The EPRI Electrotechnology Reference Guide: A Valuable Tool for the Industrial Sector

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ABSTRACT

EPRI, with support from its members, completed a comprehensive update of the Electrotechnology Reference Guide (ERG) in 2011 (EPRI, 2011). The previous thorough update of the ERG, which is a widely used reference guide by the utility industry, occurred in 1992. The 2011 ERG highlights electricity consumption for major industrial markets and technologies, includes historical electricity use, and provides forecasts to 2020. The ERG covers energy consumption of major industrial sectors (21 North American Industry Classification System (NAICS) codes), major end uses (machine drives, electro-chemical processes, process heating, process cooling and refrigeration, facility HVAC, and facility lighting), and disaggregation across 34 major technologies (within the industries of processing, materials production, materials fabrication, and industrial wastewater treatment). The energy consumption data analyzed in the ERG are based on several data sources, including the Energy Information Administration, EPRI, and the U.S. Census Bureau. The information contained in the ERG is expected to help utilities identify markets for industrial electrotechnologies and understand the potential for growth within these markets. In addition, the ERG is expected to help utilities strengthen their relationships with industrial customers, manage loads more effectively, market new service and power options, assess the competitive position of electricity, and stimulate local economies.

Introduction

Industrial electrotechnologies are broadly defined as technologies that use electricity to manufacture or transform a product. Electrotechnologies can be used in many different types of industrial processes. In most electrotechnologies, electromagnetic, electrochemical, and/or electrothermal effects are inherent parts of the process. In many applications, electricity has advantages over other energy sources based on its unique characteristics (referred to as 'form value') such as on-demand availability, work-site efficiency, precise control, cleanliness, reliability, and security of supply. Electrotechnologies capitalize on electricity's high form value to compete with alternative technologies.

The Electrotechnology Reference Guide (ERG) was first published by EPRI in the early 1980s, with many subsequent partial or complete updates in 1986, 1988, 1992, and 2007). The 2011 update of the ERG is designed to help utility analysts and representatives identify markets for electrotechnologies and understand the potential electricity consumption impacts of these markets. This information can help utilities 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 participate in stimulating their local economy.

The 2011 ERG includes analysis of historical industrial electricity and natural gas consumption data for 1998-2008, electricity consumption forecasts through 2020 for 34 electrotechnologies, and an analysis of end-use applications of electricity and natural gas within the industrial sector for 1998-2008. The historical consumption data are presented for 21 North American Industry Classification System (NAICS) codes for manufacturing (NAICS 31-33), and are grouped into four general categories: 1) process industries, 2) materials production, 3) metals fabrication, and 4) non-metals fabrication. The electrotechnology consumption forecasts are presented for 34 electrotechnologies, which are grouped into four similar, but slightly different, categories:

- Process industries
- Materials production
- Materials fabrication (metals and non-metals)
- Industrial wastewater treatment

Many of the electrotechnologies are used in a single industrial sector, but some are cross-cutting or broadly applicable to all manufacturing sectors.

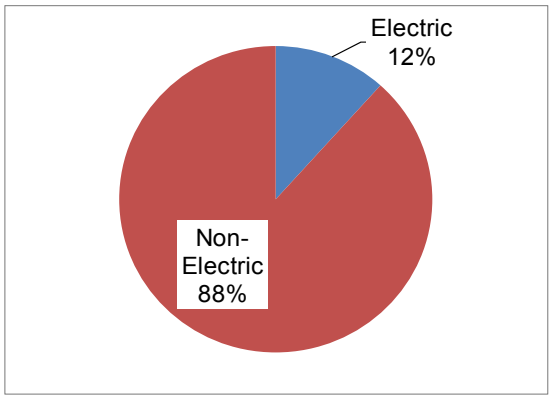
Industry Electricity Use

Electricity accounts for a growing and significant share of energy consumption in the United States. Electricity's share of U.S. end-use energy increased from 11.7% in 1998 to 12.8% in 2008. As illustrated in Figure 1, total U.S. energy use increased from 95 to 99 quadrillion Btu (quads) from 1998 to 2008. During the same time, however, industrial electricity use (which includes manufacturing, agriculture, mining, and construction sectors) decreased from 1,051 to 1,009 billion kWh, a decrease of 4%.

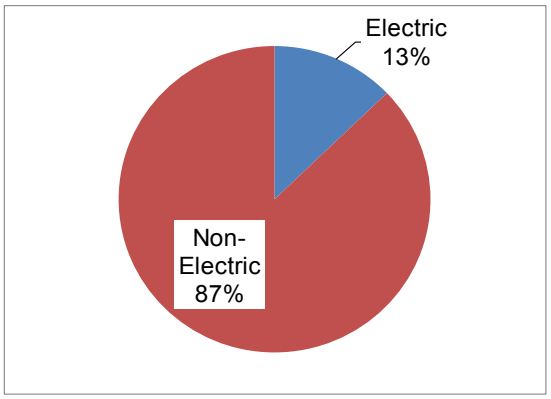
Electricity use for process industries decreased 6% between 1998 and 2008, and use for materials fabrication decreased over 10%, while use for materials production declined by 13%. In contrast, electricity consumption for non-manufacturing industrial sectors (agriculture, mining, and construction) increased by 26% between 1998 and 2008, with almost all of the growth occurring in the construction sector (EPRI, 2011; Table 2-2).

Figure 1. Electricity Use, 1998 and 2008

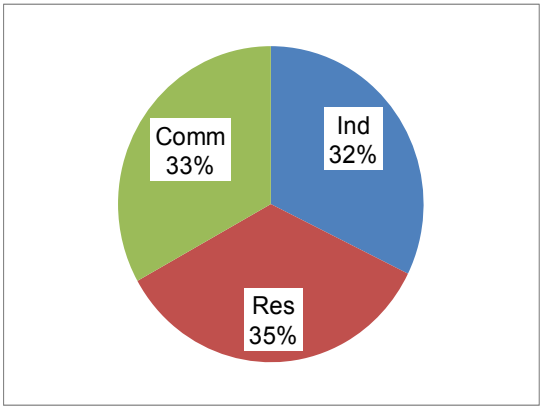
1998 Total Energy Use
95.19 quad (27,899 billion kWh)



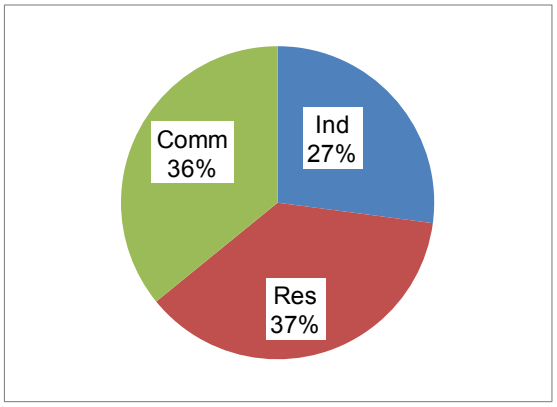
2008 Total Energy Use
99.38 quad (29,127 billion kWh)



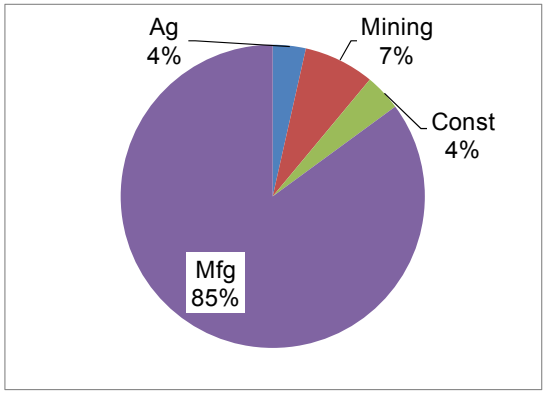
1998 Total Electricity Use
3,264 billion kWh



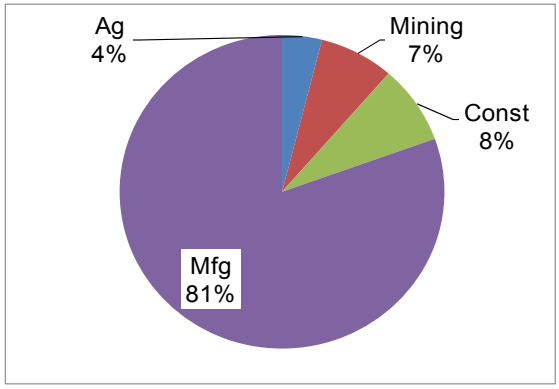
2008 Total Electricity Use
3,733 billion kWh



1998 Industrial Electricity Use
1,051 billion kWh



2008 Industrial Electricity Use
1,009 billion kWh



Source: EPRI (2011)

The industrial sector (NAICS 11-33) consists of manufacturing and non-manufacturing (agriculture, mining, construction) industries. The manufacturing sector dominates industrial energy use, accounting for 80% of the total purchased fuels and electric use and 78% of energy used for heat and power (Table 1). Overall, the manufacturing sector accounts for 79% of total industrial energy use. For electricity, the manufacturing sector represents 80% of purchased electricity, 99% of on-site generation, and 81% of total electricity demand in industry.

Table 1. Industrial Energy Use Summary, 2008

NAICS	Industry	Total Purchased Fuels and Electric Use (trillion Btu)	Energy Used for Heat and Power (trillion Btu)	Total Energy Use (trillion Btu)	Electric Purchases (billion kWh)	Electric Self-Generated Less Sold (billion kWh)	Electric Total (billion kWh)
31-33	Manufacturing	14,655	14,158	18,760	812	86	898
11	Agriculture	964	1,067	1,067	40	0	40
21	Mining	866	2,099	2,119	75	1	76
23	Construction	1,853	798	1,853	82	0	82
11-33	Total Industrial	18,338	18,122	23,799	1,009	87	1,096

Source: EPRI (2011)

The manufacturing sector (NAICS 31-33) consists of a variety of industries. Table 2 shows the electricity trends in the manufacturing sector from 1998 to 2008, with the manufacturing sector categorized into three major groups:

- Process industries
- Industries that are involved in materials production
- Industries that fabricate metals and non-metals

Table 2. Manufacturing Electricity Use Summary, 1998 and 2008

NAICS	Industry	Total Electricity Consumption			Electricity Use As % of Total Energy Use
		Energy Use (billion kWh)		Annual Change (%)	
		1998	2008		2008
Process Industries					
325	Chemicals	170	150	-1.2%	9%
324	Petroleum and Coal	37	40	0.7%	9%
322	Paper	71	70	-0.2%	22%
311	Food	63	73	1.5%	21%
313	Textile Mills	30	15	-6.7%	36%
312	Beverage and Tobacco	7	8	1.4%	29%
314	Textile Products	5	5	-1.5%	26%
Subtotal, Process Industries		383	360	-0.6%	13%
Materials Production					
331	Primary Metals	161	136	-1.7%	25%
327	Nonmetallic Minerals	39	38	-0.4%	13%
Subtotal, Materials Production		200	174	-1.4%	21%
Metals Fabrication					
336	Transportation Equipment	57	53	-0.7%	39%
332	Fabricated Metal Products	52	42	-2.0%	34%
333	Machinery	28	33	1.6%	52%
334	Computer and Electronic Products	40	35	-1.5%	63%
335	Electrical Equipment	16	13	-2.1%	46%
339	Misc Manufacturing	12	10	-2.0%	52%
Subtotal, Metals Fabrication		206	186	-1.0%	44%
Non-Metals Fabrication					
326	Rubber and Plastics	54	47	-1.3%	52%
321	Wood Products	21	22	0.1%	37%
323	Printing	15	13	-1.6%	50%
337	Furniture	9	8	-0.6%	54%
315	Apparel	5	1	-13.1%	47%
316	Leather	1	0	-12.0%	47%
Subtotal, Non-Metals Fabrication		105	92	-1.4%	47%
Subtotal, Materials Fabrication		311	278	-1.1%	45%
Subtotal, All Manufacturing		894	812	-1.0%	19%

Source: EPRI (2011)

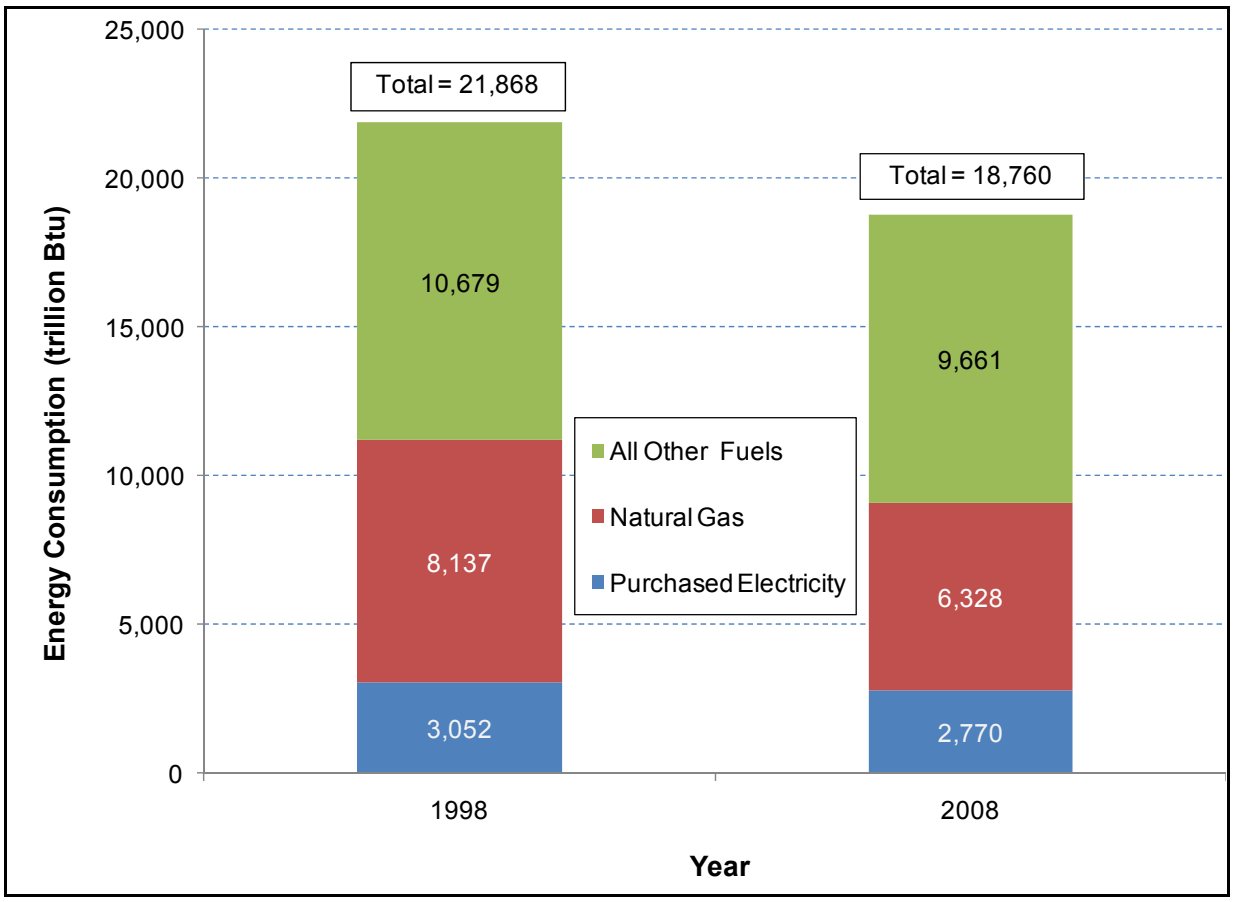
Five of the 21 sectors shown in Table 2 – petroleum and coal products, food, beverage and tobacco, machinery, and wood products – had positive growth from 1998 to 2008. The remaining 16 all showed a decline in electricity use during this time period. This trend is a product of two factors: a decline in manufacturing activity and output, and a decline in electricity intensity.

End-Use Applications

Energy consumption in the industrial manufacturing sector has been declining. Figure 2 shows manufacturing energy consumption (NAICS codes 31-33) for 1998 and 2008. During this time span, energy consumption for the entire sector declined 14% (from 21,868 to 18,760 trillion

Btu), which corresponds to an average annual reduction of 1.5% per year. Natural gas consumption declined at the highest rate, showing an average annual reduction of 2.5% (from 8,137 to 6,328 trillion Btu). Other fuels, which include coal, propane, and fuel oil, declined from 10,680 to 9,661 trillion Btu (an average annual reduction of 1.0%). Purchased electricity consumption declined at a slower rate than the sector average, moving from 3,052 trillion Btu in 1998 to 2,770 trillion Btu in 2008 (average annual decline of 1.0%).

Figure 2. Energy Consumption in the Manufacturing Sector (NAICS 31-33), 1998 and 2008



Source: EPRI (2011)

The primary industrial end-use applications of electricity are machine drives (i.e., electric motors), process heating, process cooling and refrigeration, facility heating ventilation and air conditioning (HVAC), facility lighting, and electrochemical processes. Machine drives are the largest single electric end-use in most industrial subsectors. One exception is primary metals material production, where process heating and electrochemical processes are equally important. Another exception is computer and electronic products, where facility HVAC is a bigger consumer of electricity.

Electricity is the dominant energy source for machine drives for pumps, conveyors, fans, and compressors, as well as for a broad spectrum of crushing, grinding, stamping, trimming,

mixing, cutting, and milling operations throughout the manufacturing industries. Electric motors that drive machines account for just over 50% of total manufacturing electricity use: 417.2 billion kWh of electricity use in 2008.

Electrotechnologies

The electrotechnologies included in the ERG are organized under the three manufacturing categories plus industrial wastewater treatment (see Table 3). Although classified under a specific category, applications of a given electrotechnology often cross over into other categories.

Table 3. Electrotechnologies by Industry Category

Process Industries	**Materials Fabrication (Metals and Non-metals)**
1 - Electrochemical Synthesis	17 - Electric Discharge Machining
2 - Electrolytic Separation	18 - Electrochemical Machining
3 - Freeze Concentration	19 - Electrofinishing
4 - Industrial Process Heat Pumps	20 - Electroforming
5 - Membrane Processes	21 - Electron Beam Processing
6 - Electric Boilers	22 - Flexible Manufacturing Systems/Automation
7 - Pulsed Power	23 - Induction Heating
	24 - Infrared Processing
	25 - Laser Processing
Materials Production	26 - Microwave Heating And Drying
8 - Direct Arc Melting	27 - Radio-Frequency Heating And Drying
9 - Electrogalvanization	28 - Ultraviolet Curing
10 - Electrolytic Reduction	29 - Acoustics/Ultrasound
11 - Electroslag Processing	30 - Industrial Process Measurement, Control, and Integration
12 - Resistance Heating And Melting	31 - Cryogenics
13 - Induction Melting	**Industrial Wastewater Treatment**
14 - Ladle Refining	32 - Industrial Ozonation
15 - Plasma Processing	33 - Industrial Reverse Osmosis
16 - Vacuum Melting	34 - Industrial Ultraviolet Disinfection

Source: EPRI (2011)

National electricity consumption by each manufacturing electrotechnology was estimated for 2010 and was projected to 2020, as summarized in Table 4. The methodology used to make these projections is described as follows:

1. Determine baseline growth of electrotechnology electricity consumption during last decade
2. Determine baseline growth of electricity consumption by end-use application within each industrial sector during last decade
3. Obtain EIA forecast of the growth of electricity consumption by end-use application within each industrial sector during next decade
4. Match electrotechnologies with one or more end-use application within industrial sectors

5. As a first approximation, assume growth of electrotechnology electricity consumption in the next decade will be the same as the baseline growth of electrotechnology electricity consumption during last decade
6. Then correct the electrotechnology electricity consumption forecast based on the difference between electricity consumption growth in the corresponding end-use application(s) forecast for the next decade and the electricity consumption growth in the end-use application(s) in the last decade

Table 4. Electrotechnology Electricity Consumption by Manufacturing Category, 2000-2020

Electrotechnology	Electricity Consumption (million kWh)		
	Historical		Projected
	2000	2010 (est.)	2020
Process Industries			
1 - Electrochemical Synthesis	2,800	1,500	1,900
2 - Electrolytic Separation	42,000	29,000	46,000
3 - Freeze Concentration	35	32	39
4 - Industrial Process Heat Pumps	3,100	4,400	5,000
5 - Membrane Processes	1,200	1,200	1,400
6 - Electric Boilers	3,800	10,000	23,000
7 - Pulsed Power	300	900	4,100
Total Process Industries	53,000	47,000	81,000
Materials Production			
8 - Direct Arc Melting	20,000	13,000	21,000
9 - Electrogalvanization	1,600	400	480
10 - Electrolytic Reduction	59,000	27,000	53,000
11 - Electroslag Processing	740	480	1,300
12 - Resistance Heating And Melting	33,000	21,000	30,000
13 - Induction Melting	2,100	1,200	1,500
14 - Ladle Refining	1,400	510	430
15 - Plasma Processing	170	210	200
16 - Vacuum Melting	120	100	180
Total Materials Production	118,000	64,000	108,000
Materials Fabrication (Metals and Non-metals)			
17 - Electric Discharge Machining	370	140	150
18 - Electrochemical Machining	270	100	120
19 - Electrofinishing	6,100	2,300	2,600
20 - Electroforming	3	1	1
21 - Electron Beam Processing	170	63	72
22 - Flexible Manufacturing Systems/Automation	420	340	410
23 - Induction Heating	63,000	62,000	86,000
24 - Infrared Processing	6,300	4,600	5,700
25 - Laser Processing	130	100	120
26 - Microwave Heating and Drying	220	240	320
27 - Radio-Frequency Heating and Drying	3,800	3,800	4,900

Electrotechnology	Electricity Consumption (million kWh)		
	Historical		Projected
	2000	2010 (est.)	2020
28 - Ultraviolet Curing	4,900	4,200	5,800
29 - Acoustics/Ultrasound	70	150	180
30 - Industrial Process Measurement, Control and Integration	210	190	270
31 - Cryogenics	700	640	790
Total Materials Fabrication (Metals and Non-metals)	87,000	79,000	107,000
Industrial Wastewater Treatment			
32 - Industrial Ozonation	60	110	290
33 - Industrial Reverse Osmosis	28	71	270
34 - Industrial Ultraviolet Disinfection	4	8	25
Total Wastewater Treatment	92	190	590
Total Manufacturing	258,000	190,000	297,000

Source: EPRI (2011)

Generally, electricity consumption by each electrotechnology dropped in the last decade. Major exceptions are industrial process heat pumps, electric boilers, pulsed power, and acoustics/ultrasound. Almost all manufacturing electrotechnologies are projected to grow in the next ten years, except for ladle refining of steel and plasma processing.

Table 5 identifies electrotechnologies showing the greatest potential for kWh growth on a nationwide basis over the next decade. These electrotechnologies account for over 95% of total projected electrotechnology electricity growth. Most of the high growth industry categories involve a process in which electrotechnologies offer unique advantages over competing technologies. For example, electrolytic reduction, induction heating, electrolytic separation, pulsed power, ultraviolet curing, infrared processing, radio-frequency heating and drying, and electroslag processing are electrotechnologies that have unique advantages.

Table 5. Manufacturing Electrotechnologies with Greatest Growth Potential, 2010-2020

Rank	Electrotechnology	Industry Category	Projected Growth (million kWh)	Annual Growth Rate (%)
1	Electrolytic Reduction	Materials Production	26,000	7.0%
2	Induction Heating	Materials Fabrication	24,000	3.3%
3	Electrolytic Separation	Process Industries	17,000	4.7%
4	Electric Boilers	Process Industries	13,000	8.7%
5	Resistance Heating and Melting	Materials Production	9,000	3.6%
6	Direct Arc Melting	Materials Production	8,000	4.9%
7	Pulsed Power	Process Industries	3,200	16.4%
8	Ultraviolet Curing	Materials Fabrication	1,600	3.3%
9	Infrared Processing	Materials Fabrication	1,100	2.2%
10	Radio-Frequency Heating and Drying	Materials Fabrication	1,100	2.6%
11	Electroslag Processing	Materials Production	820	10.5%

Source: EPRI (2011)

Several factors are considered to have contributed to the growth rates for the 11 high potential electrotechnologies shown in Table 5. These factors include:

1. **Electrolytic reduction** is used to produce metallic aluminum from aluminum oxide, to extract metallic zinc from an acid bath by electrolysis, to electro-refine pure copper from impure copper, and to electrowin copper from copper oxide ores. The growth potential for electrolytic reduction is driven by the nearly 7% annual growth rate projected for Electro-Chemical Processes in the Primary Metals Sector.
2. **Induction heating** heats metals from within by placing the work piece inside a coil through which alternating electric current flows. Induction heating has numerous applications in metals fabrication, where its unique advantages are highly valued. It offers several advantages over conventional furnaces: faster startup, quicker heating, higher production rates, less scaling loss, reduced energy consumption, and lower emissions.
3. **Electrolytic separation** is used to produce chlorine and caustic soda, and for purification through a direct current applied to electrodes immersed in an electrolyte. Advantages of electrolytic separation over chemical processes are higher material and energy efficiency, higher control process control, lower processing temperatures, and reduced pollution.
4. **Electric boilers** compete with boilers burning fossil fuels, typically natural gas. Depending on the cost of natural gas and electricity, the total cost of owning an electric boiler often is lower than the total cost of owning a gas boiler. Factors favoring electric boilers are higher fuel efficiency, lower upfront cost of electric boilers, and potentially lower costs of enhanced environmental regulation, litigation, and valuation risks, etc., compared to gas boilers.
5. **Resistance heating/melting** is two technologies. Direct heating dissipates electric energy in a metal work piece relatively resistant to electricity flow. Indirect heating/melting is used to heat materials by passing a current through a resistance heating element that transfers the heat to the work piece. It has several distinct advantages over conventional fuel-fired furnaces: rapid heating, faster start-up, no combustion gases, energy savings, higher production rates, ease of automation, and lower maintenance costs.
6. **Direct arc melting** is used in steel making, where three-phase AC electric arc furnaces with graphite electrodes are commonly used. The main advantage of electric arc furnaces over basic oxygen furnaces is their capability to treat charges containing up to 100% of scrap.
7. **Pulsed power** is finding broad industrial applications. Repetitively operated pulsed power generators with a moderate peak power have been developed for industrial applications, are reliable, and have low maintenance. Industrial applications include food processing, medical treatment, water treatment, exhaust gas treatment, ozone generation, and engine ignition.
8. **Ultraviolet curing** induces a rapid transformation of a liquid substrate to a solid coating. Ultraviolet curing enjoys several advantages over other technologies: quicker drying and curing speeds, reduction or elimination of organic solids, ability to coat heat sensitive materials, increased production rates, and more efficient use of coating materials.
9. **Infrared processing** is used to dry paints and inks. Rapid growth is projected due to its advantages over competing technologies: improved quality, increased productivity, waste reduction, improved process control, safer operation at lower temperatures, and the ability of infrared technologies to reduce volatile hydrocarbon emissions.

10. **Radio-Frequency heating and drying** uses electromagnetic radiation to heat dielectric materials. Increased market penetration and sales of smaller sized systems are expected to lead to steady growth in many applications.
11. **Electroslag processing** remelts a consumable electrode using heat generated by an electric current passing through a molten slag between the electrode and the solidifying ingot. The consumable electrodes are cast or forged cylindrical parts made of the alloy to be remelted.

Summary

The 2011 ERG shows that electricity's share of U.S. end-use energy increased from 11.7 to 12.8% between 1998 and 2008. At the same time, however, industrial electricity use (which includes manufacturing, agriculture, mining, and construction sectors) decreased from 1,051 to 1,009 billion kWh, a decrease of 4.0%, with an additional decrease of 13% (to 877 billion kWh) estimated for 2009. Electricity use for process industries decreased 6.0% between 1998 and 2008, and use for materials fabrication decreased 10.6%, while use for materials production declined by 13.0%. In contrast, electricity consumption for non-manufacturing industrial sectors (agriculture, mining, and construction) increased by 25.8% between 1998 and 2008, with almost all of the growth occurring in the construction sector.

Analysis of 34 specific electrotechnologies showed that induction heating was the largest user of electricity in 2010, followed in decreasing order by electrolytic separation, electrolytic reduction, resistance heating and melting, direct arc melting (electric arc furnaces), and electric boilers. In contrast, the electrotechnology with the greatest potential growth in electrical consumption through 2020 is expected to be electrolytic reduction, followed in decreasing order by induction heating, electrolytic separation, electric boilers, resistance heating and melting, and direct arc melting. The same six electrotechnologies appear at the top of these rankings, out of 34 electrotechnologies studied.

Analysis of end-use applications shows that motor drives use just over half of electricity in the manufacturing sector, but it suggests that "other" industrial electricity applications offer the highest opportunity for growth in electricity consumption. The "other" category includes emergency and computer power supply systems, process control equipment, and power supply systems for communication and instrumentation.

Of the four major subsectors–manufacturing, agriculture, mining, and construction sectors–the fastest growing subsector with respect to electric energy consumption is construction.

The ERG analyses indicate significant electricity growth opportunities for electrolytic reduction, induction heating, electrolytic separation, electric boilers, resistance heating and melting, and direct arc melting. Significant opportunities also exist in new end-use applications of electricity, such as power supply systems for computers (e.g., data centers to support telecommunications, digital data storage, and the internet) and process control equipment.

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