Miscellaneous	W	71	6	10	8.33%	N/A	48.1%
		Total Metals Fabrication	1,326	1,438	157	184	2.15%	40.4%	43.7%
		Non Metals Fabrication							
326	30	Plastics and Rubber Products	287	351	44	53	2.56%	52.3%	51.5%
321	24	Wood Products	491	377	20	22	1.25%	13.9%	19.9%
323	27	Printing and Related Support	112	98	17	15	-1.47%	51.8%	52.2%
337	25	Furniture and Related Products	69	64	7	7	0.00%	34.6%	37.3%
314	23	Textile Product Mills	W	60	4	5	3.13%	N/A	28.4%
315	23	Apparel	W	30	4	4	0.00%	N/A	45.5%
316	31	Leather & Allied Products	W	7	1.0	1.0	0.00%	N/A	48.7%
		Total Non Metals Fabrication	959	987	97	107	1.29%	34.5%	37.0%
		Total Materials Fabrication	2,285	2,425	254	291	1.82%	37.9%	40.9%
		Total Industries	21,528	22,666	791	844	0.83%	12.5%	12.7%

Table 2-3: Manufacturing Purchased Fuels and Electricity Use by Sector

NAICS code	SIC code equivalent	Industry	Total Purchased Fuels and Electric Use						
			Trillion BTU		Billion kWh		Percent Annual Growth	Percent Electricity	
			1994	2002	1994	2002	1994-2002	1994	2002
311	20	Food	1,142	1,123	59	68	1.91%	17.6%	20.7%
312	21	Beverage & Tobacco	51	105	1	8	87.50%	6.7%	26.0%
313	22	Textile Mills	310	207	33	25	-3.03%	36.3%	41.2%
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335	38	Electrical Equip., Appliances, and Components	107	172	13	14	0.96%	41.5%	27.8%
336	37	Transportation Equipment	363	429	39	51	3.85%	36.7%	40.6%
339	39	Miscellaneous	W	71	6	10	8.33%	N/A	48.1%
314	23	Textile Product Mills	W	60	4	5	3.13%	N/A	28.4%
315	23	Apparel	W	30	4	4	0.00%	N/A	45.5%
316	31	Leather & Allied Products	W	7	0.8	0.7	-1.56%	N/A	34.1%
321	24	Wood Products	491	377	20	21	0.63%	13.9%	19.0%
323	27	Printing and Related Support	112	98	17	15	-1.47%	51.8%	52.2%
326	30	Plastics and Rubber Products	287	351	44	53	2.56%	52.3%	51.5%
337	25	Furniture and Related Products	69	64	7	7	0.00%	34.6%	37.3%
		Totals	21,528	22,666	791	844	0.84%	12.5%	12.7%

Table 2-4: Manufacturing Energy Use Summary

NAICS code	SIC code equivalent	Industry	Total Energy Use (Trillion BTU)					Total Electricity Consumption (million kWh)		
			Total Purchased Fuels & Electric Use	By-Product Fuel Use	Energy Used for Heat & Power	Energy Used for Feedstocks	Primary Energy Use	Electricity Purchases	Electric Self-Generated Less Sold	Electricity Total
311	20	Food	1,123	6	1,129	8	1,137	63,907	3,614	67,521
312	21	Beverage & Tobacco	105	2	107	1	108	7,207	691	7,898
313	22	Textile Mills	207	0	207	1	208	23,915	1,472	25,387
314	23	Textile Product Mills	60	0	60	0	60	4,528	342	4,870
315	23	Apparel	30	0	30	0	30	3,508	71	3,579
316	31	Leather & Allied Products	7	0	7	0	7	711	6	717
321	24	Wood Products	377	210	587	4	591	20,255	1,270	21,525
322	26	Paper	2,363	1,158	3,521	1	3,522	64,021	1,458	65,479
323	27	Printing and Related Support	98	0	98	0	98	14,164	568	14,732
324	29	Petroleum & Coal Products	6,799	1,966	8,765	3689	12,454	32,608	8,672	41,280
325	28	Chemicals	6,465	503	6,968	3750	10,718	128,891	31,469	160,360
326	30	Plastics and Rubber Products	351	0	351	0	351	49,804	3,392	53,196
327	32	Nonmetallic Mineral Products	1,059	96	1,155	7	1,162	37,100	4,306	41,406
331	33	Primary Metals	2,120	306	2,426	646	3,072	109,953	34,549	144,502
332	34	Fabricated Metal Products	388	0	388	1	389	45,249	1,872	47,121
334	36	Computer & Electronic Products	177	0	177	2	179	22,591	1,896	24,487
333	35	Machinery	201	0	201	1	202	34,821	3,607	38,428
335	38	Electrical Equip., Appliances, and Components	172	0	172	69	241	13,092	809	13,901
336	37	Transportation Equipment	429	3	432	5	437	47,298	3,210	50,508
339	39	Miscellaneous	64	10	74	0	74	6,656	456	7,112
337	25	Furniture and Related Products	71	0	71	0	71	9,601	770	10,371
		Totals	22,666	4,260	26,926	8,185	35,111	739,880	104,500	844,380

Table 2-5: Manufacturing Natural Gas Use by Category and Sector

			1994			2002		
NAICS code	SIC code equivalent	Industries	Total Purchased Fuels and Electric Use (trillion BTU)	Natural Gas (trillion BTU)	Percent Natural Gas	Total Purchased Fuels and Electric Use (trillion BTU)	Natural Gas (trillion BTU)	Percent Natural Gas
		Process Industries						
325	28	Chemicals	5,328	2,560	48.0%	6,465	2,304	35.6%
311	20	Food	1,142	629	55.1%	1,123	582	51.8%
322	26	Paper	2,665	573	21.5%	2,363	503	21.3%
324	29	Petroleum & Coal Products	6,339	808	12.8%	6,799	876	12.9%
313	22	Textile Mills	310	116	37.4%	207	75	36.2%
312	21	Beverage & Tobacco	51	6	11.8%	105	46	44.0%
		Total Process Industries	15,835	4,692	29.6%	17,062	4,386	25.7%
		Materials Production						
331	33	Primary Metals	2,464	807	32.8%	2,120	704	33.2%
327	32	Non Metallic Mineral Products	944	430	45.5%	1,059	422	39.8%
		Total Materials Production	3,408	1,237	36.3%	3,179	1,126	35.4%
		Metals Fabrication						
336	37	Transportation Equipment	363	157	43.2%	429	203	47.4%
332	34	Fabricated Metal Products	367	220	59.8%	388	209	53.9%
334	36	Computer & Electronic Products	243	87	35.9%	201	66	32.7%
333	35	Machinery	246	111	45.0%	177	82	46.4%
335	38	Electrical Equip., Appliances, and Components	107	29	26.8%	172	53	31.0%
339	39	Miscellaneous	W	19	N/A	71	32	44.8%
		Total Metals Fabrication	1,326	623	47.0%	1,438	645	44.9%
		Non Metals Fabrication						
326	30	Plastics and Rubber Products	287	110	38.3%	351	128	36.5%
321	24	Wood Products	491	47	9.6%	377	57	15.2%
323	27	Printing and Related Support	112	47	42.1%	98	46	47.1%
337	25	Furniture and Related Products	69	24	34.2%	64	25	38.5%
314	23	Textile Product Mills	W	12	N/A	60	29	47.9%
315	23	Apparel	W	13	N/A	30	16	54.7%
316	31	Leather & Allied Products	W	1	N/A	7	4	58.6%
		Total Non Metals Fabrication	959	254	26.5%	987	306	31.0%
		Total Industries	21,528	6,806	31.6%	22,666	6,463	28.5%

Table 2-6: Comparison of Manufacturing Electricity and Natural Gas Consumption

NAICS code	SIC code equivalent	Industry	Natual Gas Consumption Trillion BTU 1994	 2002	 Percent Annual Growth 1994-2002	Electricity Consumption Billion kWh 1994	 2002	 Percent Annual Growth 1994-2002
		Process Industries						
325	28	Chemicals	2,560	2,304	-1.25%	156	160	0.32%
311	20	Food	629	582	-0.94%	59	68	1.91%
322	26	Paper	573	503	-1.52%	72	65	-1.22%
324	29	Petroleum & Coal Products	808	876	1.05%	36	41	1.74%
313	22	Textile Mills	116	75	-4.42%	33	25	-3.03%
312	21	Beverage & Tobacco	6	46	83.69%	1	8	64.42%
		Total Process Industries	4,692	4,386	-0.81%	357	367	0.34%
		Materials Production						
331	33	Primary Metals	807	704	-1.60%	144	145	0.09%
327	32	Non Metallic Mineral Products	430	422	-0.24%	36	41	1.74%
		Total Materials Production	1,237	1,126	-1.13%	180	186	0.42%
		Metals Fabrication						
336	37	Transportation Equipment	157	203	3.68%	39	51	3.85%
332	34	Fabricated Metal Products	220	209	-0.58%	34	47	4.78%
334	36	Computer & Electronic Products	87	66	-3.09%	33	38	1.89%
333	35	Machinery	111	82	-3.24%	32	25	-2.73%
335	38	Electrical Equip., Appliances, and Components	29	53	10.71%	13	14	0.96%
339	39	Miscellaneous	19	32	7.89%	6	10	8.33%
		Total Metals Fabrication	623	645	0.45%	157	185	2.23%
		Non Metals Fabrication						
326	30	Plastics and Rubber Products	110	128	2.10%	44	53	2.56%
321	24	Wood Products	47	57	2.78%	20	21	0.63%
323	27	Printing and Related Support	47	46	-0.27%	17	15	-1.47%
337	25	Furniture and Related Products	24	25	0.54%	7	7	0.00%
314	23	Textile Product Mills	12	29	16.67%	4	5	3.13%
315	23	Apparel	13	16	2.88%	4	4	0.00%
316	31	Leather & Allied Products	1	4	38.80%	0.8	0.7	-1.56%
		Total Non Metals Fabrication	254	306	2.53%	97	106	1.15%
		Total Industries	6,806	6,463	-0.63%	791	844	0.83%

3

END-USE APPLICATION ANALYSIS

Applications in the manufacturing sector can be classified into four basic end-uses:

1. Motor Drives
2. Process Heating
3. Electrolytics
4. Lighting and Other

Motor drives are the largest electricity end-use in manufacturing, representing 57% of total manufacturing electricity use in 2002. This is consistent with the amount of manufacturing electricity consumption by motor driven equipment in 1994, when it was also 57% of total manufacturing electricity use (see Figures 3-1 and 3-2). Electricity is the primary energy source for applications such as pumps, compressed air systems, fans, conveying equipment as well as a wide variety of crushing, grinding, stamping, trimming, cutting, mixing and milling operations that are commonly found in the manufacturing sector.

Although manufacturing motor drive electricity consumption grew at a compound rate of about 7.4% between 1994 and 2002 (from roughly 448 to 481 billion kWh), some sectors experienced more significant changes in the compound growth rate of electricity use of motor-driven systems. Notable increases were seen for food (18.2%), petroleum and coal products (14.3%), primary metals (10.4%), non-metallic mineral products (18.2%) transportation equipment (41.8%), fabricated metal products (29.5%), electrical equipment, appliances and components (30.2%), and plastics and rubber products (19.4%). Manufacturing sectors with significant aggregate decreases in motor-drive electricity use over this period include chemicals (5.8%), textile mills (13.7%), machinery (14.8%) and printing and related support (8.1%).

With respect to process heating applications electricity accounts for a small share of the total energy used because most of these applications are thermal processes such as cooking, softening, melting, distilling, annealing and fusing. Nevertheless, the amount of electricity used for process heating in industry continues to grow. Electric process heating applications consumed 85.2 billion kWh and 100.7 billion kWh in 1994 and 2002 respectively. This follows an increase of almost 20 billion kWh between 1980 and 1990. The greatest increase in electricity consumption by process heating application was for heating, which rose from 37 billion kWh in 1994 to 47.3 billion kWh in 2002. The industrial sectors that recorded the highest increases in process heating electricity use included petroleum and coal products (2.2 billion kWh), textile mills (0.6 billion kWh), primary metals (5.8 billion kWh) and fabricated metal products (6.6 billion kWh). Three industrial sectors recorded important decreases in process heating electricity consumption: computer and electronic products (1.2 billion kWh), machinery (1.3 billion kWh) and apparel (1.3 billion kWh).

Electrolytic applications are uniquely electric and include a variety of electrochemical processes used to separate, reduce and refine metals and chemicals, as well as to apply finishes on many types of metallic surfaces. Between 1994 and 2002, electricity used by this application actually decreased 12.3% from 81.1 billion kWh to 71.1 billion kWh.

Industrial lighting equipment is completely electric. It consists of a wide variety of fixtures, bulbs, ballasts and ancillary hardware designed for specific applications. Because many modern manufacturing plants are enclosed buildings, lighting applications are ubiquitous in industrial facilities and can consume significant amounts of energy that are unrelated to production. Other industrial electricity applications include ventilation, electric resistance space heating, emergency and computer power supply systems, plant instrumentation and controls, miscellaneous plug loads, as well as power supply systems for communication and instrumentation equipment. While the amount of lighting and other equipment electricity use rose modestly between 1994 and 2002, its share of electricity consumption remained stable at 22%.

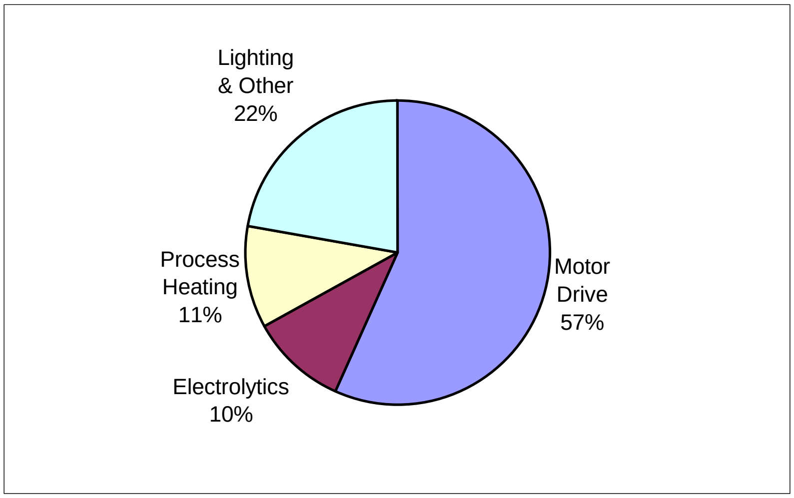

Figure 3-1: Manufacturing Electricity Consumption by End-Use Application, 1994 (Based on kWh Consumption – 791 billion kWh)

Source: Table 3-1

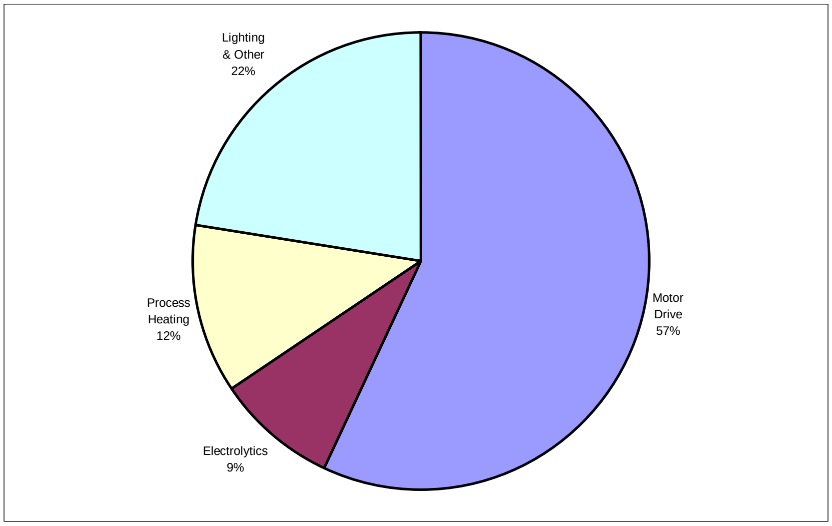

Figure 3-2: Manufacturing Electricity Consumption by End-Use Application, 2002 (Based on kWh Consumption – 844 billion kWh)

Source: Table 3-2

Tables 3-1 and 3-2 disaggregate electricity use by industrial sector and by the four applications. Figures 3-1 and 3-2 show the respective shares of electricity use by each of the four applications.

Table 3-1: Manufacturing End Use Applications of Electricity by Category and Sector 1994 (billion kWh)

NAICS code	SIC code equivalent	Industrial Sectors	Total Electrictricity Consumption	End Use Applications			
				Motor Drive	Electrolytics	Process Heating	Lighting & Other
		Process Industries					
311	20	Food	59	42.3	0.1	2.5	14.0
312	21	Beverage & Tobacco	1	0.5	0.0	0.0	0.5
313	22	Textile Mills	33	19.0	0.0	1.5	12.5
322	26	Paper	72	57.5	0.4	2.3	11.5
324	29	Petroleum & Coal Products	36	30.1	0.0	0.8	4.7
325	28	Chemicals	156	112.1	21.5	6.2	17.1
		Total Process Industries	357	261.5	22.0	13.3	60.3
		Materials Production					
327	32	Non Metallic Mineral Products	36	22.0	0.1	8.4	5.5
331	33	Primary Metals	144	40.5	55.2	36.0	12.7
		Total Materials Production	180	62.5	55.3	44.4	18.2
		Materials Fabrication					
		Metals Fabrication					
332	34	Fabricated Metal Products	34	17.3	1.6	4.3	10.8
333	35	Machinery	32	14.9	0.1	3.1	13.9
334	36	Computer & Electronic Products	33	11.6	1.3	5.5	14.6
336	37	Transportation Equipment	39	17.0	0.6	3.4	18.0
335	38	Electrical Equipment, Appliances, and Components	13	4.3	0.1	1.1	7.3
339	39	Miscellaneous	6	2.3	0.1	0.6	3.0
		Total Metals Fabrication	157	67.4	3.8	18.0	67.6
		Non Metals Fabrication					
314	23	Textile Product Mills	4	1.5	0.0	0.9	1.6
315	23	Apparel	4	1.5	0.0	0.9	1.6
316	31	Leather & Allied Products	1	0.5	0.0	0.0	0.3
321	24	Wood Products	20	14.4	0.0	1.0	4.4
323	27	Printing and Related Support	17	8.6	0.0	0.5	8.2
326	30	Plastics and Rubber Products	44	25.8	0.1	7.2	10.9
337	25	Furniture and Related Products	7	4.0	0.0	0.2	2.4
		Total Non Metals Fabrication	97	56.3	0.1	10.7	29.4
		Total Materials Fabrication	254	124	4	29	97
		Total Manufacturing	791	448	81	86	176

Note: Totals may not equal sum of components due to independent rounding

Source: U.S. Department of Commerce, Bureau of the Census, 1995 Annual Survey of Manufacturers, Washington D.C.; 1994 Manufacturing Energy Consumption Survey, U.S. Department of Energy, Energy Information Administration; RDC estimates

Table 3-2: Manufacturing end use applications of electricity by category and sector 2002 (billion kWh)

			Total	End Use Applications			
NAICS code	SIC code equivalent	Industrial Sectors	Electrictricity Consumption	Motor Drive	Electrolytics	Process Heating	Lighting & Other
		Process Industries					
311	20	Food	68	50.0	0.1	2.2	15.7
312	21	Beverage & Tobacco	8	5.3	0.0	0.2	2.1
313	22	Textile Mills	25	16.4	0.0	2.4	6.4
322	26	Paper	65	55.0	0.6	1.5	7.9
324	29	Petroleum & Coal Products	41	34.4	0.0	3.5	2.8
325	28	Chemicals	160	105.9	21.6	6.5	25.5
		Total Process Industries	367	267.0	22.4	16.3	60.4
		Materials Production					
327	32	Non Metallic Mineral Products	41	26.0	0.4	8.5	6.7
331	33	Primary Metals	145	44.8	46.1	41.8	11.9
		Total Materials Production	186	70.8	46.5	50.3	18.6
		Materials Fabrication					
		Metals Fabrication					
332	34	Fabricated Metal Products	47	22.4	0.3	10.9	13.5
333	35	Machinery	24	12.7	0.2	1.8	9.9
334	36	Computer & Electronic Products	38	12.2	0.6	4.3	21.3
336	37	Transportation Equipment	51	24.1	0.5	4.8	21.2
335	38	Electrical Equipment, Appliances, and Components	14	5.6	0.4	2.6	5.3
339	39	Miscellaneous	10	4.4	0.0	1.0	6.0
		Total Metals Fabrication	184	81.4	2.0	25.4	77.2
		Non Metals Fabrication					
314	23	Textile Product Mills	5	2.9	0.0	0.4	1.7
315	23	Apparel	4	1.4	0.0	0.1	2.1
316	31	Leather & Allied Products	1	0.4	0.0	0.0	0.3
321	24	Wood Products	22	14.9	0.0	1.0	5.1
323	27	Printing and Related Support	15	7.9	0.0	0.4	6.4
326	30	Plastics and Rubber Products	53	30.8	0.2	7.7	14.5
337	25	Furniture and Related Products	7	3.7	0.0	0.3	3.0
		Total Non Metals Fabrication	107	62.0	0.3	9.9	33.1
		Total Materials Fabrication	292	143	2	35	110
		Total Manufacturing	844	481	71	102	189

Note: Totals may not equal sum of components due to independent rounding

Source: U.S. Department of Commerce, Bureau of the Census, 2002 Annual Survey of Manufactures, Washington D.C.; Manufacturing Energy Consumption Survey, U.S. Department of Energy, Energy Information Administration; RDC estimates

Opportunities for Efficient Technologies

The average annual growth rates for electricity consumption by the manufacturing sectors in each end use application category for the 1994-2002 period are shown in Figure 3-3. Electricity consumption rose in that period for motor drives, process heating and lighting and other equipment. Electricity consumption only declined for electrolytic applications. The greatest rate of annual increase came in process heating applications for which electricity consumption has grown steadily for over 30 years. Along with the motor drives category, which is the largest industrial electricity application, process heating offers the greatest opportunities for substitution with efficient electric applications.

The increase in electricity consumption for process heating applications was mainly found in heating, followed by melting and holding. Many of the electrotechnologies discussed in Section 4, fall under the process heating category. The metals fabrication industries were responsible for the largest increases in heating electricity use, accounting for over half of the electric power consumed by those sectors in 2002. For melting and holding applications, the materials production sectors' consumption grew significantly and also accounted for the majority of these applications' electricity use.

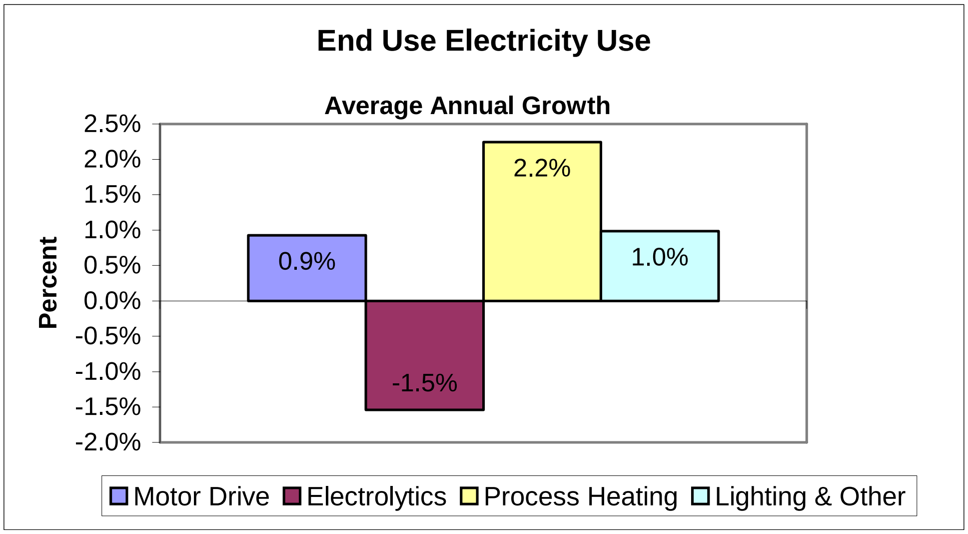

Figure 3-3: Annual Growth in Manufacturing Electricity Consumption by End-Use Application

Source: Tables 3-1, 3-2

The remainder of this section will discuss the three most important end-use application groups (motor drives, process heating and electrolytics) in detail, and will discuss cogeneration and natural gas end-use applications, which are two important elements for characterizing the industrial market for electricity and electrotechnologies.

Motor Drives

Motor driven electric applications represent the largest industrial use of electricity. Motor driven applications are mainly used to move materials and compounds through a wide range of industrial processes. These applications can be categorized into three basic categories:

<u>Pumps, fans & compressors</u> – these devices continue to play traditional and important roles throughout manufacturing. In some cases their roles have expanded, as newer generations of some production equipment are more dependent on some of these devices. From HVAC applications, to fluid processing, to electricity production, motor drives for pumps, fans and compressors provide significant control to many existing and new systems. These applications are also part of some electrotechnologies including compressors that drive freeze-concentration and membrane separation technologies. Although industrial process heat pumps are also compressor-driven, these units are included under process heating due to their role in generating process heat. In 2002, pumps fans and compressors accounted for about 52% of motor drive electricity consumption (see Figure 3-4).

Materials Processing – motor drives provide the energy for a variety of operations including crushing, grinding, mixing and cutting of manufacturing materials in a wide variety of industries. In 2002, materials processing applications were responsible for 25% of total motor drive electricity use (Figure 3-4).

Materials handling – Motor drives control the handling of materials by equipment such as cranes, conveyors, elevators and robots. In addition, motor drives in materials handling applications also provide significant control in regulating the movement of manufacturing materials to help meet the process requirements. In 2002, these applications used about 10.5% of total motor drive electricity (Figure 3-4).

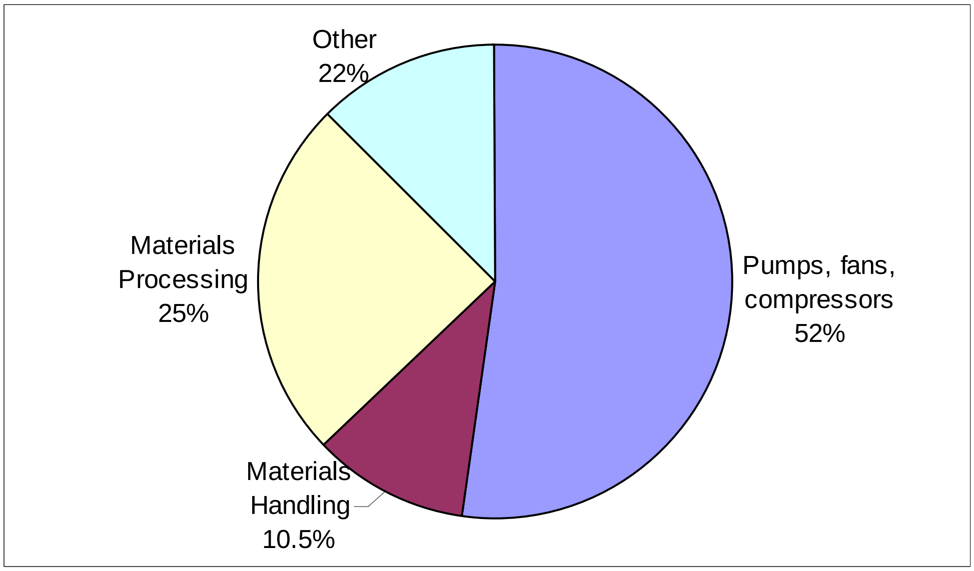

Figure 3-4: Motor Drive Electricity Use by Manufacturing Application, 2002 (based on kWh consumption 481 billion kWh).

Source: Tables 3-1, 3-2

As seen in Tables 3-3 and 3-4 fans, pumps and compressors account for more than half of total motor-drive electricity consumption. Within the motor drive applications the compound growth rate in electricity consumption was greatest for materials handling, followed by materials processing and then fans, pumps and compressors. The annual electricity use growth rates for the motor drive applications are 0.7% for motor drives, 1.5% for materials handling, 1.1% for materials processing, and 1.2% for other.

The largest motor drive electricity consuming industry is still the chemicals industry despite the fact that its aggregate electricity use declined during this period. The largest increases in electricity consumption for pumps, fans and compressors were recorded for the petroleum & coal products, food, primary metals, fabricated metal products, transportation equipment and plastics and rubber products industries. The largest increases in electricity consumption for materials handling were seen in primary metals and transportation equipment. For materials processing, the largest increases in electricity consumption were in the food, non-metallic mineral products, fabricated metal products and plastics and rubber products sectors.

Table 3-3: Manufacturing Motor Drive Electricity Consumption by Category and Sector 1994 (billion kWh)

				Motor Drive Applications			
NAICS code	SIC code equivalent	Industrial Sectors	Total Motor Drive Electricity Consumption	Pumps, Fans, Compressors	Materials Handling	Materials Processing	Other
		Process Industries					
311	20	Food	42.3	13.4	2.6	11.1	15.2
312	21	Beverage & Tobacco	0.5	0.2	0.05	0.15	0.1
313	22	Textile Mills	19.0	9.0	2.0	5.9	2.1
322	26	Paper	57.5	31.9	4.2	12.2	9.2
324	29	Petroleum & Coal Products	30.1	25.1	0.8	3.4	0.8
325	28	Chemicals	112.1	73.6	1.6	26.4	10.5
		Total Process Industries	261.5	153.2	11.3	59.2	37.9
		Materials Production					
327	32	Non Metallic Mineral Products	22.0	10.5	2.3	6.8	2.4
331	33	Primary Metals	40.5	15.5	19.1	5.1	0.8
		Total Materials Production	62.5	26.0	21.4	11.9	3.2
		Materials Fabrication					
		Metals Fabrication					
332	34	Fabricated Metal Products	17.3	8.2	1.8	5.4	1.9
333	35	Machinery	14.9	7.1	1.5	4.6	1.7
334	36	Computer & Electronic Products	11.6	5.5	1.2	3.6	1.3
336	37	Transportation Equipment	17.0	8.1	1.8	5.3	1.8
335	38	Electrical Equipment, Appliances, and Components	4.3	2.0	0.4	1.4	0.5
339	39	Miscellaneous	2.3	1.1	0.2	0.7	0.3
		Total Metals Fabrication	67.4	32.0	6.9	21.0	7.5
		Non Metals Fabrication					
314	23	Textile Product Mills	1.5	0.7	0.16	0.50	0.16
315	23	Apparel	1.5	0.7	0.16	0.50	0.16
316	31	Leather & Allied Products	0.5	0.24	0.05	0.16	0.05
321	24	Wood Products	14.4	6.8	1.5	4.5	1.6
323	27	Printing and Related Support	8.6	4.1	0.9	2.7	0.9
326	30	Plastics and Rubber Products	25.8	12.3	2.7	8.0	2.8
337	25	Furniture and Related Products	4.0	1.9	0.4	1.2	0.5
		Total Non Metals Fabrication	56.3	26.7	5.9	17.6	6.2
		Total Materials Fabrication	124	59	13	39	14
		Total Manufacturing	448	238	45	110	55

Note: Totals may not equal sum of components due to independent rounding

Source: U.S. Department of Commerce, Bureau of the Census, 1995 Annual Survey of Manufacturers, Washington D.C.; Table 3-1; RDC estimates

Table 3-4: Manufacturing Motor Drive Electricity Consumption by Category and Sector 2002 (billion kWh)

NAICS code	SIC code equivalent	Industrial Sectors	Total Motor Drive Electricity Consumption	Motor Drive Applications			
				Pumps, Fans, Compressors	Materials Handling	Materials Processing	Other
		Process Industries					
311	20	Food	50.0	16.0	3.1	13.1	17.8
312	21	Beverage & Tobacco	5.3	2.5	0.60	1.60	0.6
313	22	Textile Mills	16.4	7.8	1.7	5.1	1.8
322	26	Paper	55.0	30.6	4.0	11.8	8.6
324	29	Petroleum & Coal Products	34.4	28.1	1.3	4.1	0.9
325	28	Chemicals	105.6	67.9	1.9	25.3	10.5
		Total Process Industries	266.7	152.9	12.6	61.0	40.2
		Materials Production					
327	32	Non Metallic Mineral Products	26.0	12.3	2.7	8.1	2.9
331	33	Primary Metals	44.7	17.0	21.0	5.6	1.1
		Total Materials Production	70.7	29.3	23.7	13.7	4.0
		Materials Fabrication					
		Metals Fabrication					
332	34	Fabricated Metal Products	22.4	10.6	2.3	6.9	2.6
333	35	Machinery	12.7	6.0	1.3	4.0	1.4
334	36	Computer & Electronic Products	12.2	5.8	1.3	3.8	1.3
336	37	Transportation Equipment	24.1	11.5	2.3	7.5	2.8
335	38	Electrical Equipment, Appliances, and Components	5.6	2.7	0.6	1.7	0.6
339	39	Miscellaneous	4.4	2.1	0.4	1.4	0.5
		Total Metals Fabrication	81.4	38.7	8.2	25.3	9.2
		Non Metals Fabrication					
314	23	Textile Product Mills	2.9	1.4	0.30	0.90	0.30
315	23	Apparel	1.4	0.70	0.14	0.40	0.16
316	31	Leather & Allied Products	0.4	0.20	0.04	0.12	0.05
321	24	Wood Products	14.9	7.1	1.5	4.6	1.7
323	27	Printing and Related Support	7.9	3.8	0.8	2.5	0.8
326	30	Plastics and Rubber Products	30.8	14.6	3.2	9.6	3.4
337	25	Furniture and Related Products	3.7	1.8	0.4	1.1	0.4
		Total Non Metals Fabrication	62.0	29.6	6.4	19.2	6.8
		Total Materials Fabrication	143	68	15	45	16
		Total Manufacturing	480.8	250.5	50.9	119.2	60.2

Note: Totals may not equal sum of components due to independent rounding

Source: Table 3-2; RDC estimates

The two greatest opportunities for energy efficiency for motor-driven systems are with electronic a.c. adjustable speed drives (ASD) and retrofitting existing motors with newer, more efficient models. The implementation of ASDs has continued to grow in the U.S. In 1990 there were 646,952 ASDs installed in motor systems in U.S. industry with estimated energy savings of 20 GWh per year. By 2002, there were 1,097,328 ASDs installed across the U.S. in industrial motor systems with estimated annual energy savings well in excess of 25 GWh[1]. The primary motivations for this growth in ASD implementation includes better efficiency, better process control, rebate programs and improved process reliability.

Most opportunities for ASD installations exist with motors serving pumps, fans, compressors and material processing equipment. The applications for which ASDs are most optimal are those that frequently operate at variable speed (or part load) and that require precise controllability. As of 2002, most ASD

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[1] Xenergy Motor System Market Opportunity Assessment, 2002 P. 49

installations have been on fans and pumps and compressors (12.2% of all motors). For motors in material processing systems, ASDs were installed on approximately 11.4% of them in 2002.

The impact of ASDs on motor drive electricity consumption can be significant. While the total savings represent just 3% of total industrial electricity consumption in 2002, they represent slightly less than 6% of the total electricity used by pumps, fans and compressors, and more than 9% of the electricity consumed by material processing applications. In addition, energy savings from ASD installations have increased by just over 2% annually.

Due to the magnitude of electricity savings from ASD installations, these instruments are correctly labeled as a conservation measure. However, the coupling of ASDs and electric motor drives can be an attractive alternative to steam turbine drives. Steam turbines not only provide a non-electric energy source for powering equipment, but they are also frequently used for cogeneration – the steam is used to both drive a turbine and generate electricity. The replacement of steam turbines with electric motors can therefore result in increased loads for utilities.

As a result of the energy policy act (EPAct) that was enacted in 1992, retrofitting aging electric motors can yield important efficiency gains for motor driven industrial systems. This is because the EPAct mandates that most polyphase (3-phase), integral horsepower electric motors between 1-200 hp sold in the U.S. as of October 1997 meet minimum efficiency standards. These efficiency standards, which increase with each horsepower category, are based on the NEMA MG-1 Table 12-10. While the minimum EPAct standards are higher than the efficiency ratings of many older motors, they are below current high efficiency motors. As a result, motors currently on the market that are rated for “premium efficiency” are more efficient than the EPAct minimum standard, particularly in the lower horsepower ranges. Energy savings from retrofitting all motors to the minimum EPAct levels, including those greater than 200-hp, have been estimated as high as 13 GWh per year[2].

The electricity use impact of most electrotechnologies is limited when compared to the electricity use impact of electric motor drives for the process industries and for the non-metals fabrication industries. About 73% of process industries’ and 58% of non-metals fabrication industries’ electricity consumption is used to power electric motors. Only in the materials production industries do electrolytics and electric process heating together account for more than 52% of electricity consumption. In larger applications of the process industries steam turbine drives compete with electric motors and in some large, old plants steam turbine mechanical drives are still used to power large pumps and compressors. Table 3-5 shows the growth of motor drive electricity use.

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[2] Xenergy Motor System Market Opportunity Assessment, 2002 P. 56

Table 3-5: Growth Rates for Manufacturing Electric Motor Drives 1994-2002

NAICS code	SIC code equivalent	Industry	Electric Motor Drive Electricity		
			Billion kWh		Percent Annual Growth
			1994	2002	1994-2002
		Process Industries			
325	28	Chemicals	112.1	105.9	-0.69%
311	20	Food	42.3	50.0	2.28%
322	26	Paper	57.5	55.0	-0.54%
324	29	Petroleum & Coal Products	30.1	34.4	1.79%
313	22	Textile Mills	19.0	16.4	-1.71%
312	21	Beverage & Tobacco	0.5	5.3	120.00%
		Total Process Industries	261.5	267.0	0.26%
		Materials Production			
331	33	Primary Metals	40.5	44.7	1.30%
327	32	Non Metallic Mineral Products	22.0	26.0	2.27%
		Total Materials Production	62.5	70.7	1.64%
		Materials Fabrication			
		Metals Fabrication			
336	37	Transportation Equipment	17.0	24.1	5.22%
332	34	Fabricated Metal Products	17.3	22.4	3.68%
334	36	Computer & Electronic Products	11.6	12.2	0.65%
333	35	Machinery	14.9	12.7	-1.85%
335	38	Electrical Equip., Appliances, and Components	4.3	5.6	3.78%
339	39	Miscellaneous	2.3	4.4	11.41%
		Total Metals Fabrication	67.4	81.4	2.60%
		Non Metals Fabrication			
326	30	Plastics and Rubber Products	25.8	30.8	2.42%
321	24	Wood Products	14.4	14.9	0.43%
323	27	Printing and Related Support	8.6	7.9	-1.02%
337	25	Furniture and Related Products	4.0	3.7	-0.94%
314	23	Textile Product Mills	1.5	2.9	11.67%
315	23	Apparel	1.5	1.4	-0.83%
316	31	Leather & Allied Products	0.5	0.4	N/A
		Total Non Metals Fabrication	56.3	62.0	1.27%
		Total Materials Fabrication	124	143	1.99%
		Total Industries	448	481	0.93%

Note: Totals may not equal sum of components due to independent rounding

Source: Tables 3-1, 3-2; RDC estimates

Process Heating

Electric process heating applications are relatively small within the manufacturing sector. In 2002, these applications accounted for about 101 billion kWh or 1.7% of all the energy used for industrial process heating. The main reason for this limited role for electricity is that lower cost fuels (primarily natural gas) are often used to provide the thermal energy required for process heating operations.

Tables 3-6 and 3-7 display the amounts of electricity used for melting, heating, drying and curing applications by individual industry groups. Together, these tables show the growth in electricity used in process heating applications between 1994 and 2002. Melting and heating applications experienced the greatest increases in electricity use during this time.

Electric process heating applications are concentrated in the materials production and metals fabrication industries where high temperatures are needed for many heating and melting operations that are part of those industries' production processes. Historically, the metals fabrication industries accounted for just over half of total process heating electricity use. As seen in Tables 3-6 and 3-7, the materials production industries, particularly primary metals, are the largest consumers of electricity for process heating with 50% of process heating electricity use. In the process industries, industrial process heat pumps provide electric-based process heating, particularly for the chemicals and petroleum & coal products sectors. Within non-metals fabrication the plastics and rubber products sector uses the majority of electric process heat. Many of the manufacturing sectors use small quantities of electric process heat for drying processes. Low usage levels and continued development of newer electric process heating technologies present electrification opportunities.

Figure 3-5 displays the major electric process heating applications and their share of the total process heating electricity use in 2002. These process heating applications are:

Melting and Holding – this process is primarily performed in the materials production sectors, particularly by primary metals. In this thermal process known as metal casting, metals or alloys are transformed form solids into liquids. This application accounted for just over 45% of the electricity used by electric process heating in 2002. (See Figure 3-5).

Heating – these processes add energy to various substances, particularly liquids, to raise their temperature, make them expand and cause them to undergo various changes. Heating is used extensively in the metal fabrication sectors to heat various products so that they are easier to mold. It is also used to great extent in the plastics and rubber industries to heat set resins and warm plastic. Many sectors in the process industries also use heating to heat liquids such as dyes (in the textile mills) and to heat set synthetic fabric. Electricity used for heating applications in 2002 accounted for slightly less than 47% of the electricity used by electric process heating applications (Figure 3-5).

Drying and Curing – these processes apply heat to various materials for purposes such as removal of gases and moisture, hardening of surface coatings, or bringing about changes in the molecular structure of coatings. In 2002, drying and curing applications used about 7.5% of process heating electricity (Figure 3-5).

Table 3-6: Manufacturing Process Heating Electricity Consumption by Category and Sector, 1994

			Total Process Heat*		Electric Process Heating Applications (billion kWh)			
NAICS code	SIC code equivalent	Industrial Sectors	Trillion BTU	Percent Electric	Total Electricity	Melting and Holding	Heating	Drying and Curing
		Process Industries						
325	28	Chemicals	5,138	0.4%	6.0	0.0	6.0	0.0
311	20	Food	1,069	0.7%	2.3	1.6	0.7	0.0
322	26	Paper	2,463	0.2%	1.7	0.0	0.0	1.7
324	29	Petroleum & Coal Products	6,281	0.0%	0.8	0.0	0.8	0.0
313	22	Textile Mills	285	1.8%	1.5	0.0	0.0	1.5
312	21	Beverage & Tobacco	50	0.0%	0.0	0.0	0.0	0.0
		Total Process Industries	15,286	0	12.3	1.6	7.5	3.2
		Materials Production						
331	33	Primary Metals	2,382	5.2%	36.0	33.5	2.5	0.0
327	32	Non Metallic Mineral Products	919	3.1%	8.4	5.2	3.2	0.0
		Total Materials Production	3,301	4.6%	44.4	38.7	5.7	0.0
		Materials Fabrication						
		Metals Fabrication						
336	37	Transportation Equipment	303	3.8%	3.4	0.0	3.2	0.2
332	34	Fabricated Metal Products	307	4.8%	4.3	0.0	4.2	0.1
334	36	Computer & Electronic Products	200	9.4%	5.5	0.0	5.4	0.1
333	35	Machinery	184	11.1%	3.1	0.0	3.1	0.0
335	38	Electrical Equip., Appliances, and Components	83	3.7%	0.9	0.0	0.9	0.0
339	39	Miscellaneous	W		0.6	0.0	0.6	0.0
		Total Metals Fabrication	1,077	6.6%	17.8	0.0	17.4	0.4
		Non Metals Fabrication						
326	30	Plastics and Rubber Products	253	9.7%	7.2	0.0	6.2	1.0
321	24	Wood Products	474	0.7%	1.0	0.0	0.0	1.0
323	27	Printing and Related Support	85	2.0%	0.5	0.0	0.2	0.3
337	25	Furniture and Related Products	57	1.2%	0.2	0.0	0.0	0.2
314	23	Textile Product Mills	W		0.9	0.0	0.0	0.9
315	23	Apparel	W		0.9	0.0	0.0	0.9
316	31	Leather & Allied Products	W		0.0	0.0	0.0	0.0
		Total Non Metals Fabrication	869	4.2%	10.7	0.0	6.4	4.3
		Total Materials Fabrication	1946	5.1%	29	0	24	5
		Total Industries	20,533	1.5%	85.2	40.3	37.0	7.9

* Purchased fuels less space heating fuels and fuels used for cogeneration, plus the BTU equivalent of electric process heat

Note: Totals may not equal sum of components due to independent rounding

Source: U.S. Department of Commerce, Bureau of the Census, 1995 Annual Survey of Manufacturers, Washington D.C.; RDC estimates

Table 3-7: Manufacturing Process Heating Electricity Consumption by Category and Sector, 2002

NAICS code	SIC code equivalent	Industrial Sectors	Total Process Heat*		Electric Process Heating Applications (billion kWh)			
			Trillion BTU	Percent Electric	Total Electricity Consumption	Melting and Holding	Heating	Drying and Curing
		Process Industries						
325	28	Chemicals	5,708	0.3%	5.8	0.0	5.8	0.0
311	20	Food	924	0.8%	2.2	1.5	0.6	0.0
322	26	Paper	1,946	0.3%	1.5	0.0	0.0	1.5
324	29	Petroleum & Coal Products	6,644	0.2%	3.0	0.0	3.0	0.0
313	22	Textile Mills	200	4.1%	2.4	0.0	0.0	2.4
312	21	Beverage & Tobacco	84	0.8%	0.2	0.0	0.2	0.0
		Total Process Industries	15,506	0.3%	15.1	1.5	9.6	3.9
		Materials Production						
331	33	Primary Metals	2,026	1.4%	41.8	38.9	2.9	0.0
327	32	Non Metallic Mineral Products	1,026	13.9%	8.5	5.3	3.2	0.0
		Total Materials Production	3,052	5.6%	50.3	44.2	6.1	0.0
		Materials Fabrication						
		Metals Fabrication						
336	37	Transportation Equipment	331	4.9%	4.8	0.0	4.5	0.3
332	34	Fabricated Metal Products	328	11.3%	10.9	0.0	10.7	0.2
334	36	Computer & Electronic Products	144	10.2%	4.3	0.0	4.2	0.1
333	35	Machinery	130	4.7%	1.8	0.0	1.8	0.0
335	38	Electrical Equip., Appliances, and Components	149	6.0%	2.6	0.0	2.6	0.0
339	39	Miscellaneous	54	6.3%	1.0	0.0	1.0	0.0
		Total Metals Fabrication	1,136	0.7%	25.4	0.0	24.8	0.6
		Non Metals Fabrication						
326	30	Plastics and Rubber Products	307	8.6%	7.7	0.0	6.6	1.1
321	24	Wood Products	365	0.9%	1.0	0.0	0.0	1.0
323	27	Printing and Related Support	74	1.8%	0.4	0.0	0.2	0.2
337	25	Furniture and Related Products	52	2.0%	0.3	0.0	0.0	0.3
314	23	Textile Product Mills	60	2.3%	0.4	0.0	0.0	0.4
315	23	Apparel	29	1.2%	0.1	0.0	0.0	0.1
316	31	Leather & Allied Products	2	0.0%	0.0	0.0	0.0	0.0
		Total Non Metals Fabrication	889	3.8%	9.9	0.0	6.8	3.1
		Total Materials Fabrication	2025	5.9%	35	0	32	4
		Total Industries	20,583	1.7%	100.7	45.7	47.3	7.6

* Purchased fuels less space heating fuels and fuels used for cogeneration, plus the BTU equivalent of electric process heat

Note: Totals may not equal sum of components due to independent rounding

Source: Table 3-2; RDC estimates

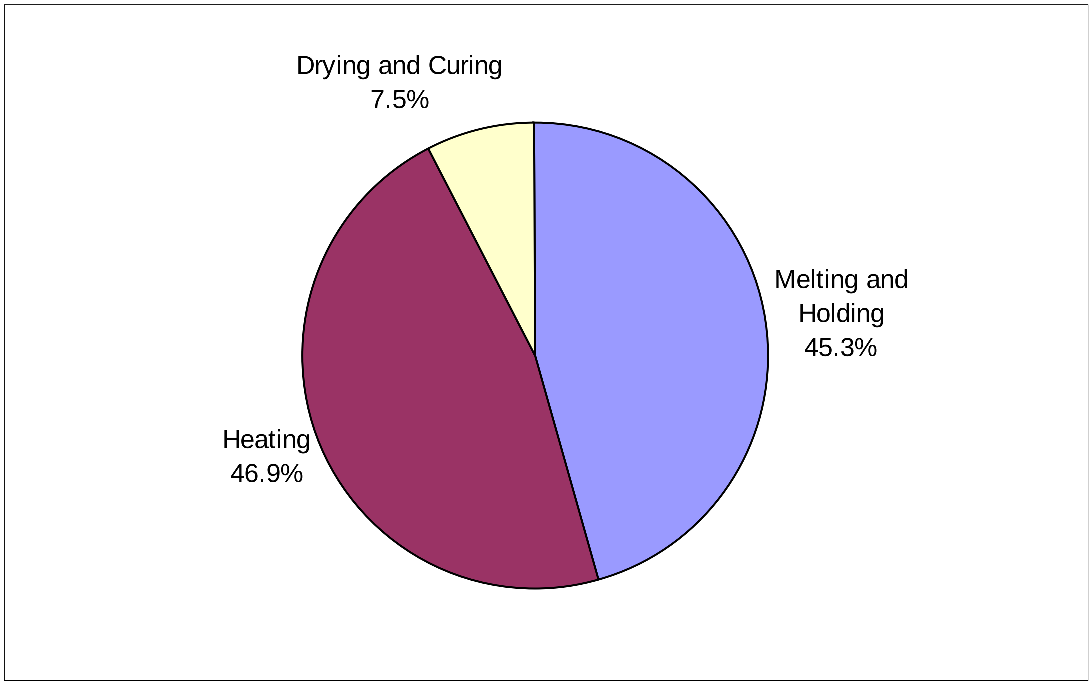

Figure 3-5: Process Heating Electricity Use by Manufacturing Applications, 2002 (based on kWh consumption – 100.7 billion kWh).

Source: Table 3-7

Electrolytics

Electricity consumption for electrolytic processes is concentrated in the process and materials production industries. In fact, these two groups of manufacturing sectors account for 98% of the electricity used in electrolytic processes. In 2002, electrolytic processes consumed 46.5 billion kWh in the materials production industry (65.5% of the total for all industries). For the process industries, electrolytic processes consumed 22.4 billion kWh, representing 32% of manufacturing's total.

In electrolytic processes, process reactants are maintained in ionic form in an electrolyte. By applying voltage to electrodes immersed in the electrolyte, the ions in the electrolyte can be separated. A common application of this process in the chemicals industry is during the production of chlorine. Other frequently found applications of electrolytics include electrolytic separation and electrochemical synthesis, electrogalvanization, electrolytic reduction, electrochemical machining and electrofinishing. These processes can be classified into three broad categories:

<u>Electrolytic Separation/Synthesis</u> – separation processes are among the most frequently performed processes in the chemicals industry. Many chemicals and compounds such as chlorine and caustic soda are produced via electrolytic separation. A promising application of electrolytic separation is electrodialysis, which is used for the recovery of valuable materials from waste streams. Separation and synthesis represent slightly more than 30% of the electricity used in electrolytics. (See Figure 3-6).

<u>Electrolytic Reduction</u> – electrolytic reduction processes typically employ high-temperatures (usually greater than 100°C) using molten salt electrolyte to extract metals from ores. Aluminum is the dominant product produced by high-temperature electrolytic processes. Other products made using high

temperature electrolytic reduction include sodium and magnesium. Zinc, copper and manganese are produced in low-temperature electrolytic cells from aqueous solutions. Copper is the most commercially significant product made using which low-temperature electrolytic reduction processes (10% of all copper produced is through low-temperature electrolytic reduction). Chromium and lead are also produced in small quantities through electrolysis. About 65% of the electricity used in electrolytics is for reduction (Figure 3-6).

Electrolytic Deposition/Removal – these electrolytic processes are used to deposit finishes on metal or remove metal from a metallic work piece. Electrogalvanization uses and electrolytic cell and a zinc salt solution to form a protective ring coating on a steel strip. Electrofinishing uses a variety of electrolytic methods to produce finishes on manufactured products. Electrochemical machining passes current through an electrolyte to a conductive work piece, dissolving material by the electrochemical reaction produced. These methods use between 4% and 5% of electrolytics electricity consumption (Figure 3-6).

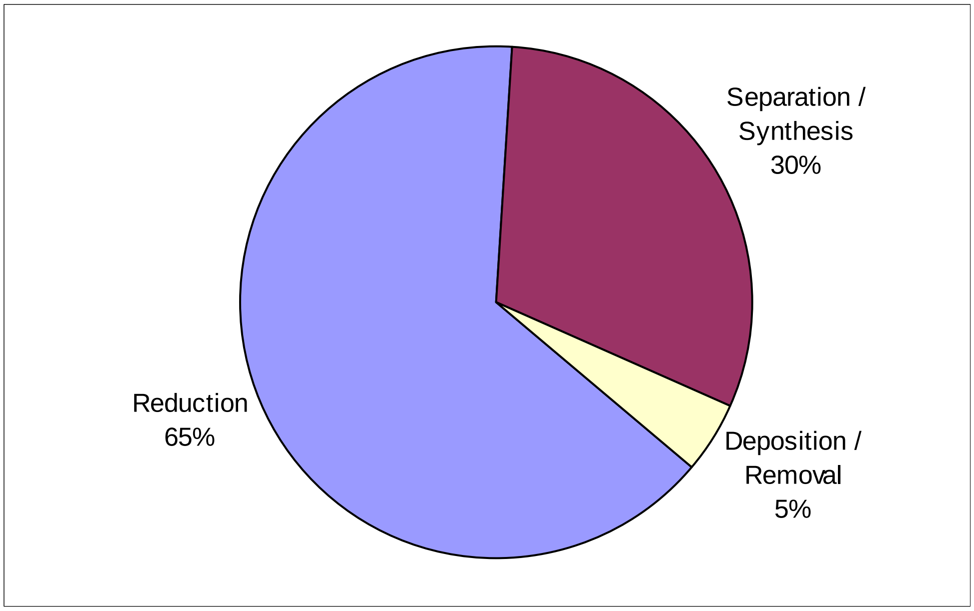

Figure 3-6: Electrolytics Electricity Use by Manufacturing Application, 2002 (based on kWh consumption – 71.1 billion kWh).

Source: Table 3-2, RDC estimates.

Cogeneration

Cogeneration is the sequential production of thermal and electric energy. It is most widely used in the process industries that usually have large electric and thermal loads and access to relatively inexpensive byproduct fuels. In the late 1980s and early 1990s cogeneration became more widespread as electricity prices rose while natural gas prices remained relatively unchanged. However, as natural gas prices rose and became more variable starting in the late 1990s, cogeneration activity began to decline and manufacturing plants began to search more aggressively for cost-effective electricity suppliers.

Most industrial plants require both thermal and electrical energy. Historically, these energy requirements were met for most industries through independent purchases of electricity and other fuels such as natural gas, coal or distillates. Electricity was purchased from the local utility and fuels were bought from local suppliers (natural gas from a pipeline or local distribution company, oil from a major oil company or local distributor, and coal from a producer or broker). Changes in relative fuel prices and restructuring in the electric power industry affected a trend of rising use of cogeneration technologies.

As shown in Table 3-8 cogeneration is most commonly found in industries that have significant process heating requirements. Traditionally, the process industries have accounted for the majority of cogenerated electricity on a self-generated-less-sold basis. This situation was again true over the 1994-2002 period, however the amount of cogenerated electricity from the other industrial categories grew in comparison to their historical amounts. In particular, the materials production industries relied on cogeneration to a larger extent (21%) than was true in the 1980s. Although the process industries' use of cogeneration was robust, it declined from 30% in 1994 to 26% in 2002 on a self-generated-less-sold basis. While the total amount of cogenerated electricity declined over the 1994-2002 period from 162.5 billion kWh to 153.5 billion kWh, it still represented an important share of total electricity consumption (18%), suggesting that onsite power generation technologies are well-entrenched in manufacturing.

The economics of cogeneration depend on the relative costs and reliability of cogeneration and its conventional alternatives in meeting electric and thermal loads. Cogeneration is relatively more cost-effective when cogeneration fuel prices are very low and electricity prices are relatively high. Cogeneration competes with both the motor drive and process heating electrotechnology end-use groups. Steam-driven turbines compete with electric motors and steam heating competes with some process heating electrotechnologies.

Many of the electrotechnologies discussed in the *Guide* present alternatives to cogeneration. Improving manufacturing plant efficiency by substituting thermal-based processes with electrically-based ones will result in decreased thermal loads and therefore, fewer cogeneration opportunities. In addition, the electrotechnologies being used in place of the thermal ones may be better matched to the actual requirements of certain production processes. As an example, replacing a steam turbine mechanical drive with an electric motor drive within the scope of an overall process thermal efficiency improvement program could be an attractive alternative to cogeneration in the process industries.

Table 3-8: Trends in Manufacturing Cogeneration 1994-2002

NAICS code	SIC code equivalent	Industry	Electricity Consumption (billion kWh)			Self-Generated Less Sold				
			(Billion kWh)		Percent Annual Growth	(Billion kWh)		Percent Annual Growth	Self-Generated Less Sold as a percent of Total Consumption	
			1994	2002	1994-2002	1994	2002	1994-2002	1994	2002
		Process Industries								
325	28	Chemicals	156	160	0.32%	39.1	31.5	-2.4%	25%	20%
311	20	Food	59	68	1.91%	5.1	3.6	-3.7%	9%	5%
322	26	Paper	72	65	-1.22%	49.6	50.5	0.2%	69%	78%
324	29	Petroleum & Coal Products	36	41	1.74%	12.6	8.7	-3.9%	35%	21%
313	22	Textile Mills	33	25	-2.95%	1.9	1.5	-2.6%	6%	6%
312	21	Beverage & Tobacco	1	8	82.50%	0.1	0.7	75.0%	10%	9%
		Total Process Industries	357	367	0.34%	108.4	96.5	-1.4%	30%	26%
		Materials Production								
331	33	Primary Metals	144	145	0.04%	34.5	34.6	0.04%	24%	24%
327	32	Non Metallic Mineral Products	36	41	1.74%	3.6	4.3	2.4%	10%	10%
		Total Materials Production	180	186		38.1	38.9	0.3%	21%	21%
		Materials Fabrication								
		Metals Fabrication								
336	37	Transportation Equipment	39	51	3.72%	2.3	3.2	4.9%	6%	6%
332	34	Fabricated Metal Products	34	47	4.82%	1.3	1.9	5.8%	4%	4%
334	36	Computer & Electronic Products	33	38	2.05%	3.2	3.6	1.6%	10%	9%
333	35	Machinery	32	24	-3.13%	2.6	1.9	-3.4%	8%	8%
335	38	Electrical Equip., Appliances, and Components	13	14	0.87%	1.3	0.8	-4.8%	10%	6%
339	39	Miscellaneous	6	10	9.17%	0.5	0.8	7.5%	8%	8%
		Total Metals Fabrication	157	184	2.18%	11.2	12.2	1.1%	7%	7%
		Non Metals Fabrication								
326	30	Plastics and Rubber Products	44	53	2.61%	2.6	3.4	3.8%	6%	6%
321	24	Wood Products	20	22	1.25%	0.9	1.3	5.6%	5%	6%
323	27	Printing and Related Support	17	15	-1.47%	0.7	0.6	-1.8%	4%	4%
337	25	Furniture and Related Products	7	7	0.76%	0.5	0.5	0.0%	8%	7%
314	23	Textile Product Mills	4	5	3.13%	0.0	0.0	0.0%	0%	0%
315	23	Apparel	4	4	0.00%	0.1	0.1	-3.6%	3%	2%
316	31	Leather & Allied Products	1	1	0.00%	0.0	0.0	0.0%	0%	1%
		Total Non Metals Fabrication	96.6	107.2	1.37%	4.8	5.9	2.8%	5%	5%
		Total Materials Fabrication	254	292	1.87%	16	18	1.63%	6%	6%
		Total Industries	791	844	0.84%	162.5	153.5	-0.7%	21%	18%

Note: Totals may not equal sum of components due to independent rounding

Source: U.S. Department of Commerce, Bureau of the Census, 2003 Annual Survey of Manufactures; Manufacturing Energy Consumption Survey, U.S. Department of Energy, Energy Information Administration; RDC estimates

Natural Gas Use

There are three primary end-use applications of natural gas in the manufacturing sector:

1. Process Heating
    - Direct fired
    - Process steam
2. Feedstocks
3. Space Heating

The breakdown between these end-use applications varies by industry category and sector. For example, natural gas used for cogeneration is high in the process industries, accounting for 9% of the total natural gas consumed in these industries in 2002. However, in the metals fabrication industries natural gas use for cogeneration was less than 1% of the total in 2002. Natural gas used as feedstocks is consumed as process feed material for conversion to other chemicals such as ammonia, methanol, hydrogen and carbon black. In 2002, natural gas used for feedstocks by all the manufacturing industries amounted to 821 trillion BTU or 12.8% of the total. Tables 3-9 and 3-10 provide the breakdowns of end-use application consumption of natural gas in 1994 and 2002.

Table 3-9: Manufacturing End-Use Applications of Natural Gas by Category and Sector 1994 (trillion BTU)

NAICS code	SIC code equivalent	Industries	Total Natural Gas Use	Process Heat		Cogen-eration	Feedstock	Space Heating & Other
				Direct Fired	Process Steam			
		Process Industries						
325	28	Chemicals	2,560	865	808	151	729	8
311	20	Food	629	183	375	23	0	47
322	26	Paper	573	102	212	174	28	57
324	29	Petroleum & Coal Products	808	282	385	49	4	89
313	22	Textile Mills	116	33	69	2	0	10
312	21	Tobacco Products	6	1	2	0	0	3
		Total Process Industries	4,692	1466	1851	398	761	214
		Materials Production						
331	33	Primary Metals	807	604	95	19	15	69
327	32	Non Metallic Mineral Products	430	369	20	1	7	33
		Total Materials Production	1,237	973	115	20	22	102
		Materials Fabrication						
		Metals Fabrication						
336	37	Transportation Equipment	157	61	51	3	0	43
332	34	Fabricated Metal Products	220	115	39	0	1	65
334	36	Computer & Electronic Products	87	33	29	0	1	24
333	35	Machinery	111	36	21	1	4	50
335	38	Electrical Equip., Appliances, and Components	29	12	5	5	0	8
339	39	Miscellaneous	19	6	5	0		8
		Total Metals Fabrication	623	263	150	8	6	198
		Non Metals Fabrication						
326	30	Plastics and Rubber Products	110	23	56	0	0	30
321	24	Wood Products	47	21	15	7	0	10
323	27	Printing and Related Support	47	15	11	0	0	21
337	25	Furniture and Related Products	24	8	4	0	0	12
314	23	Textile Product Mills	12	3	5	0	0	4
315	23	Apparel	13	3	5	0	0	5
316	31	Leather & Allied Products	1	1	0	0	0	0
		Total Non Metals Fabrication	254	74	96	7	0	82
		Total Materials Fabrication	877	337	246	15	6	280
		Total Industries	6,806	2776	2212	433	789	596

Note: Totals may not equal sum of components due to independent rounding

Source: U.S. Department of Commerce, Bureau of the Census, 1995 Annual Survey of Manufacturers; 1994 Manufacturing Energy Consumption Survey, U.S. Department of Energy, Energy Information Administration; RDC estimates

Table 3-10: Manufacturing End-Use Applications of Natural Gas by Category and Sector 2002 (trillion BTU)

NAICS code	SIC code equivalent	Industries	Total Natural Gas Use	Process Heat		Cogen-eration	Feedstock	Space Heating & Other
				Direct Fired	Process Steam			
		Process Industries						
325	28	Chemicals	2,304	682	562	163	780	117
311	20	Food	575	211	249	18	0	97
322	26	Paper	504	141	194	156	2	11
324	29	Petroleum & Coal Products	878	586	187	58	31	16
313	22	Textile Mills	74	23	37	1	1	13
312	21	Beverage & Tobacco	46	8	30	0	0	8
		Total Process Industries	4,381	1,651	1259	395	814	262
		Materials Production						
331	33	Primary Metals	669	546	41	15	0	68
327	32	Non Metallic Mineral Products	422	359	10	2	7	44
		Total Materials Production	1,091	905	51	17	7	112
		Materials Fabrication						
		Metals Fabrication						
336	37	Transportation Equipment	203	63	48	3	0	89
332	34	Fabricated Metal Products	209	130	32	2	0	45
334	36	Computer & Electronic Products	66	10	29	0	0	27
333	35	Machinery	82	31	13	0	0	38
335	38	Electrical Equip., Appliances, and Components	53	28	6	0	0	19
339	39	Miscellaneous	32	8	11	0	0	13
		Total Metals Fabrication	645	270	139	5	0	231
		Non Metals Fabrication						
326	30	Plastics and Rubber Products	128	38	48	0	0	41
321	24	Wood Products	57	30	15	7	0	6
323	27	Printing and Related Support	46	20	6	0	0	20
337	25	Furniture and Related Products	25	11	1	0	0	13
314	23	Textile Product Mills	29	10	13	0	0	6
315	23	Apparel	16	5	4	0	0	7
316	31	Leather & Allied Products	4	3	0	0	0	1
		Total Non Metals Fabrication	306	117	87	7	0	93
		Total Materials Fabrication	951	387	226	12	0	324
		Total Industries	6,423	2,943	1536	424	821	698

Note: Totals may not equal sum of components due to independent rounding

Source: Table 2-5; 2002 Manufacturing Energy Consumption Survey, U.S. Department of Energy, Energy Information Administration; RDC estimates

Process heating and cogeneration compete directly with electrotechnologies. Because natural gas-based cogeneration has been discussed, the rest of this section will discuss natural gas-based process heating.

Process heating applications represent a large share of natural gas consumption in the materials production and materials fabrication industries. In 2002, these applications accounted for 87% and 64% of natural gas use respectively for these industry categories. While the share of natural gas use by the process industries was smaller at 64%, the aggregate amount of natural gas used for process heating by the process industries was much greater (2,910 trillion BTU) than the combined total natural gas used by the materials production and materials fabrication industries (1,365 trillion but). This underscores how energy intensive the process industries are relative to the other manufacturing sectors.

Tables 3-11 and 3-12 display the process heating applications of natural gas for all the manufacturing industries. These applications are found in five basic processes:

Baking, Drying and Curing – as with electric process heating applications, baking, drying and curing processes are performed to remove moisture and cure coatings, and in a variety of baking processes. In 2002, these three processes represented about 21% of the natural gas-based process heating. (See Figure 3-7).

Heating – this process heating application consists of tasks such as calcining and metal heating including steel reheat, ferrous and non-ferrous forgings as well as a variety of furnace and non-furnace heating processes that are widespread in the materials fabrication industries. Also included in heating processes are heat treating, glass annealing and ladle heating. In 2002, these processes accounted for 12% of natural gas process heating consumption (Figure 3-7).

Fluid Heating – this process is mainly confined to the petrochemical industries. Natural gas is used to heat fluids (liquids or gases) for a variety of purposes including:

- Preparing a mixture of chemicals for separation through distillation,
- Preheating feedstocks,
- Inducing cracking or the restructuring of molecules.

The heating of water is included under steam production when this is needed for process use or under baking, drying and curing when removed from the product. The heating of fluids that are used to process materials (e.g. salt baths for metal heat treating) is included under heating. In 2002, fluid heating accounted for 25% of natural gas process heating consumption (Figure 3-7).

Melting (including smelting) – these processes are used primarily in the primary metals production and materials fabrication industries in smelting and metal melting furnaces. Over 90% of natural gas used for melting is by the primary metals and non-metallic mineral products industries to melt metals and for glass melting. In 2002, these processes accounted for 7% of natural gas process heating consumption (Figure 3-7).

Process Steam – in steam production, natural gas (or any other fuel) is used to fire boilers, which in turn generate steam for the desired industrial process. Many industrial processes require steam for a variety of applications. These applications include cooking, washing, bleaching, drying, evaporation, distillation, vulcanization, cleaning, cooking, hydroforming, finishing and various others. These applications can be found in all manufacturing industries, however the process industries consume the greatest amounts of steam (80%). In 2002, process steam production represented about 35% of natural gas process heating consumption (Figure 3-7).

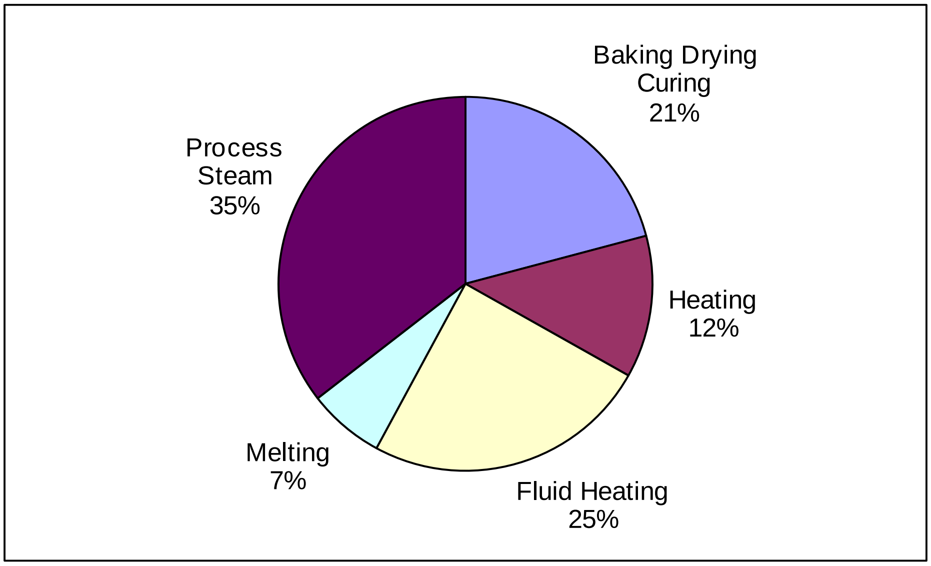

Figure 3-7. Natural Gas Process Heating by Manufacturing Application, 2002 (based on BTU consumption – 4,479 trillion BTU).

Source: Table 3-12

Table 3-11 Manufacturing Process Heating Natural Gas Consumption by Category and Sector 1994

NAICS code	SIC code equivalent	Industry	Total Process Heat - Natural Gas	Direct Fired				Process Steam
				Baking Drying	Heating	Fluid Heating	Melting	
		Process Industries						
325	28	Chemicals	1,473	65		796		811
311	20	Food	558	182	0	0	0	375
322	26	Paper	314	28	74	0	0	212
324	29	Petroleum & Coal Products	600	0	0	255	0	385
313	22	Textile Mills	103	33	0	0	0	69
312	21	Beverage & Tobacco	3	1	0	0	0	2
		Total Process Industries	3,051	309	74	1,051	0	1,854
		Materials Production						
331	33	Primary Metals	699	175	318	0	111	95
327	32	Non Metallic Mineral Products	389	181	93	0	95	20
		Total Materials Production	1,088	356	411	0	206	115
		Materials Fabrication						
		Metals Fabrication						
336	37	Transportation Equipment	112	37	18	0	6	51
332	34	Fabricated Metal Products	154	13	90	0	12	39
334	36	Computer & Electronic Products	62	24	5	0	4	29
333	35	Machinery	57	19	14	0	3	21
335	38	Electrical Equip., Appliances, and Components	17	11	1	0	0	5
339	39	Miscellaneous	11	3	3	0	0	5
		Total Metals Fabrication	413	107	131	0	25	150
		Non Metals Fabrication						
326	30	Plastics and Rubber Products	79	23	0	0	0	56
321	24	Wood Products	36	21	0	0	0	15
323	27	Printing and Related Support	26	15	0	0	0	11
337	25	Furniture and Related Products	12	8	0	0	0	4
314	23	Textile Product Mills	8	3	0	0	0	5
315	23	Apparel	8	3	0	0	0	5
316	31	Leather & Allied Products	1	1	0	0	0	0
		Total Non Metals Fabrication	170	74	0	0	0	96
		Total Materials Fabrication	583	181	131	0	25	246
		Total Industries	4,722	846	616	1,051	231	2,215

Note: Totals may not equal sum of components due to independent rounding

Source: U.S. Department of Commerce, Bureau of the Census, 1995 Annual Survey of Manufacturers; 1994 Manufacturing Energy Consumption Survey, U.S. Department of Energy, Energy Information Administration; RDC estimates

Table 3-12 Manufacturing Process Heating Natural Gas Consumption by Category and Sector 2002

NAICS code	SIC code equivalent	Industry	Total Process Heat - Natural Gas	Direct Fired				Process Steam
				Baking Drying	Heating	Fluid Heating	Melting	
		Process Industries						
325	28	Chemicals	1,244	61	0	527	0	562
311	20	Food	460	205	0	0	0	249
322	26	Paper	335	71	83	0	0	194
324	29	Petroleum & Coal Products	773	0	0	544	0	187
313	22	Textile Mills	60	23	0	0	0	37
312	21	Beverage & Tobacco	38	7	0	0	0	30
		Total Process Industries	2,910	367	83	1,071	0	1,259
		Materials Production						
331	33	Primary Metals	587	153	227	0	150	41
327	32	Non Metallic Mineral Products	369	164	84	0	110	10
		Total Materials Production	956	317	311	0	260	51
		Materials Fabrication						
		Metals Fabrication						
336	37	Transportation Equipment	111	36	19	0	8	48
332	34	Fabricated Metal Products	162	15	101	0	14	32
334	36	Computer & Electronic Products	39	7	1	0	1	29
333	35	Machinery	44	16	11	0	3	13
335	38	Electrical Equip., Appliances, and Components	34	25	2	0	0	6
339	39	Miscellaneous	19	4	4	0	0	11
		Total Metals Fabrication	409	103	138	0	26	139
		Non Metals Fabrication						
326	30	Plastics and Rubber Products	86	37	0	0	0	48
321	24	Wood Products	45	30	0	0	0	15
323	27	Printing and Related Support	26	20	0	0	0	6
337	25	Furniture and Related Products	12	11	0	0	0	1
314	23	Textile Product Mills	23	10	0	0	0	13
315	23	Apparel	9	5	0	0	0	4
316	31	Leather & Allied Products	3	3	0	0	0	0
		Total Non Metals Fabrication	204	116	0	0	0	87
		Total Materials Fabrication	613	219	138	0	26	226
		Total Industries	4,479	903	532	1,071	286	1,536

Note: Totals may not equal sum of components due to independent rounding

Source: Table 3-10; 2002 Manufacturing Energy Consumption Survey, U.S. Department of Energy, Energy Information Administration; RDC estimates

4

DESCRIPTION OF ENERGY EFFICIENT TECHNOLOGIES

Efficient electrotechnologies (or electric-based manufacturing systems) use electricity to make or transform a product. Many electrotechnologies are used for heating applications that perform operations like heat treating, drying, curing, melting, and forming. Others are used for applications like separation, machining, and welding.

Such technologies generally have good controllability, cleanliness, and efficiency. In some cases, electrotechnologies are chosen for technical reasons, while in other cases the relative price of natural gas (or other fuels) and electricity is the deciding factor. In some cases, the application cannot be done economically without an electrotechnology. For some industrial applications, electrotechnologies have the majority of the installed base, while in others electrotechnologies are only used in certain niche applications.

The rest of this section describes the different energy efficient electric technologies currently available. They have been categorized into the following classes: process heating, electrolytic, and machining & welding.

Process Heating[3]

Electric-based process heating systems use electric currents or electromagnetic fields to heat materials. Direct heating methods generate heat within the work piece, by either:

1. Passing an electrical current through the material,
2. Inducing an electrical current into the material, or
3. By exciting atoms/molecules within the material with electromagnetic radiation

Indirect heating methods use one of these three methods to heat an element which transfers the heat either by conduction, convection, radiation or a combination of these to the work piece.

Electrotechnologies used for process heating include:

- Arc furnaces
- Electric infrared electric processing
- Electroslag remelting
- Electron beam processing
- Induction heating and melting
- Laser heating
- Microwave processing
- Plasma processing (arc and non-transferred arc)
- Radio-frequency processing
- Resistance heating and melting (direct and indirect)

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[3] Portions of many of the descriptions of the process heating electrotechnologies in this document are based on work done to develop *Improving Process Heating Performance: A Sourcebook for Industry, 2nd Edition*, U.S. Department of Energy, Industrial Technologies Program, 2007.

The following electric-based technologies can supplement or replace other electric, fuel, or steam-based process heating technologies but are not actual heating technologies:

- Freeze concentration
- Industrial process heat pumps and mechanical recompression
- Membrane separation
- Ultraviolet curing

Arc Furnaces

Electric arc furnaces have been in use in the U.S. for over 100 years when they were first used to produce specialty metals such as spring steel. Presently, they are used for the production of more common carbon and low-alloy steels and to melt iron and steel for casting operations.

There are two primary types of arc furnaces: direct and indirect arc furnaces. With direct arc furnaces, a charge of metal is placed into the furnace, the furnace is sealed, and the arc is struck. These furnaces melt steel or iron- scrap by direct contact with an electric arc struck from an electrode to the metal charge. Direct arc furnaces range from under 10 tons (used in foundries to melt iron and steel for castings) to more than 400 tons (for industrial-scale steelmaking from scrap-steel).

With indirect arc furnaces, an arc is drawn between two carbon electrodes placed above the metal charge, and heat is transferred by radiation from the arc to the metal. These furnaces typically have a horizontal barrel-shaped steel shell that is lined with refractory materials. The shell rotates and reverses to avoid excessive heating of the refractory above the melt level. Indirect arc furnaces are commonly used for applications such as producing copper alloys and they tend to be much smaller than direct arc furnaces.

A third type of arc furnace is the submerged arc furnace. In these furnaces, electrodes are positioned deep in the furnace and the reaction takes place at the tip of these electrodes. Submerged arc furnaces are used to produce metals and materials such as silicon alloys, ferromanganese, calcium carbide, and ferronickel. Ore materials are mixed with a reducing agent (usually carbon) outside the furnace, which is then added periodically to the furnace. Therefore, the reduction reaction occurs continuously inside the furnace. As newly created metal accumulates the furnace is tapped at regular intervals.

Direct arc furnaces used for steelmaking (also called mini-mills) make new steel from scrap iron and scrap steel, while conventional coal-fired basic oxygen furnaces use fresh iron ore. In terms of capital costs, direct arc furnaces are less expensive (in terms of $/ton of steel capacity) than basic oxygen furnaces. One ton of steel in an electric arc furnace requires around 400-500 kilowatt-hours per short ton, which is about one-third to one-tenth the energy required by basic oxygen furnaces or integrated blast furnaces. Electric arc furnaces used for steelmaking are typically smaller than the larger, integrated basic oxygen furnaces, and are usually used where there is a plentiful and inexpensive supply of electric power and a good supply of scrap iron and steel.

Direct arc furnaces used in foundries typically produce iron for casting operations. These units tend to be smaller (under 25 tons) and also use scrap steel and scrap iron. Indirect and submerged arc furnaces are used for a variety of metal melting applications and perform the same processes as various types of fuel-based furnaces.

Process Heating Applications: High Temperature Melting, Smelting, Casting, Forming.

Industries Used In: Primary Metals, Fabricated Steel Products, Metal Casting, Transportation Equipment, Aerospace Equipment.

Electric Infrared Processing

The implementation of industrial electric IR systems dates back to the mid 1930s when Ford first used IR systems to cure paint on auto bodies. With the advent of new infrared-specific coatings, improved emitter designs, and better computer controls, electric IR is now used in many applications throughout the manufacturing sector.

IR is the part of the electromagnetic spectrum between visible light and radio waves. IR wavelengths range from 0.8 to 1000 microns. IR energy can be transmitted, absorbed and reflected. IR usually used in applications where the object being heated is in line-of-sight of the emitters and/or reflector.

Electric IR heating systems are typically comprised of an emitter, a reflector system, and controls. Most electric IR applications also come with material handling system and ventilation systems. Because IR systems can dry or cure a product in seconds, very accurate control is critical. Many varieties of emitters are available, including long-tube type panel heaters, ceramic bodies with embedded coils, metal coils, ribbons, foils, fiber heaters, and other designs. These choices in design variations make electric IR a flexible technology with uses in many manufacturing applications.

IR radiation is emitted by conducting electric current through the emitter or filament, and IR systems are classified by wavelength: short, medium, and long. Each class of wave-length has its own heat transfer qualities.

Short-wavelength emitters often resemble long-tube fluorescent light bulbs and are filled with an inert gas such as argon to prevent oxidation of the filament. Operating temperatures are around 3500°F and heat-up times are less than 10 seconds. Short-wave systems are often used for spot heating or in booster ovens. Medium-wavelength emitters come in two main varieties. The first type has a helically wound coil encased in a long, unsealed quartz glass tube. These systems heat through convection. The second type uses a resistance coil surrounded by magnesium oxide that is encased in a metal tube. Long wave emitters consist of wires embedded in ceramic panels. Typical applications for medium- and long-wave length systems are drying and heating.

Electric IR is ideal for situations where a fairly flat product is being heated, dried, or cured, but it can work well for other types of products. Because IR primarily heats the surface of a work piece, it is usually not well-suited for products that need to be heated deep beneath the product surface. Products with complex hidden surfaces usually require a hybrid system with a convection oven, or a material handling systems that can rotate parts. The work piece or coating must also have a reasonable absorption in the infrared part of the spectrum. Special paints, adhesives and other coatings specifically require infrared drying. Common industrial applications of IR include adhesive drying, drying of parts, ink curing and powder coating curing.

Electric infrared (IR) processing systems are used in many manufacturing sectors for heating, drying, curing, thermal-bonding, sintering, and sterilizing applications. Electric IR is often used in some of the same applications as direct-fired and steam-fired process heating systems. Sometimes fuel-based equipment is used in conjunction with electric IR in hybrid systems. UV curing, another electric-based process heating system, is used for curing inks, coatings, adhesives, liquids and powdered coatings. UV systems usually require less energy and have lower volatile organic compounds (VOC) emissions than IR or convection ovens, but can only be used with certain coatings for niche applications.

In many applications, electric IR systems are deployed with conventional direct-fired process heaters like convection ovens. In some cases, the IR system begins the drying process, which is finished in a conventional oven. An example is auto body production where IR is used to rapidly set the paint on the body and then the finish is set in a convection oven. An additional benefit of a hybrid system is the potential to increase throughput by increased line speed. Some hybrid systems can be configured to switch from natural gas to electricity based on energy costs.

Process Heating Applications: High Temperature Heating, Drying & Curing, Drying, Low Temperature Heating, Dyeing, Curing.

Industries Used In: Food Processing, Textiles, Wood Products & Furniture, Paper, Rubber & Plastics, Glass Products, Fabricated Metal Products, Machinery, Electronics, Transportation Equipment, Instruments.

Electro Slag Remelting

Electro slag remelting, ESR, (also called electro flux remelting) was invented in the 1930s for remelting and refining steels and special alloys. ESR uses highly reactive slags to reduce the amount of type A sulfide present in biometal alloys. ESR also reduces other types of inclusions and is an alternative to vacuum arc remelting that is prevalent in US industry. With ESR it is possible to produce a wide range of small weight ingots of tool steels and superalloys, and heavy forging ingots up to raw ingot weights of 165 tons.

In the ESR process, a consumable electrode is dipped into a pool of slag within a water-cooled mold. Current (usually AC) passes through the slag, between the electrode and the ingot being formed and superheats the slag so that drops of metal are melted from the electrode. These drops travel through the slag to the bottom of the water-cooled mold where they solidify. The new ingot of refined material is homogeneous, directionally solidified and free from the central unsoundness that can occur in conventionally cast ingots as they solidify from the outside inwards. ESR furnaces can be designed for remelting of round, square and rectangular ingots.

Significant progress in plant design, coaxial current feeding and computer control and regulation has achieved fully-automatic remelting processes. Now, ESR offers very high, consistent, and predictable product quality. Finely controlled solidification improves soundness and structural integrity. Ingot surface quality is improved by the formation of a solidified thin slag skin between the ingot and mold wall during remelting. This has made ESR the preferred method for producing high-performance superalloys.

Process Heating Applications: High Temperature Heating, Melting, Casting.

Industries Used In: Fabricated Metal Products, Metal Casting, Aerospace, Nuclear Equipment, Energy, Defense, Transportation Equipment.

Electron Beam Processing

With electron beam heating, the kinetic energy of an accelerated stream of electrons is converted to heat when the electrons impinge on the surface of the product being heated. Electron beam processing has been around since the turn of the 20th century, but its use for heat treating applications is relatively new, with the primary application being in the transportation industry, where it is used for local surface hardening of high-wear components. It is also used for curing applications such as film lamination and wood finishing.

In electron beam heating, metals are heated to intense temperatures when a directed beam of electrons is focused on the work surface. In electron beam curing, a liquid is chemically transformed to a solid on the work surface by a stream of directed electrons. Electron beam processing can be done under vacuum, partial vacuum and non-vacuum conditions. High vacuum conditions remove gaseous molecules from the air between the electron gun and the work piece, allowing for a tighter beam, which yields less scattering. Electron beam processing of materials in a high vacuum is a non-contaminating melting technique used to produce materials ranging from refractory metal alloys to metallic coatings on plastic jewelry. Electron beam processing allows for super-pure materials, and can impart unique properties to existing products.

Electron beam systems are amenable to computer control and can move from point to point easily and rapidly. They can be easily pulsed from on to off and because they produce energy in a very small area, they can be used for selective surface hardening. In addition, these systems are environmentally friendly because they don’t use solvents.

Electron beam curing is generally used to cure thick, heavily pigmented coatings for which UV curing is not as effective. Electron beam curing systems often have a large footprint and can require skilled labor to operate them. However, because they can reduce curing times from minutes to one second or less, they can significantly improve productivity levels.

Process Heating Applications: Drying & Curing, High Temperature Melting, Machining.

Industries Used In: Leather Products, Textiles/Clothing, Steel, Fabricated Metal Products, Transportation Equipment, Aerospace, Chemicals, Electronics, Defense Equipment.

Induction Heating and Melting

Induction heating and melting has been part of manufacturing since the 1930s, when the first channel-type induction furnaces were introduced for metals melting operations. Soon afterward, coreless induction furnaces were developed for melting, superheating, and holding. Later, the technology was applied to harden metal engine parts. More recently, an emphasis on improved quality control has led to increased use of induction heating technology in the ferrous and nonferrous metals industries.

In an induction heating or melting system, AC current is sent through a copper coil that surrounds the part to be heated or melted. When a metal part is placed within the coil, circulating eddy currents are induced within it, creating a magnetic field. These currents flow against the electrical resistivity of the metal, generating precise and localized heat without any direct contact between the part and the coil. When the part begins to melt, electromagnetic forces agitate and mix it. Mixing and melting rates are controlled by varying the frequency and power of the current in the wire coil. For heating operations, the control system can moderate the temperature.

Coreless furnaces have a refractory crucible surrounded by a water-cooled AC current coil. Coreless induction furnaces are used primarily for remelting in foundry operations and for vacuum refining of specialty metals.

Channel furnaces have a primary coil wound on a core. The secondary side of the core is in the furnace interior, surrounded by a molten metal loop. Channel furnaces, which are generally more efficient than coreless ones, are usually holding furnaces for nonferrous metals melting combined with a fuel-fired cupola, arc, or coreless induction furnace, although they are also used for melting as well.

The efficiency of induction heating systems varies by specific application and depends on several factors: the characteristics of the work piece, coil design, the types and capacity of the power supply, and the degree of temperature change required for the application. Induction heating only works directly with conductive materials, usually just metals. Induction heating can be used to heat plastics and other non-conductive materials by heating a conductive metal susceptor that transfers the heat to the non-conductive material. Induction heating can also be used to heat liquids in vessels and pipelines. Induction heating is often used by the petrochemical industry.

When heating conductive materials, about 80 percent of the heating effect occurs on the surface of the part. Because the heat intensity diminishes as the distance from the surface increases, small or thin parts generally heat more quickly than large or thick parts, especially if the larger parts need to be heated all the way through. Induction heating has no contact between the material being heated and the heat source, which is important for some operations. This facilitates automation of manufacturing processes because once an induction system is calibrated for a part, work pieces can be loaded and unloaded automatically. Other examples using induction heating include heat treating, curing of coatings, and drying.

It is easier to heat magnetic materials with induction technology. Magnetic materials also produce heat through the hysteresis effect – friction caused by magnetic resistance to rapidly alternating electrical fields, in addition to the heat induced by eddy currents.
Induction processing is mainly used in the refining and remelting of metals such as aluminum, copper, brass, bronze, iron, steel, and zinc. Induction heating is often used where repetitive operations are performed. Induction systems are also found in applications where only a small selected part of a work piece needs to be heated. Because induction systems are clean and release no emissions, a part can be hardened on an assembly line without having to go to a remote heat treating operation.

Process Heating Applications: Forming, Heat Treating, High Temperature Heating.

Industries Used In: Steel & Metal Production, Metal Casting, Aluminum, Fabricated Metal Products, Defense (ordnance), Machinery, Electronics, Transportation Equipment, Medical Equipment, Miscellaneous Manufacturing.

Laser Heating

Laser processing systems have grown from small laboratory lasers created in the 1960s to powerful tools found in many industrial sectors. Because lasers have high energy density, they can be applied in a wide range of manufacturing processes. Industrial lasers are well-suited for operations such as cutting, welding, surface heating, melting, roughening, and cleaning. Currently, thousands of industrial-scale units are in use in highly automated workstations for surface hardening, material removal, and welding operations.

Lasers produce a source of high-intensity, high-energy light by passing electricity through a lasing medium. All of a laser’s light is of the same wavelength and in the same phase, yielding a very high energy density. Lasing mediums can be gases or solid state. Gas lasers use mixtures of carbon dioxide, helium, and nitrogen. Solid state lasers use materials like yttrium-aluminum-garnet crystals. Both gas and solid state lasers are commonly found in industrial manufacturing processes.

The most common process heating application using lasers is for surface hardening. With laser beam heating, a laser beam is focused on a work piece area, causing the surface to be heated rapidly. For surface hardening, laser heat treating transmits energy to a material’s surface and transforms the metal to create a hardened layer. After being heated, the material is either quenched or else heat sinking from the surrounding area provides self-quenching. They are best used to harden a specific area instead of an entire part. Laser hardening is usually an energy efficient technology.

Lasers can be precisely controlled, making laser heating well-suited for applications where selective areas within a given work piece are subject to high stress such as crankshafts, gears, and high-wear areas in engine components. Except for single phase stainless steels and certain types of cast iron, most common steels, stainless steels and cast irons can be hardened by laser processing.

Process Heating Applications: Heat Treating, Machining, Welding.

Industries Used In: Primary Metals, Fabricated Metal Products, Textiles, Electronics.

Microwave Processing

Microwave processing technology was spun off from research on radar systems during World War II. The first industrial use of microwave processing was in the food industry. Few other, viable industrial applications emerged until the 1980s when the technology showed promise for increasing productivity and reducing energy costs in other industrial sectors.

Microwave refers to the radio-frequency portion of the electromagnetic spectrum between 300 and 300,000 MHz. Microwaves are well-suited to heat materials that are electrically non-conductive (dielectrics). The material to be heated also needs to be composed of polar molecules, like water. Polar molecules have an asymmetric structure and align themselves to an imposed electric field. When the direction of the electric field is rapidly alternated, the molecules move in synchronization, creating friction and producing heat.

Microwaves are produced by magnetron tubes, which are composed of a rod-shaped cathode surrounded by a cylindrical anode. Electrons flow from the cathode to the anode, creating an electric and magnetic field. The field frequency is a function of the dimension of the slots and cavities in the magnetron. The oscillations in the slots and cavities form microwaves.

A microwave processing system is usually comprised for four components:

1. Microwave generator. The power supply and the magnetron. Magnetrons are typically water- or air-cooled and must be replaced approximately every 6,000 hours.

2. Applicator. Wave guides direct the microwaves to the product being heated.

3. Materials Handling System. A system that position the product under the applicator or exposure area.

4. Controller. A system that monitors the heating and regulates exposure time.

The most widespread use of industrial microwave processing is in the food industry for applications like heating, tempering, drying, and precooking. Other non-food applications include rubber vulcanization, welding of plastics, and drying textiles.

Microwaves have a higher power density and usually heat material faster than radio-frequency waves. Radio-frequency processing's lower frequency waves are better suited for heating thicker materials. For a given application, one technology is usually better than the other.

Process Heating Applications: High Temperature Heating, Low Temperature Heating, Drying, Curing, Heat Treating.

Industries Used In: Food Products, Paper/Wood Products, Pharmaceuticals, Textiles, Chemicals, Rubber & Plastics, Leather, Textiles, Construction Materials.

Plasma Processing (arc and non-transferred arc)

Industrial plasma processing systems have been in use for over 30 years. Initially, plasma processing was used for welding and cutting operations. More recently, plasma processing was successfully developed for metals heating and melting applications.

Plasma is a state of matter formed when a gas is ionized. It can be generated by exposing a gas to a high-intensity electric arc, or by rapidly changing electromagnetic fields generated by induction, capacitive, or microwave generators. These processes raise the gas's temperatures to as much as 20,000^{0}F, freeing electrons from their atoms. Power is regulated by changing the levels of arc current and arc voltage.

There are two types of plasma processing; transferred arc and non-transferred arc. In transferred arc processing, an arc forms between the plasma torch and the material to be heated. The plasma torch acts as a cathode, the material as the anode, and an inert gas passing through the arc is the plasma. These systems are commonly used for metals heating and melting. With non-transferred arc processing, both the anode and the cathode are in the torch itself. The torch heats a plasma gas composed of gases like argon or hydrogen, creating extremely high temperatures that can provide heat for chemical reactions and other processes.

Applications include melting of scrap metals and remelting in the refining processes. Plasma processing is common in the titanium industry, as well as for melting high-alloy steels, tungsten, and zirconium. Plasma processing can also be used in the reduction process for sponge iron and smelting reduction of iron ore and scrap.

Process Heating Applications: High Temperature Heating & Melting, Casting.

Industries Used In: Primary Metals, Metal Casting, Fabricated Steel Products, Electronics, Chemicals, Miscellaneous Manufacturing.

Radio-Frequency Processing

The concept of using radio waves to heat material was discovered in the late 19th century, but industrial applications were not developed until the 1930s, when techniques for generating very high-power radio waves were discovered.

The radio-frequency portion of the electromagnetic spectrum is between 2 and 100 MHz. As with microwaves radio-frequency waves can only be used to heat materials that are electrically non-conductive (dielectrics).

Radio-frequency waves are produced by radio frequency generators. These are either a controlled frequency oscillator with a power amplifier (called “50-ohm” or “fixed impedance” RF generators) or a power oscillator in which the load to be heated is part of the resonant circuit (“free-running oscillators). 50-ohm generators are used exclusively in industrial heating applications in Europe, Japan, and in the semiconductor industry. The older, free-running oscillator is still found in industrial heating applications in the U.S., but many are being replaced with fixed impedance generators due their many advantages.

A radio-frequency processing system is usually composed for five components:

1. RF generator. The oscillator and an amplifier.
2. Impedance matching network (for 50-ohm generators).
3. Applicator. Electrodes that expose the RF electric field to the product.
4. Materials handling system. Systems that position the product under the applicator or exposure area.
5. Controller. System that monitors the heating and regulates exposure time.

Although convection ovens can perform the same heating tasks as RF ovens, radio-frequency processing is generally more productive, more energy efficient, and requires less labor and space. In some cases hybrid systems have both radio-frequency processing and a convection oven.

Microwave processing systems have higher power density than radio-frequency waves and usually heat material faster, white radio-frequency processing’s lower frequency waves are better suited for thicker materials. For a given application, one technology is usually better than the other.

Process Heating Applications: High Temperature Heating, Drying, Curing, Low Temperature Heating.

Industries Used In: Food Processing, Textiles, Clothing, Wood Products, Furniture, Paper Products, Printing, Rubber & Plastics, Chemicals, Glass, Fabricated Metal Products, Machinery, Electronics, Transportation Equipment, Instrumentation, Miscellaneous Manufacturing.

Resistance Heating and Melting

Resistance heating is the simplest and oldest electric-based method of heating and melting metals and non-metals. Resistance heating applications can be precisely controlled, are easily automated, have low maintenance, and no emissions from combustion. Resistance heating is commonly found in both high- and low-temperature applications ranging from melting metals to heating food products. In many cases resistance heating is chosen because of its simplicity and efficiency, which can reach near 100 percent. There are two basic types of resistance heating: direct and indirect.

Direct Resistance Heating. With direct resistance heating, electricity is passed directly through the material to be heated, heating it directly due to the Joule effect, which states when electricity flows through a substance, the rate of evolution of heat in watts equals the resistance of the substance in ohms times the square of the current in amperes. Typically, metal is clamped to electrodes in the walls of a furnace and charged with electric current. Electric resistance within the load or material generates heat, which heats or melts the metal. The temperature is controlled by adjusting the current, which can be either AC or DC.

The material to be heated must conduct at least a portion of the electric current for direct resistance to work. The lower the conductivity, the greater the resistance and the amount of heat generated. For metals such as steel, that have low conductivity, resistance heating is quite efficient. Direct resistance heating is used application like heat treating, forging, extruding, wire making, seam welding, and glass heating. Direct resistance heating is also used to raise the temperature of steel pieces prior to forging, rolling, or drawing applications. Direct resistance furnaces are also used for holding molten iron and aluminum.

Process Heating Applications: High Temperature Melting, Casting.

Industries Used In: Primary Metals, Fabricated Metal Products, Stone, Glass & Mineral Products.

Indirect Resistance Heating. With indirect resistance heating, a resistance heating element transfers heat to the material by radiation, convection, or conduction. The heating element is made of a very high resistance material such as graphite or silicon carbide. Heating is usually done in a furnace lined with ceramic, brick, and fiber batting, and furnace interiors can be air, inert gas, or a vacuum.

Indirect resistance heating is also done in encased heaters, where the resistive element is enclosed in an insulator. The heater is placed in a tank filled with a liquid that needs to be heated or close to a solid that requires heating. Numerous other types of resistance heating equipment are used, including strip heaters, cartridge heaters, and tubular heaters.

Resistance heaters that use convection as the primary heat transfer method are primarily used for applications below 1250º F, while those that use radiation are used in applications that require higher temperatures, sometimes in vacuum furnaces. Indirect resistance furnaces come in a variety of materials and configurations. Some are small enough to fit on a counter top and others are as big as a semi-truck.

Indirect resistance heaters are used for a variety of applications, including heating water, sintering ceramics, heat pressing fabrics, brazing and preheating metal for forging, stress relieving, and sintering.

Indirect resistance heating is also used to heat liquids, including paraffins and acids. Heating is typically done with immersion heaters, circulation heaters, or band heaters. Many hybrid applications also exist, including “boosting” in fuel-fired furnaces to increase production capacity.

Process Heating Applications: High Temperature Heating, Low Temperature Heating, Melting, Casting, Heat Treating, Drying & Curing.

Industries Used In: Food Processing, Textiles, Furniture, Printing, Chemicals, Rubber & Plastics, Leather Products, Stone, Glass & Mineral Products, Steel, Metal Casting Aluminum, Fabricated Metal

Products, Machinery, Electronic Equipment, Transportation Equipment, Instrumentation, Miscellaneous Manufacturing.

The following electrotechnologies compete against process heating applications, but they do not strictly involve heating a product.

Freeze Concentration – uses a refrigeration cycle to reduce the temperature of a solution, crystallizing the solvent. Removing the crystallized solvent leaves a concentrated product. Freeze concentration is used in the citrus industry to concentrate juices, in other food industries, and for salt water desalination. Its advantages over the two other major alternatives, physical separation and vaporization, have enabled its rapid adoption. The benefits of freeze concentration include lower energy consumption, better product quality, greater product recovery, and reduced capital, maintenance and transportation costs. While there are many types of freeze concentration systems, indirect freeze concentration models are best suited for food processing. A heat-exchange surface keeps the product separate from the refrigerant and a mechanical device scrapes the surface to prevent ice deposits from forming as the components freeze. In addition, freeze concentration has been shown to be an efficient volume reduction technology for bleaching plant effluents in paper-pulp mills and for removing adsorbable organic halogens and or non-process elements from recycled water.

Process Heating Applications: Drying, Separating
Industries Used In: Food Processing, Paper, Chemicals (Alkalis & Chlorine, Synthetic Fibers), Pharmaceuticals, Petroleum.

Industrial Process Heat Pumps – use a compression cycle to raise the temperature of a working fluid. This technology is well suited where large quantities of hot water, low-pressure steam, or water vapor are needed; for industrial dehumidification and drying processes at low and moderate temperatures (maximum 212ºF); and also for fractional distillation in the petroleum and chemical industries. Other applications include drying of pulp and paper, various food products, wood and lumber, and evaporation and distillation processes. The most prevalent type of heat pumps in industry is electric closed-cycle compression heat pumps. This technology's adoption has grown steadily because it saves energy, has lower emissions and a reduced footprint, and it yields better product quality. However, in some applications natural gas-based heating and cogeneration have been competitive enough to mitigate its adoption.

Process Heating Applications: Drying, Separating, Low Temperature Heating, Heat Treating, Other Heating Processes (washing, cleaning, dyeing).

Industries Used In: Food Processing, Tobacco Products, Textiles, Wood Products, Furniture, Paper, Chemicals, Petroleum, Rubber & Plastics, Electronic Equipment.

Membrane Processing – depends on an electric motor to drive a product stream through a semi-permeable barrier for purification and to fractionate or concentrate liquids and gases. The main types of membrane separation technology include reverse osmosis, ultra filtration, and microfiltration. This technology's rapid growth is due to the technological advantages it possesses over competing technologies such as vaporization, which include lower energy use, better production reliability, reduced footprint, lower capital costs, lower emissions, and better product quality. In addition, salable by-products such as corn syrup and edible oils can be reclaimed from waste streams. More and more food processing businesses that handle fluids -- from wine to cheese, juice to gelatin are choosing new membrane separation technology for fluid clarification, concentration, and more.

Process Heating Applications: Drying, Separating, Other Heating Processes (washing, dyeing).

Industries Used In: Food & Beverage Processing, Textiles, Paper, Chemicals, Petroleum, Electronic Equipment.

UV Curing - Ultraviolet (UV) processing has been used for many years to cure various types of industrial coatings and adhesives, as well as for curing operations in printing and electronic parts applications. Other types of UV processing are used extensively in the wastewater industry to treat water and in air treatment systems to purify indoor air. The four main applications for UV curing are coatings, printing, adhesives, and electronic parts.

UV radiation is the part of the electromagnetic spectrum with a wavelength from 4 to 400 nanometers. Applying UV radiation to certain liquid polymeric substances transforms (cures) the substance into a solid. Curing is the process of bonding or fusing a coating to a substrate – curing can also develop specific properties in the coating.

UV radiation is created using UV lamps which are typically use a mercury vapor lamp or xenon gas arc. The most common industrial UV system is a medium-pressure mercury-based lamp. A high voltage discharge ionizes in a tube filled with mercury gas, which creates UV radiation. The discharge can be created by an arc between two electrodes or by microwave radiation. The lamp is housed in an enclosure with a reflector. The lamp is usually cooled with a fan or uses water cooling to prolong lamp life.

Convection and radiant systems can perform the same curing processes as UV-based systems however UV-based systems typically have more rapid curing speeds and do not produce as much VOC-based emissions. UV-based systems require special UV-curable coatings and generally require a custom-made UV lamp system for a particular application. UV curing uses around 25 percent of the energy required by a thermally-based system using a fuel-fired oven. UV systems can increase output because of the nearly instantaneous curing time. Although UV coatings are more expensive per gallon, when they are used the plant does not require a costly thermal oxidizer to destroy VOCs emitted by solvent-based coatings.

Process Heating Applications: Drying & Curing.

Industries Used In: Textiles, Furniture, Paper, Printing, Rubber, Plastics, Stone & Glass, Fabricated Metal Products, Electronic Equipment, Miscellaneous Manufacturing.

Electrolytics

Electrolytics are used primarily in the process and materials production industries. In electrolytic processes, process reactants are maintained in ionic form in an electrolyte. Voltage is applied to electrodes that are immersed in the electrolyte, and the ions are separated. Electrolytics are used to produce materials such as chlorine, caustic soda, metals, and to deposit finishes. Electrolytic processes can be classified in the following three broad categories:

<u>Electrolytic Separation/Synthesis</u> – electrolytic separation processes are among the most frequently performed processes in the chemicals industry. Many chemicals and compounds such as chlorine and caustic soda are produced via electrolytic separation. An important application of electrolytic synthesis is electrodialysis, in which ions are transported through ion permeable membranes from one solution to another under the influence of a potential gradient. This requires the application of voltage between two end electrodes to generate the required electrical field. Because the membranes used in electrodialysis can selectively transport ions having positive or negative charge and reject ions of the opposite charge, useful concentration, removal, or separation of electrolytes can be achieved. Electrodialysis has become widespread for uses including reducing electrolyte content in fluids, recovering valuable materials from waste streams, salt splitting and ion substitution. Separation and synthesis represent slightly more than 30 percent of the electricity used in electrolytics.

Process Heating Applications: Separation.
Industries Used In: Chemicals.

Electrolytic Reduction – electrolytic reduction processes typically employ high-temperatures (usually greater than 1832^0 F) using molten salt electrolyte to extract metals from ores. The chief advantage of electrolytic reduction is that the density of the electric current can be precisely controlled, leading to high product purity/quality. Aluminum is the dominant product produced by high-temperature electrolytic processes. Other products made using this process include sodium and magnesium. Zinc, copper and manganese are produced in low-temperature electrolytic cells from aqueous solutions. Copper is the most commercially significant product made using low-temperature electrolytic reduction processes (10 percent of all copper produced is through low-temperature electrolytic reduction). Chromium and lead are also produced in small quantities through electrolysis. In addition, electrolytic reduction cleaning is one of the most efficient and effective methods of conserving metal artifacts or components. About 65 percent of the electricity used in electrolytics is for reduction.

Process Heating Applications: Reduction.
Industries Used In: Primary Metals, Metal Casting, Aluminum.

Electrolytic Deposition/Removal – these electrolytic processes are used to deposit finishes on metal or remove metal from a metallic work piece. Electrogalvanization uses an electrolytic cell and a zinc salt solution to form a protective ring coating on a steel strip. Electrofinishing uses a variety of electrolytic methods to produce finishes on manufactured products. Electrochemical machining passes current through an electrolyte to a conductive work piece, dissolving material by the electrochemical reaction produced. This is particularly useful for removing rust from tools or artifacts without altering the surface of the metal. These methods use between 4 percent and 5 percent of electrolytic processes' electricity consumption.

Process Heating Applications: Deposition, Removal.
Industries Used In: Primary Metals, Metal Casting, Aluminum.

Machining and Welding

Some electrotechnologies compete with conventional machining operations or are used for welding operations.

Machining

Electron Beam Machining

As with electron beam heating, electron beam machining (EBM) uses a high energy beam of electrons. However, instead of using the beam for heating applications, in EBM it is used for drilling and cutting, metals, non-metals, ceramics, and composite materials. EBM is very similar to laser-beam machining and many of the same rules and guidelines for selecting when to use electron beam machining are the same. The biggest difference between electron-beam machining and laser-beam machining is that electron-beam machining requires a vacuum chamber, which limits the size of the part to be machined. A vacuum chamber is required because if the beam comes into contact with air molecules, these molecules can alter the course of the beam.

In EMB a stream of electrons is accelerated and forced through a valve in the electron beam machine. After passing through the valve, the beam is focused onto the surface of the work piece by a series of electromagnetic lenses and deflector coils. This bombardment with electrons causes the affected section of work piece to heat up and vaporize. If the impulse of the electron beam is too great, the part will over heat and potentially ruin the machined piece by either distorting a feature or relaxing strength built up from material cold-working or tempering.

For machining operations, other systems include numerically-controlled machine tools. For melting and heat treating operations, electron beam systems can perform the same operations as electron furnaces.

Industries Used In: Primary Metals, Fabricated Metal Products, Glass, Ceramics.

Electric Discharge Machining

EDM is a machining method primarily used for hard metals or metals that would be impossible to machine using traditional techniques. EDM is particularly well-suited for cutting intricate contours or delicate cavities that are difficult to produce with a grinder, an end mill or other metal cutting tools. Metals that are commonly machined with EDM include hastalloy, hardened tool-steel, titanium, carbide, inconel and kovar. One critical limitation of EDM is that it only works with materials that are electrically conductive.

EDM removes metal by producing a rapid series of repetitive electrical discharges that melt away small metal particles. These electrical discharges are passed between an electrode and the work piece. The small amount of material that is removed from the work piece is flushed away with a continuously flowing fluid. The repetitive discharges create a set of successively deeper craters in the work piece until the final shape is produced.

There are two primary EDM methods: ram EDM and wire EDM. The primary difference between the two involves the electrode that is used to perform the machining. In a typical ram EDM application, a graphite electrode is machined with traditional tools. The now specially-shaped electrode is connected to the power source, attached to a ram, and slowly fed into the work piece. The entire machining operation is usually performed while submerged in a fluid bath that serves the following three purposes:

- Flushes material away
- Serves as a coolant to minimize the heat affected zone (thereby preventing potential damage to the work piece)
- Acts as a conductor for the current to pass between the electrode and the work piece

In wire EDM, which is typically done in a bath of water, a very thin wire serves as the electrode. Special brass wires are typically used and the wire is slowly fed through the material where the electrical discharges cut out complex contours in the work pieces. This is often used in the production of moulds and dies, and for improving the surface quality (roughness and metallurgical structure) of machined pieces.

Industries Used In: Food & Beverages, Primary Metals, Fabricated Metal Products, Rubber & Plastics, Transportation Equipment, Electronic Equipment, Medical Equipment.

Electrochemical Machining

Electrochemical Machining (ECM) is a newer technology that removes metal by anodic dissolution in which a direct current with high density (10 – 100 A/cm2) and low voltage (8 to 30 V) is passed from a pre-shaped tool acting as a cathode onto a work piece acting as the anode. The metal on the surface of the work piece surface is dissolved into metallic ions by the deplating reaction, and thus the tool shape is copied into the work piece. Dissolved material, gas, and heat are removed from the narrow machining gap by the flow of electrolyte pumped through the gap at a high velocity (5 – 50 m/s).

ECM is capable of machining any electrically-conductive material with high stock removal rates regardless of their mechanical properties. In particular, removal rate in ECM is independent of the hardness, toughness and other properties of the material being machined. There is no need to use a tool made of a harder material than the work piece, and there is practically no tool wear. Recently, ECM has become more widespread in manufacturing facilities and in computer-aided systems to design tool electrodes.

ECM offers a number of advantages over other machining methods. Complex-shaped parts can be produced by simply moving the tool without rotation. Also, because ECM leaves no burrs one ECM operation can replace several operations of mechanical machining. ECM can remove a defective layer of material and eliminate the flaws inherited by the surface layer from a previous treatment without any residual stress in the work piece. Since there is no contact between the tool and the work piece, ECM is the machining method of choice in the case of thin-walled, easily deformable components and also brittle materials likely to develop cracks in the surface layer.

At the same time, ECM has some disadvantages. Accurate replication of the tool electrode shape is hard because there is some difficulty in confining the ECM process precisely within the areas that must be machined. Some metal is also dissolved from adjacent areas on the work piece. ECM machines often cost more than conventional metal-cutting machines and have a larger footprint. The electrolytes used in ECM attack the equipment and the waste sludge created by ECM equipment is environmentally hazardous.

The most common uses for ECM include:

(1) Duplicating, drilling and sinking operations in the manufacture of dies, press and glass-making moulds, the manufacture of turbine and compressor blades for gas-turbine engine, the generation of passages, cavities, holes and slots in parts, and the like.
(2) Electrochemical shaping of rotating work piece and ECM using rotating tool-electrode.

Industries Used In: Primary Metals, Fabricated Metal Products, Electronics, Transportation Equipment, Medical Equipment.

Electroforming

Electroforming is a highly specialized process that uses electrodeposition in a plating bath over a base form or mandrel which is subsequently removed. The process synthesizes a metal layer on a metal surface, or any surface that has been rendered electroconductive through the application of a paint that contains metal particles. This process is different from electroplating because the layer is much thicker and can exist as a self-supporting structure if the original work piece is removed. The object being electroformed can be a permanent part of the end product or can be temporary (as in the case of wax), and removed later, leaving only the metal form, the “electroform.”

In the basic electroforming process, an electrolytic bath is used to deposit nickel or other electroplatable metals onto a conductive patterned surface, such as glass or stainless steel. Once the plated material is built up to the desired thickness, the electroformed part is stripped off the base. This process allows high-quality duplication of the master form and ensures high product quality with high repeatability and excellent process control.

Compared to other basic metal forming processes (casting, forging, stamping, deep drawing, machining and fabricating) electroforming is very effective, particularly when requirements call for extreme tolerances, complexity or light weight. The precision and resolution inherent in the photographically produced conductive patterned base, allows finer geometries to be produced to tighter tolerances while maintaining superior edge definition with a near optical finish. Electroformed metal is extremely pure, with superior properties over wrought metal due to its refined crystal structure. Multiple layers of electroformed metal can be molecularly bonded together, or to different substrate materials to produce complex structures with flanges and bosses.

A wide variety of shapes and sizes can be made by electroforming, the principal limitation being the need to strip the product from the base. Since the fabrication of a product requires only a single pattern or mandrel, low production quantities can be made economically. In recent years, electroforming has taken on new importance in the fabrication of micro and nano scale metallic devices and in producing precision injection molds with micro and nano scale features for production of nonmetallic micro molded objects. Electroforming tolerances of 1.5 to 3 nano meters have been reported.

Industries Used In: Primary Metals, Fabricated Metal Products, Rubber & Plastics, Printing, Aerospace, Electronics, Medical Equipment.

Electrochemical Finishing

Electrochemical finishing is a process that protects or prepares a metallic surface with electrolytic substances. An item to be electrochemically finished is immersed in an electrolyte and is made the positive electrode. When the electric current passes through the electrolyte, metal is dissolved from the anode surface, with protrusions being dissolved faster than depressions, thereby producing a smoothening of the surface.

Common electrofinishing processes include passivation, bluing, and parkerizing. Passivation is the process of making a material "passive" in relation to another material prior to using the materials together. For example, prior to storing hydrogen peroxide in an aluminum container, the container can be passivated by rinsing it with a dilute solution of nitric acid and peroxide alternating with deionized water. The nitric acid and peroxide oxidizes and dissolves any impurities on the inner surface of the container and the deionized water rinses away the acid and oxidized impurities. Bluing is a passivation process in which steel is partially protected against rust, and is named after the blue-black appearance of the resulting protective finish. Bluing is most commonly used by gun manufacturers, gunsmiths and gun owners to improve the cosmetic appearance and provide limited resistance against rust of the firearm. Bluing is also used for providing coloring for steel parts of fine clocks and other fine metalwork. Parkerizing (also called phosphating and phosphatizing) is a method of protecting a steel surface from corrosion and increasing its resistance to wear through the application of an electrochemical conversion coating.

Industries Used In: Primary Metals, Fabricated Metal Products, Aluminum, Medical Equipment.

Laser Beam Machining

Laser-beam machining (LBM) is a process that uses a laser beam to melt, burn or vaporize unwanted material away from a work piece. LBM is well suited for making accurately placed holes and can be used to perform precision micromachining on all microelectronic substrates such as ceramic, silicon, diamond, and graphite. Examples of microelectronic micromachining include cutting, scribing & drilling all substrates, trimming any hybrid resistors, patterning displays of glass or plastic and trace cutting on semiconductor wafers and chips.

The LBM process can make holes in refractory metals and ceramics and in very thin materials without warping the work piece. The laser can scribe, drill, mark, and cut thin metals and ceramics, trim resistors, and process plastics, silicon, diamond, and graphite with tolerances to one micron leaving an edge with a high quality surface finish.

Because the laser beam can be precisely controlled and varied in output and by timeframe, laser machining is generally an energy efficiency technology. Laser machining can rapidly and accurately cut most materials with little heat-induced distortion. These attributes also make laser machining good for precise material removal.

Advantages of LBM over conventional machining include: lack of physical contact with the work piece, high precision and lower risk of warping due to the small heat affected zone. Also, some materials that are very difficult or impossible to machine using conventional methods can be machined using LBM.

Industries Used In: Fabricated Metal Products, Aluminum, Rubber & Plastics, Glass, Electronics, Transportation Equipment, Medical Equipment.

Water Jet Cutting

Laser-beam machining (LBM) is a process that uses a laser beam to melt, burn or vaporize unwanted material away from a work piece. LBM is well suited for making accurately placed holes and can be used to perform precision micromachining on all microelectronic substrates such as ceramic, silicon, diamond, and graphite. Examples of microelectronic micromachining include cutting, scribing & drilling all substrates, trimming any hybrid resistors, patterning displays of glass or plastic and trace cutting on semiconductor wafers and chips.

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Industries Used In: Fabricated Metal Products, Aluminum, Rubber & Plastics, Glass, Electronics, Transportation Equipment, Medical Equipment.

Welding

Electron Beam Welding

Electron beam welding (EBW) is a fusion welding process in which a beam of high-velocity electrons is applied to the materials being joined. Electron beam processing is used for welding metals, machining holes and slots, to harden the surface of metals, and for heat treating and melting. Electron beam processing can be over ten times as fast as conventional welding systems. Other competitive benefits include minimal thermal distortions because the power density and energy input can be precisely controlled, substantially reduced set-up and post cleaning time, lower labor costs, and the ability to achieve complex and precise heating patterns.

Electron beams operate at temperatures of around 45,000 °F. The heat penetrates deeply, making it possible to weld much thicker work pieces than is possible with most other welding processes. Because the electron beam is tightly focused, the total heat input is lower than that of any arc welding process, resulting in a small heat-affected zone that lessens the impact on surrounding material, minimizes distortions, and enables the work piece to cool rapidly. Another advantage of the tight beam and high melting rate is higher welding speeds. Almost all metals can be welded by the process, but those most commonly welded are stainless steels, super alloys, and reactive and refractory metals. The process is also widely used to perform welds of a variety of dissimilar metals combinations.

Present-day electron-beam welding is performed using an electron gun enclosed in a large vacuum chamber, which limits the size of the work piece that can be welded and requires large vacuum pumps that consume large amounts of electricity and special, expensive lubricants. A promising emerging technology, called a plasma window, is expected to overcome these obstacles by facilitating non-vacuum electron-beam welding in which the plasma window is mounted on the electron gun and maintains the small vacuum area needed to propagate the electron beam. This EB welding technique is more energy-efficient and can allow for faster production as well as welding of larger structures, such as airplanes and ships.

Industries Used In: Fabricated Metal Products, Aluminum, Aerospace, Glass, Electronics, Transportation Equipment, Medical Equipment, Petroleum, Energy, Paper, and Chemicals.

Laser Beam Welding

Laser beam welding (LBW) is a welding technique used to join multiple pieces of metal through the use of a laser. The beam provides a concentrated heat source, allowing for narrow, deep welds and high welding rates. Laser processing tends to be faster and has less product distortion compared to conventional welding techniques.

As with electron beam welding, laser beam welding has high power density, resulting in small heat-affected zones and high heating and cooling rates. LBW is a versatile process, capable of welding carbon steels, high strength low alloy steels, stainless steel, aluminum, and titanium. Due to high cooling rates, cracking is a concern when welding high-carbon steels. The weld quality is high, similar to that of electron beam welding. The speed of welding is proportional to the amount of power supplied but also depends on the type and thickness of the work pieces.

A derivative of LBW, laser-hybrid welding, combines the laser of LBW with an arc welding method. This combination allows for greater positioning flexibility, since the arc melting method supplies molten metal to fill the joint, and due to the use of a laser, increases the welding speed over what is normally possible with arc melting. Weld quality tends to be higher as well, since the potential for undercutting is reduced.

Industries Used In: Fabricated Metal Products, Aluminum, Rubber & Plastics, Glass, Electronics, Transportation Equipment, Medical Equipment, Defense, Research & Development, Petrochemical, Communications, and Energy.

Plasma Welding

The plasma welding process was introduced to the welding industry in 1964 as a way to improve control in lower current ranges of arc welding processes. Today, plasma welding retains the original advantages it brought to industry by providing an advanced level of control and accuracy to produce high quality welds in miniature or precision applications and to provide long electrode life for high production requirements. Plasma welding is equally suited to manual and automatic applications and is used in a variety of applications ranging from high volume welding of strip metal, to precision welding of surgical instruments, to automatic repair of jet engine blades, to the manual welding of kitchen equipment.

Similar to the Tungsten Inert Gas (TIG) process, the plasma arc welding process uses plasma to transfer an electric arc through a Tungsten torch to a work piece. However, by positioning the electrode within the body of the torch, the plasma arc can be separated from the shielding gas envelope. Plasma is then forced through a fine-bore copper nozzle causing an arc. The metal to be welded is melted by the intense heat of the arc and fuses together. By forcing the plasma arc through a constricted orifice, the welding torch delivers a high concentration of heat to a small area. With high performance welding equipment, the plasma process produces exceptionally high quality welds.

Three operating modes can be produced by varying bore diameter and plasma gas flow rate: Micro plasma (0.1 to 15A), Medium current (15 to 200A) and Keyhole plasma (over 100A). Micro plasma is generally used for welding thin sheets (down to 0.1 mm thickness), and wire and mesh sections. The needle-like stiff arc minimizes arc wander and distortion. At medium currents, from 15 to 200A, the process characteristics of the plasma arc are similar to those of the TIG arc, but because the plasma is constricted, the arc is stiffer. The main advantages over the TIG process are deeper penetration (from higher plasma gas flow) and greater tolerance to surface contamination including coatings (the electrode is within the body of the torch). At the highest (keyhole) currents (> 100A) a very powerful plasma beam is created that can achieve deep penetration, as in laser or electron beam welding, and high welding speeds. This process can be used to weld thicker material (up to 10mm of stainless steel) in a single pass.

Industries Used In: Fabricated Metal Products, Aluminum, Aerospace, Glass, Electronics, Transportation Equipment, Medical Equipment, Petroleum.

Resistance Welding

Resistance welding refers to a group of welding processes (resistance spot welding, resistance seam welding, projection welding, flash welding, upset welding and high frequency resistance welding) that apply electricity and mechanical pressure to create a weld between two pieces of metal. Weld electrodes conduct the electric current to the pieces of metal as they are forged together. Some factors influencing heat or welding temperatures are the proportions of the work pieces, the electrode materials, electrode geometry, electrode pressing force, weld current and weld time. In general, resistance welding methods are efficient and cause little pollution, but their applications are limited to relatively thin materials.

Industries Used In: Food & Beverage, Fabricated Metal Products, Aluminum, Aerospace, Electronics, Transportation Equipment, Medical Equipment, Nuclear Equipment, Container Manufacturing and Hardware.

Spot welding – is a popular resistance welding method used to overlap metal sheets. Two copper electrodes are simultaneously used to clamp the metal sheets together and to pass current through them. When the current passes through the electrodes to the sheets, heat is generated in the air gap at the contact points, which melts the metal at that spot. As the heat dissipates throughout the work piece over a second or so, it cools the spot weld, causing the metal to solidify.

The advantages of spot welding include efficient energy use, limited work piece deformation, high production rates, easy automation, and no required filler materials. When high shear strength is needed, spot welding is used in preference to more costly mechanical fastening, such as riveting. While the shear strength of each weld is high, the fact that the weld spots do not form a continuous seam means that the overall strength is often significantly lower than with other welding methods.

Seam welding – like spot welding, seam welding relies on two electrodes to apply pressure and current to join metal sheets. However, instead of pointed electrodes, wheel-shaped electrodes roll along and feed the work piece, enabling long continuous welds. In the past, this process was used in the manufacture of beverage cans, but now its uses are more limited.

Projection welding – is a resistance welding process that produces coalescence of metals with the heat obtained from resistance to electrical current through work parts held together under pressure by electrodes. The welds are localized at predetermined points by projections, embossments, or intersections. Localization of heating is obtained by a projection or embossment on one or both of the parts being welded. The major advantage of projection welding is that electrode life is increased because larger contact surfaces are used. A very common use of projection welding is the use of special nuts that have projections on the portion of the part to be welded to the assembly.

Flash welding – is a resistance welding process that produces coalescence simultaneously over the entire area of two abutting surfaces by the heat obtained from resistance to electric current between the two surfaces, and by the application of pressure after heating is substantially completed. The heat is generated by the flashing and is localized in the area between the two parts. The surfaces are brought to the melting point and expelled through the abutting area. As soon as this material is flashed away another small arc is formed that continues until both abutting surfaces are at the melting temperature. Pressure is then applied, the arcs are extinguished and upsetting occurs.

Upset welding – is a resistance welding process that produces coalescence simultaneously over the entire area of abutting surfaces or progressively along a joint by the heat obtained from resistance to electric current through the area where those surfaces are in contact. Pressure is applied before heating is started and is maintained throughout the heating period. Unlike with flash welding, the parts are clamped in the welding machine and force is applied bringing them tightly together. High-amperage current is then passed through the joint, which heats the abutting surfaces. When they have been heated to a suitable forging temperature an upsetting force is applied and the current is stopped. The high temperature of the work at the abutting surfaces with the high pressure causes coalescence to take place. After cooling, the force is released and the weld is completed.

Percussion welding – is a resistance welding process that produces coalescence of abutting metal pieces using heat from an arc produced by a rapid discharge of electrical energy. This is immediately followed by application of pressure to provide an impact bringing the two parts together in a progressive percussive manner. The advantage of the process is that there is an extremely shallow depth of heating and time cycle is very short. It is used only for parts with fairly small cross-sectional areas.

High frequency resistance welding – is a resistance welding process that produces coalescence of metals with the heat generated from the resistance of the work pieces to a high-frequency alternating current in the 10,000 to 500,000 hertz range and the rapid application of an upsetting force after heating is substantially completed. The path of the current in the work piece is controlled by the proximity effect.

This process is ideally suited for making pipe, tubing, and structural shapes. It is used for other manufactured items made from continuous strips of material. In this process the high frequency welding current is introduced into the metal at the surfaces to be welded but prior to their contact with each other. Current is introduced by means of sliding contacts at the edge of the joint. The high-frequency welding current flows along one edge of the seam to the welding point between the pressure rolls and back along the opposite edge to the other sliding contact. The current is of such high frequency that it flows along the metal surface to a depth of several thousandths of an inch. Each edge of the joint is the conductor of the current and the heating is concentrated on the surface of these edges. At the area between the closing rolls the material is at the plastic temperature, and with the pressure applied, coalescence occurs.

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