A small-business guide

Plastics Products

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REPORT SUMMARY

Many of the challenges faced by small business owners can be addressed through efficient use of electric technology. Each volume in the Small Business Guide describes the current state of a business type and details new or alternative electric equipment that can help it meet its characteristic problems.

Background

Members of the small-business community historically have had little contact with their energy providers. These guides were developed to facilitate communication between electric utilities and the small businesses in their communities.

Objective

To provide utility personnel and small business owners and operators with information on the key electrotechnologies that can help these businesses compete effectively.

Approach

The project team researched small business energy, productivity, and environmental concerns and the electrotechnologies that can meet these needs. Telephone surveys, published reports, directories, buyers guides, and technical journals provided information on technology availability, suppliers, information sources and trade associations.

Results

The Small-Business Guide series covers a range of industries:

Volume 1: Wholesale Bakeries

Volume 2: Auto Body Shops

Volume 3: Lodging

Volume 4: Medical Clinics

Volume 5: Drycleaners and Launderers

Volume 6: Metal Finishers

Volume 7: Shopping Centers

Volume 8: Convenience and Grocery Stores

Volume 9: Printers

Volume 10: Office Buildings

Volume 11: Electronic Components

Volume 12: Wood Preservers

Volume 13: Plastics Products

Each guide is based on extensive and ongoing research and contains the latest information available at the time of publication. The guides have been organized as a reference document for use on an as-needed basis. Section tabs are included to facilitate quick access to topics of interest; and each volume concludes with lists of equipment suppliers, EPRI information resources, and trade organizations.

EPRI Perspective

The EPRI Small Businesses target is dedicated to research, development, and dissemination of information on electrotechnologies that address the energy, productivity, and environmental concerns of small business owners and operators. Future volumes in the Small Business series will cover

- Printers
- Office Buildings
- Electronics
- Apparel manufacturers
- Photofinishers
- Plastic products
- Wood preservers
- Wood furniture.

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Interest Categories

Building systems and analysis tools
Commercial appliances
Product and service design
Marketing

Key Words

Electrotechnologies
HVAC
Lighting
Appliances
Building systems

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This guide was prepared by the Resource Dynamics Corporation of Vienna, Virginia.

Wayne Krill manages the Small Businesses Target at EPRI and directed development of this *Guide*.

ABOUT THIS GUIDE

Members of the small-business community historically have had little contact with their energy providers. This guide was developed to facilitate communication between electric utilities and the plastics products manufacturers in their communities.

The *Plastics Products* guide is intended to familiarize readers with the business of plastics products manufacturing by providing descriptions of basic processes and practices, and summaries of the issues and challenges faced by plastics-producing facility owners and operators.

This business guide is one of a series of publications produced by EPRI about small businesses. The *Plastics Products* guide is based on extensive and ongoing research and contains the latest information available at the time of publication. Nevertheless, it is a work in progress rather than a definitive and final document. The information and resources presented offer the reader a solid perspective from which to develop electricity-based solutions to energy and business needs.

This guide is organized as a reference document for use on an as-needed basis. Section tabs are included to facilitate quick access to topics of interest; icons representing energy end uses are also provided to help with locating complete information on electrotechnology solutions.

Plastics, so ubiquitous today, were developed just 50 years ago. Since then, their physical malleability and suitability for mass production has made a lot of new things possible—and now commonplace—such as Tupperware, photographic film, and flexible piping. Increasingly, plastics are also replacing the materials conventionally used in manufacturing long-familiar products such as grocery bags, clothes hangers, and garbage cans.

Given the capacities of plastic, the future of the U.S. plastic products industry, which had a total value of sales of $90 billion in 1993, looks just as strong and flexible as the material itself. There are challenges, however, both domestic and international. In the United States, the industry is facing regulatory and environmental issues regarding the use of chlorofluorocarbons and polyvinyl chloride in manufacturing processes, and the need to boost the amount of product usefully recycled rather than sent to the dump. In addition, rising competition from foreign companies is heading the industry toward a commodity market in which U.S. producers must minimize costs and streamline processes to meet competitors' prices. In response, some domestic producers may strive to differentiate themselves by providing more technically sophisticated services and products that ensure control of the higher-profit niche markets.

To maintain a secure position in the growing world market for plastic products, U.S. manufacturers are seeking tools and procedures that will allow them to increase productivity and/or product quality, reduce operating costs, and efficiently address environmental issues. The accompanying table identifies electrotechnologies that can meet these business concerns. These electrotechnologies and other high-efficiency electric technologies are described in the *Plastics Products* guide (EPRI TR-106676-V13), copies of which are available from the EPRI Distribution Center. To order this publication, or others in the series, call the Center at (510) 934-4212.

Electrotechnologies for Plastics Producers

	Indirect Resistance Heating of Plastics	Radio-Frequency Heating and Drying of Plastics	Electric Infrared Heating of Plastics	Fusion Welding of Plastics	Outdoor Lighting
Description	A current is passed through a resistance heating element that transfers heat to the subject material by radiation, convection, or conduction.	Radio-frequency (RF) energy is a rapidly alternating electromagnetic field; polar molecules react to the energy and create heat in a manner similar to friction.	Uses portable or stationary systems of quartz lamps and reflectors to direct short- or medium-wave radiation at plastic resin pellets or molds; the heat is absorbed by the material, quickly drying or heating it from the inside out.	The three fusion welding techniques—vibration welding, ultrasonic welding, and induction welding—utilize vibrational and electromagnetic energy to melt plastics which then flow together and bond under an applied force.	Six types of lighting technologies are available. Each offers different characteristics in wattage, brightness, light tone, efficiency, and life span; they can be combined to meet site-specific needs.
Plastics Producer Need	Cost-effective, accurate, and easy-to-control heating methods are needed in the production of molded thermoplastic products.	Cost-effective methods are needed for achieving rapid, uniform heating and/or drying of plastics and molds.	Cost-effective methods are needed for achieving rapid, uniform heating and/or drying of plastics and molds.	Manufacturers need techniques that reduce bonding task time and produce strong, aesthetically pleasing weld seams.	Good outdoor lighting is needed to improve the visibility and attractiveness of a facility, reduce the potential for crime, and increase employee safety.
Application	Resistance heating is appropriate for injection molding, thermoforming, and compression molding equipment.	Common applications of RF heating include sealing layers of plastic to form laminates, preheating preforms, preheating filler, facilitating the curing of thermoset mold shapes, and drying pelletized resin.	Common applications of electric infrared (IR) heating include preheating plastic preforms, preheating flat sheets/films, and drying pelletized resin.	Fusion welding techniques are used in bonding thermoplastics, bonding plastics to different types of substrates such as glass and wood, and bonding moisture-laden polymers such as nylon.	Lighting on signs on or near the facility; in parking lots, walkways, and delivery areas; on the building facade; and in the landscape or surrounding area.
Benefits	Indirect resistance heating systems are fairly inexpensive, reliable, compact, and flexible; because they provide a high degree of temperature control, they work well in conjunction with other heating equipment.	RF heating is quick and accurate; this technology is uniquely suited to drying resins that have uneven moisture profiles and, because of its good penetration, can heat thick shapes without overheating surface areas.	Electric IR heating is quick, efficient, requires little ramp-up time, and is easy to incorporate into existing production lines.	These techniques are quicker than adhesive bonding techniques; do not require ventilation; produce strong, attractive welds; and are readily incorporated into existing production lines.	General and facade lighting can increase public perception of quality, goodwill, and success; area lighting can help reduce potential for accidents, injuries, and crime.
Cost	System costs depend on size and operating temperature. Systems are available in 25–18,000 watt sizes and cost $10–$1000, respectively.	Capital costs are $1000–$4000 per kW of rated power; a system rated at 210 kW costs approximately $570,000.	A small spot or panel heater costs $1000–$2500; a custom-designed oven costs $10,000–$250,000.	Capital costs range from $1000–$100,000 for systems with power ratings of 0.3–5 kW.	Systems are custom-designed to meet a facility's needs and budget.

CONTENTS

1 Introduction to Plastics Products Manufacturing 1-1
- Business Statistics 1-1
- The Plastics Products Manufacturing Process 1-4
- Energy Use 1-9

2 Business Challenges and Needs 2-1
- Competition 2-1
- Environmental Issues 2-3

3 Technology Solutions 3-1
- Motors and Drives 3-2
- Process Heating 3-5
- Process Cooling 3-9
- Lighting 3-10
- Heating, Ventilation, and Air Conditioning 3-11

4 Electrotechnology Profiles 4-1
- Indirect Resistance Heating of Plastics 4-1
- Radio-Frequency Heating and Drying of Plastics 4-3
- Electric Infrared Heating of Plastics 4-7
- Fusion Welding of Plastics 4-10
- Outdoor Lighting 4-15

5 Resources 5-1
- Equipment Suppliers 5-2
- Information on Efficiency Technologies 5-9
- Trade Associations 5-10

1

INTRODUCTION TO PLASTICS PRODUCTS MANUFACTURING

Plastic resins were first developed in the 1940s. Historically, they have been distilled from petroleum; today, many plastic products contain recycled plastics, and researchers are attempting to produce biodegradable plastics from organic materials such as potatoes and cornstarch. Plastics are the primary materials of consumer products ranging from beverage containers to automobile parts. They are formed by combining polymers of different molecular weights and bonding patterns. Adjusting these molecular structures alters important mechanical characteristics such as strength, flexibility, thermal conductivity, and hardness.

Business Statistics

This ability to engineer the properties of plastics is key to their widespread use. As competitive pressures in both domestic and international markets over the last 50 years have driven a variety of industries to search for less expensive yet technically adequate materials, plastics have become a commercial mainstay. Research and development efforts are continually improving the mechanical properties of plastics such that plastics can now substitute for even the most basic structural materials such as wood and metal. Once considered a “modern” product common in only industrialized nations, the miscellaneous plastics products industry is today tightly connected to the economies of both industrialized and developing countries. In industrialized nations, plastic is an essential raw material in many types of industries. In developing countries, the market for plastics increases as the buying power of the population grows, creating important export opportunities for U.S. producers.

The plastics products industry (Standard Industrial Classification [SIC] code 308) provides products for a variety of applications. Manufacturers of plastic film and sheet (SIC 3081) supply raw materials for industries ranging from packaging to agriculture. Producers of plastic bottles (SIC 3085) support a large portion of the container needs of beverage companies, while manufacturers of plastic plumbing fixtures (SIC 3088) and laminated plastic plate, sheet, and profile shapes (SIC 3083) are important suppliers to the construction industry.

The U.S. plastics products industry generated shipments valued at more than $90 billion in 1993. Historically, the United States has exported slightly more plastic products than it has imported; however, this balance is shifting toward a trade deficit under competitive pressures from countries where labor costs are lower, such as those in the Pacific Rim. Growth within the industry is most rapid in SIC 3089, Plastics Products Not Elsewhere Classified (NEC). This market segment, which produces familiar items such as air mattresses, clothes hangers, and storage containers, is currently the largest and is expected to continue to grow as advances in manufacturing and product development provide new applications, such as automobile body panels, electronic component enclosures, and furniture. Table 1 presents statistics for the various segments within the plastics products industry.

Table 1
Profile of the Plastics Products Industry (1993)

Segment	No. of Establishments	No. of Employees	Value of Shipments ($ billion)
Unsupported Plastics Film and Sheet (SIC 3081)	760	55,300	11.2
Unsupported Plastics Profile Shapes (SIC 3082)	705	28,000	3.5
Laminated Plastics Plate, Sheet, and Profiles Shapes (SIC 3083)	292	15,100	2.3
Plastics Pipe (SIC 3084)	273	13,800	2.9
Plastics Bottles (SIC 3085)	398	33,500	5.0
Plastics Foam Products (SIC 3086)	1,179	69,000	10.1
Custom Compounding of Purchased Plastic Resins (SIC 3087)	642	24,800	5.1
Plastics Plumbing Fixtures (SIC 3088)	354	12,200	1.3
Plastics Products NEC (SIC 3089)	8,335	443,900	49.2
TOTAL (SIC 308)	12,938	695,600	90.5

Source: U.S. Department of Commerce, Bureau of the Census, *County Business Patterns 1992 & 1993—United States*, CD-CBP-92/93, 1995, and *1992 Economic Census CD-ROM*, CD-EC92-1H, 1996.

The level of capitalization for manufacturers within the plastics products industry varies considerably. Manufacturers of plastic film (SIC 3081) tend to have a high ratio of capital investment per worker, while profile shape (e.g., an automobile body panel) manufacturers (SIC 3082 and 3083) are well below the industry average. The driving factor behind the level of investment is automation; producers of plastic sheet typically have highly automated processes that require operators to monitor equipment rather than manually handle production items. By shifting workers to task monitoring, rather than task performance, labor costs per unit decrease, directly enhancing the manufacturer's competitiveness. Consequently, many of the productivity improvements available to plastics manufacturers center around equipment investments that automate production procedures.

More than 70% of all plastics products manufacturers employ fewer than 50 people (see Table 2). While the value of shipments is generally increasing—rising from $61.8 billion in 1987 to $90.5 billion in 1993—overall industry employment is growing relatively slowly, gaining only 16%, from 1987 to 1993 (599,400 to 695,600). This is again largely due to increasing automation. As the stress of competition grows, the need to improve productivity is expected to continue to promote investments in automation.

Table 2
Distribution of Plastics Products Manufactures by Size (1993)

Segment	Number of Employees						Total
	Small (0–49)		Medium (50–99)		Large (100+)		
	No.	% of Total	No.	% of Total	No.	% of Total	
Unsupported Plastics Film and Sheet (SIC 3081)	454	60	151	20	155	20	**760**
Unsupported Plastics Profile Shapes (SIC 3082)	535	76	105	15	65	9	**705**
Laminated Plastics Plate, Sheet, and Profiles Shapes (SIC 3083)	234	80	20	7	38	13	**292**
Plastics Pipe (SIC 3084)	179	66	68	25	26	10	**273**
Plastics Bottles (SIC 3085)	196	49	98	25	104	26	**398**
Plastics Foam Products (SIC 3086)	837	71	168	14	174	15	**1,179**
Custom Compounding of Purchased Plastic Resins (SIC 3087)	486	76	102	16	54	8	**642**
Plastics Plumbing Fixtures (SIC 3088)	299	84	25	7	30	8	**354**
Plastics Products NEC (SIC 3089)	6013	72	1119	13	1203	14	**8,335**
TOTAL (SIC 308)	9233	71	1856	14	1849	14	**12,938**

Source: U.S. Department of Commerce, Bureau of the Census, *County Business Patterns 1992 & 1993—United States*, CBP-92/93, 1995. (Note: Some percentages may not total to 100 due to rounding.)

In 1993, California had the largest number of plastic products manufacturing establishments (almost 1700), nearly twice as many as the number two state, Ohio, which had 901. Other top plastics products manufacturing states include Michigan, Texas, Illinois, New York, Pennsylvania, New Jersey, Florida, and Indiana.

The distribution of manufacturers varies according to the type of plastic products produced because often the products are parts for other industries. To avoid the expense of shipping bulky plastic parts, manufacturers establish locations close to their customers. For example, a large number of plastics manufacturers in Ohio and Michigan support the automotive industry. In California, a more diversified manufacturing base creates the need for a wider variety of plastics fabricators.

States	**Facilities**
CA	1700
OH	901
MI	774
TX	764
IL	746
NY	608
PA	607
NJ	553
FL	550
IN	479

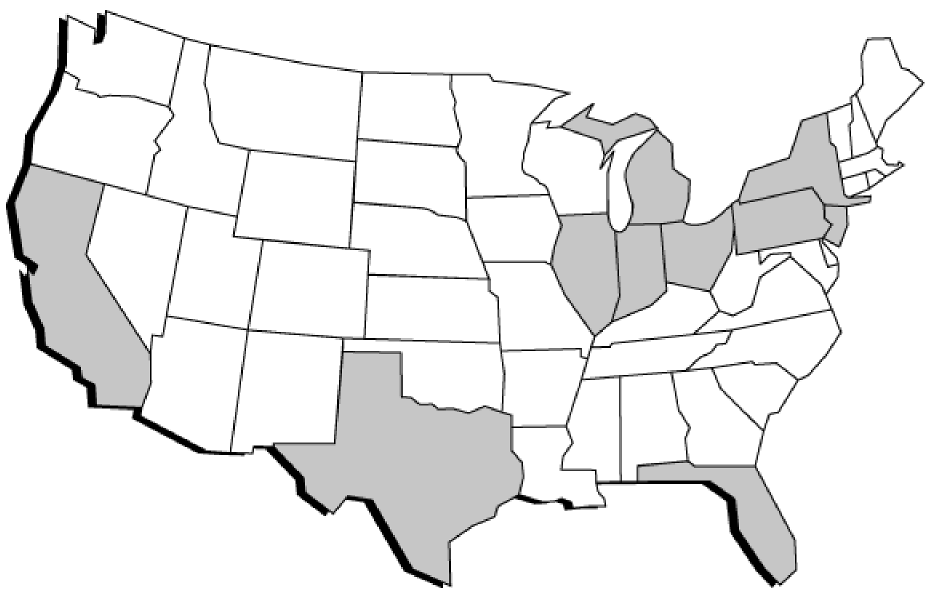


Figure 1
Top 10 Plastics Products Manufacturing States (1993)

The Plastics Products Manufacturing Process

Plastic is a polymeric organic material; when heated, it becomes a malleable fluid that takes on any desired shape. Although the term “plastic” actually refers to the homogenous plastic resin produced by plastic resin manufacturers (SIC 2821), it is often used to refer to the final product, which contains fillers, plasticizers, pigments, and stabilizers in addition to the resin. It is these additives that give plastic products specific and different physical characteristics.

Plastics can be categorized as two basic types: thermoplastics and thermosets. Thermoplastics are polymers that flow under high temperatures, hold a stable shape at low temperatures, and are capable of being reheated and reshaped repeatedly. Thermosets are polymers that rely on a chemical reaction that occurs at high temperatures to form molecular bonds that stabilize the dimensions of the plastic. These bonds are formed by irreversible reactions; therefore, thermoset plastics cannot be reshaped by reheating. The ability to reshape thermoplastics, in addition to their other favorable mechanical qualities, has allowed them to capture approximately 90% of the market.

There are five plastics processing techniques.

Injection Molding. The majority of plastic products are manufactured via injection molding. There are currently more than 7800 injection molders in the United States, operating over 89,000 injection molding machines (see Figure 2). The injection molding process uses heat and pressure to convert plastic resin—pellets or granules—into molded shapes. The extensive use of injection molding is attributable to three key factors. First, although injection molding machines are rather expensive, they take up little space and require only electrical and water connections. Second, the injection-molding process is consistent, repeatable, and almost completely automated. Although an equipment operator must monitor temperatures, pressures, and cooldown periods, little labor is required to produce an injection-molded product. Third, while the majority of final products are bulky and costly to package and transport, raw plastic feedstock is inexpensive to ship; consequently, it is more practical to ship raw materials and mold products near the point of final sale.

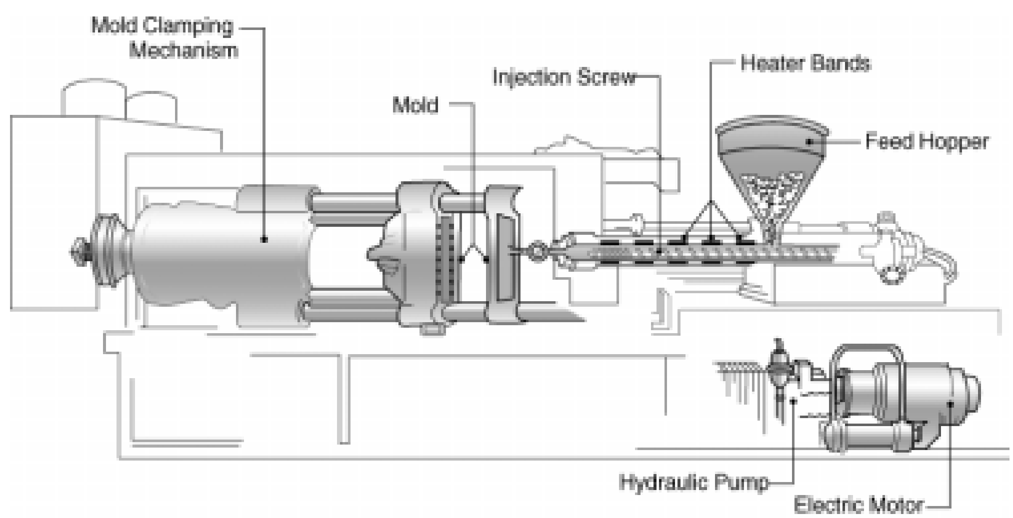


Figure 2
Injection Molding Equipment

During thermoplastic injection molding, the pellets/granules are pulled from a hopper and forced into a cylinder that contains an axial screw that turns and pushes the plastic toward the mold. The cylinder is surrounded by heating coils that warm the plastic. (The heat for these coils can be supplied either by steam or electric resistance, depending on the needs and characteristics of the production facility.) The turning action of the screw shears the plastic, creating additional heat from the friction. Combined with energy from the heating coils, the screw heats the plastic to 300–500°F, causing fluidization of the polymer. The fluid polymer is then injected into the mold. The temperature of the surface of the mold is cool and carefully controlled to prevent an undesirable thermal reaction. Pressure is applied to the mold to remove air and to force the plastic against the mold surfaces. The mold is cooled externally with water jackets or with air to approximately 75°F, at which point the plastic assumes its final shape. The mold is then opened, the piece ejected, and the process repeated. No chemical reaction is involved.

When using thermoset polymers in an injection molding machine, the plastic granules are fed from a hopper into a cylinder, heated to 300°F, and fluidized. The plastic is then injected into a heated mold where the chemical reaction occurs and shaping takes place. The product is then ejected and the process repeated.

Extrusion. The second most popular manufacturing process is extrusion. Extrusion is applicable to thermoplastics only. It is similar to injection molding in that heat and pressure are used to fluidize plastic feedstock. The extrusion process forces liquid plastic at approximately 375°F through a die to produce continuous sheets, tubes, or shapes. The extruded plastic is then cooled and cut according to the specifications of the final product. Extruded plastic products are often subsequently processed into other shapes by hot stamping or compression molding. The advantages of extrusion are similar to those of injection molding in that the raw material is inexpensive to transport, and the extruding equipment requires little labor support. A variety of extrusion techniques are used for plastics, including pultrusion, calendering, and coextrusion.

- Pultrusion. This process applies resins to a substrate, such as metal, to form a composite material having the physical properties of each component; in this case, strength and flexibility. Typically, the substrate (e.g., metal) provides tensile strength while the polymer protects against abrasion, shearing, and corrosion. Industrial applications of pultruded products include rods, tubing, drill extensions for oil exploration and extraction, and structural cables.

- Calendering. Calendering uses rollers, rather than dies, to form plastic films or sheets. Plastic pellets are taken from a hopper, heated under pressure into a liquid, then pushed through a series of rollers that determine the qualities of the final product. This process is used to manufacture sheet like products such as shower curtains, tablecloths, and floor coverings.

- Coextrusion. Coextrusion blends different polymer feedstocks to create a laminate or amalgamate compound. Coextrusion is rapidly gaining popularity as the U.S. plastics industry searches for cost-effective ways to blend plastics to achieve desired mechanical properties. Blending polymers of different properties can achieve a final product that has favorable strength, hardness, flexibility, and/or color steadfastness. For example, coextrusion is used to produce seamless plastic pipe, rods, and sheets for plumbing and other construction applications.

Thermoforming. The thermoforming process molds thermoplastic polymers using heat and pressure (see Figure 3). Unlike injection molding, where plastic pellets and granules are used, thermoforming feeds polymer films, laminates, or tubing into a mold that is then heated. Pressure is applied to the polymer to solidly force it against the mold. Seat backs, car interior panels, and plates/dishes are examples of profile-shape products that are produced cost-effectively through the thermoforming process. Electrotechnologies such as infrared heating and radio-frequency heating are becoming popular as a form of preheating prior to the thermoforming process. Warming the plastic prior to thermoforming shortens the production cycle since the plastic takes less time to heat while in the mold. Also, because the preheated plastic degasses more quickly, the consistency of the plastic part is also improved.

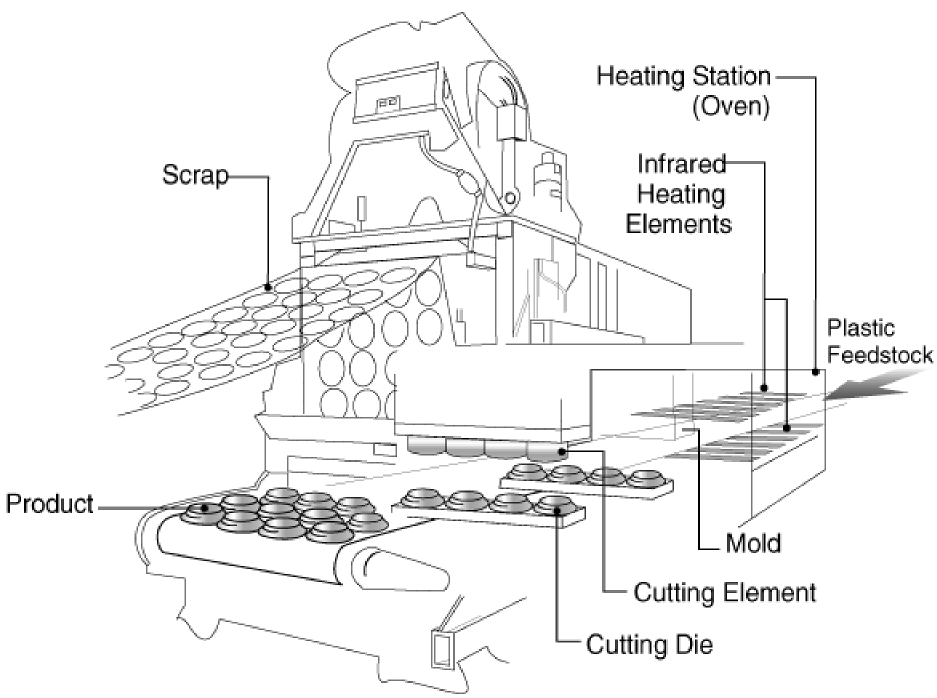


Figure 3
Thermoforming Equipment

Expandable Bead Molding. Expandable bead molding combines a polymer, such as polystyrene, with a "blowing agent" (a volatile liquid), such as cyclopentane, in a mold under slight pressure. When the pressure on the mixture is lowered, the blowing agent gasifies and expands, causing the resin to expand into the mold and ultimately create a low-density material with good impact-absorbing properties. Expandable bead molding is the preferred process in the production of plastic packaging materials; however, the market growth of this process is being hindered by the phaseout of chlorofluorocarbons (CFCs), the basis of most conventional blowing agents, and the minimal success of recycling expanded foam products. Although expanded foam is recyclable, the lack of a recycling infrastructure stymies the reuse of these polymer products.

Blow Molding. Similar to glass blowing, blow molding uses air pressure to shape plastic parts. Typically, a volume of plastic is extruded into a mold, clamped at one end, then blown against the mold surface by air at 40 pounds per square inch (psi). The cool surface of the mold solidifies the plastic into its final shape. This process is typically used for producing cylindrical shapes such as bottles, beverage containers, toys, and other hollow items.

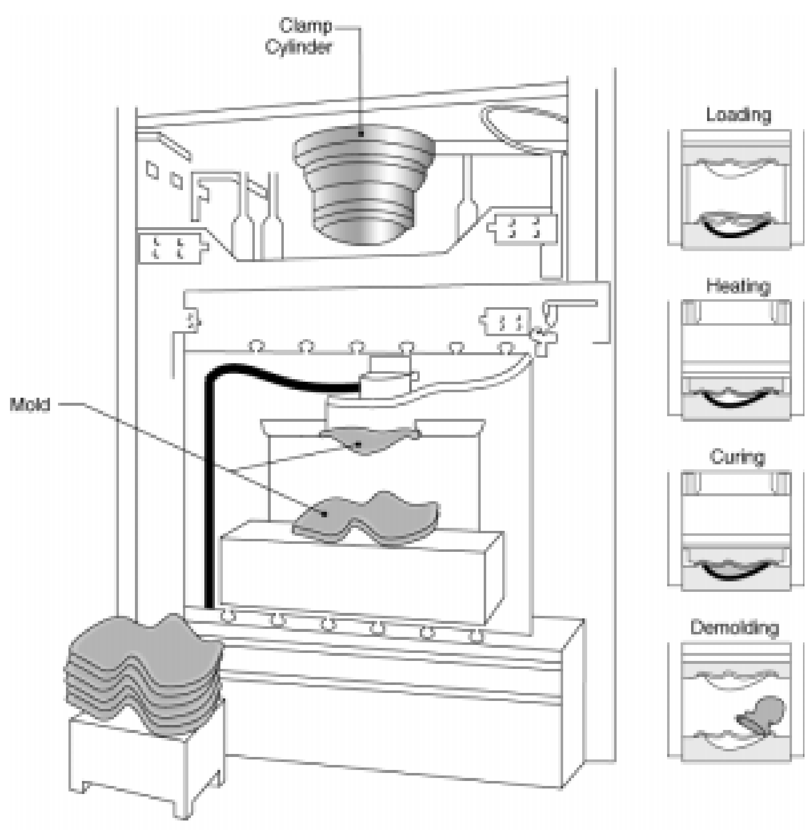


Figure 4
Compression Molding Equipment

Compression Molding. Compression molding is similar to and simpler than injection molding. In compression molding, a sheet of polymer is preheated in one half of a mold die and then the other half of the mold is clamped onto the plastic (see Figure 4). When using thermoplastic polymers, the polymer sheet is heated and compressed, the mold is cooled, and the plastic takes its final shape. For thermoset plastics, the heat in the mold is maintained for a period to allow the cross-linking reaction to occur. This method of plastics production is popular for making simple, rugged products such as knobs, buttons, and truck panels.

Energy Use

According to the U.S. Department of Energy, in 1991, the plastics products industry (SIC 308) consumed more than 152 trillion Btu of energy. More than 57% of this energy was in the form of electricity, roughly 34% was supplied by natural gas, and the remaining 9% was supplied by residual fuel oil, coal, and liquefied petroleum gas. The cost of electricity to plastics products manufacturers as a percent of the total material cost ranges from 1.9% for SIC 3088 (Plastics Plumbing Fixtures) to 7.3% for SIC 3085 (Plastics Bottles).

Of the 25,590 million kWh of electricity consumed by plastics products manufacturers in 1991, over 85% was consumed in process-related uses, mostly for machine drive (51%). The other process uses are process heating (19%), process cooling (8%), and other (8%). The key nonprocess uses of electricity included heating, ventilation, and air conditioning (HVAC) (7%) and lighting (7%) (see Figure 5).

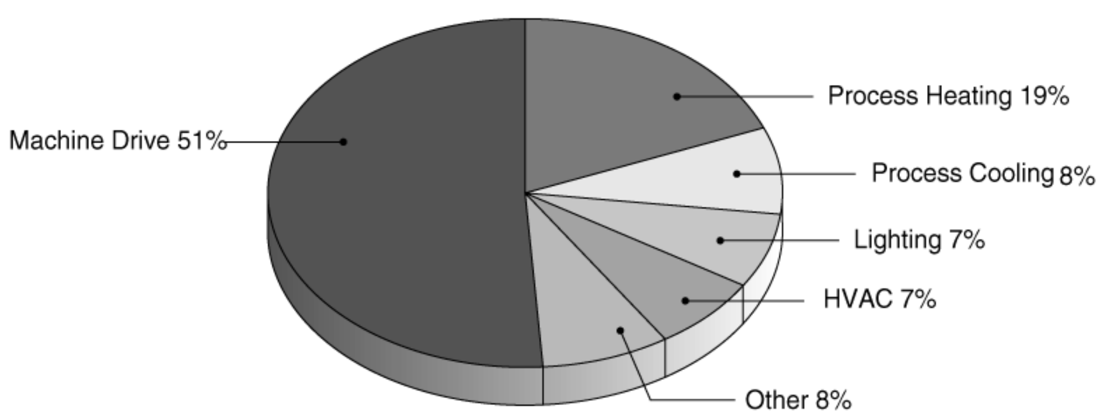


Figure 5
Electricity Use in the Plastics Products Industry

2

BUSINESS CHALLENGES AND NEEDS

The demand for plastics is projected to rise considerably over the next 10 years, commensurate with the global need for lower cost alternatives to conventional materials such as metal, wood, and paper. The plastics products industry is, however, heading toward a commodity market within which domestic manufacturers face increasing foreign competition. To compete in a commodity market, U.S. manufacturers must reduce their prime operating costs (i.e., labor and energy) and increase the productivity of their process operations.

Competition

Regulatory and environmental issues also present significant concerns for plastics manufacturers. In the late 1980s and early 1990s, the plastics products industry responded to regulations restricting CFC use by developing alternative blowing agents for expanded foam manufacturing. In the same time period, awareness of increasing solid waste generation and decreasing landfill space began to exert pressure on plastics manufacturers to incorporate greater quantities of recycled plastics into their products. In addition, questions about the impact of chlorine released during the manufacture and incineration of polyvinyl chloride (PVC) products are creating uncertainty about the continued production of this polymer.

The challenge of international competition is forcing U.S. plastics products manufacturers to either endure low profit margins, shift production efforts to high-end applications, or increase productivity while decreasing costs. There is currently excess manufacturing capacity for commodity plastics in the developing countries of the Pacific Rim. In addition, low labor costs overseas enable relatively inexpensive production of products. In response to this competitive pressure, many domestic producers are exploiting their manufacturing and technical experience to serve niche markets that require more complex plastics and provide a higher profit margin. In light of the advances in the mechanical properties of plastics, these applications are likely to increase, and the market for highly engineered polymers should continue to provide domestic manufacturers a healthy demand for higher-priced plastic products.

Need

Increase Productivity and Quality

An increasingly price-driven plastics products industry creates a market environment in which domestic manufacturers must either establish sufficiently high levels of quality to justify higher product prices or increase throughput against their existing costs. Otherwise, domestic producers must shift their manufacturing and research and development efforts toward high-profit products that serve niche markets. Unfortunately, shifting to higher-end products may require manufacturers to retool and reconfigure their plants, a potentially risky and expensive alternative.

Technology Solutions

Many electric-based technologies can provide productivity and quality improvements in plastics manufacturing by increasing the level of automation within a production process. Automating a process often allows greater control of the task parameters which, in turn, improves product consistency. The technologies that may offer the potential to speed up the production process and improve product quality include injection molding machines and adjustable speed drives (ASDs). Electrotechnologies such as radio-frequency heating, fusion welding, and electric infrared (IR) heating can be used as cost-effective methods of preheating, heating, welding, and/or drying plastics to produce high-quality products while increasing the speed of throughput. Indirectly, the use of proper indoor lighting can improve productivity by increasing employee safety and thereby preventing accidents and time off the job.

See pages 3-3, 3-7, 3-8, 3-9, 3-10

Need

Reduce Operating Costs

Plastics products manufacturers can also improve their competitive position by decreasing their overall operating costs. Operating costs can be reduced through gains in energy efficiency and/or labor effectiveness. This can help U.S. manufacturers to compete domestically and with foreign manufacturers that have much lower labor costs.

Technology Solutions

A number of technologies are available that can provide opportunities to reduce labor and energy costs in plastics products manufacturing. The efficiency technologies that may offer the potential to decrease operating costs include injection molding machines, energy-efficient motors, and ASDs. The primary advantage afforded by these technologies is greater production process energy efficiency, albeit their payback periods may be long compared to other capital investments. The electrotechnologies that offer potential opportunities to reduce operating costs in the manufacturing process include radio-frequency heating, fusion welding, and electric IR heating. Energy-efficient indoor and outdoor lighting offer plastic products manufacturers additional opportunities to reduce their energy expenditures.

See pages 3-3, 3-4, 3-7, 3-8, 3-9, 3-10, 3-11

Environmental Issues

The two most pressing environmental issues the plastics products industry faces are the phaseout of CFCs and a push for plastics recycling to reduce pressure on landfills. A less significant concern, but one the industry is tracking, is consumer perception of a health threat from PVC-related emissions of chlorine. Although plastics products manufacturers are in the process of transitioning to non-CFC agents for foam blowing (responding to the phaseout of CFC production in January 1996), the other issues remain unresolved.

The biggest environmental challenge is solid-waste disposal. Since plastics are so widely used, they are a major component of landfilled waste. Recycling advocacy groups have begun targeting the industry, urging it to take a larger role in reducing the solid-waste burden it creates. Consumer participation in recycling is increasing, and federal, state, and local governments are considering enacting requirements for manufacturers to receive and process recycled plastics. Currently, the majority of recyclable plastics are marked by an identification code within the “three arrow” universal recycling symbol. This code specifies the type of resin in the product and facilitates sorting during the recycling process.

A growing and related regulatory trend is a requirement that manufacturers include a specified percentage of recycled plastic, known as “recyclate,” in their plastic products. California and Oregon have already passed laws that address this and cover the “rates and dates” issue. (“Rates and dates” legislation requires manufacturers to adopt a level of recycling by a certain date.) Compliance options for manufacturers include using a lower volume of plastics, incorporating a higher recyclate content into plastics production, or achieving a higher consumer recycling rate.

The potential regulation of PVC is a challenge to many manufacturers in the plastics products industry. The public perceives the emission of chlorine as both a health and an environmental threat. Although plastics manufacturing does not produce large amounts of chlorine emissions, and a credible scientific connection between plastics manufacturing and health problems has not been established, health and environmental questions threaten to restrict the use of PVC.

Need

Decrease Solid-Waste Generation

In response to consumer and community concerns about the shrinking availability of landfill space and the threat of more restrictive environmental legislation, plastics products manufacturers are adapting their processes to become more environmentally responsible. Environmental protection groups are advocating legislation that would require many plastics products to contain specific percentages of recycled plastics. Recognizing that it is difficult for individual manufacturers to remain competitive while incorporating expensive recycling technology into their production processes, legislation is considered necessary to force the industry as a whole to decrease solid-waste generation. The largest barrier to cost-effectively incorporating post-consumer recyclate (PCR) into the plastics production process is the expense of collecting and sorting the PCR.

Although many municipalities provide recycling services, many plastics are not collected. Beverage containers have high recycle rates due to extensive consumer awareness; however, other plastics, such as packaging and plastic film, are not consistently included in recycling programs. A significant barrier to broad-spectrum plastics collection is the lack of an infrastructure to educate consumers, provide reasonable access to recycling services, and allow cost-effective sorting of PCR prior to remanufacturing.

Development of this infrastructure requires the concurrent participation of consumers, municipalities, waste management companies, and plastics products manufacturers. Legislation that requires manufacturers to accept PCR and incorporate it into the production stream will create a market demand for sources of PCR which, in turn, will create additional business opportunities. The behavior of upstream stakeholders, such as consumers and waste management companies, is expected to adjust quickly once collection and recycling opportunities are made easier. (Germany has enacted similar legislation and reports a dramatic increase in consumer recycling efforts.) U.S. manufacturers should be alert for prospective changes in the regulatory environment that would force them to invest in process modifications in order to accommodate PCR in their material supply stream.

In response to the specter of legislative action and the growth in consumer environmental awareness, plastics products manufacturers are searching for recycling methods that can cost-effectively meet the consumer demand for environmental responsibility and still ensure end-product quality. This effort is complicated by collection and sorting difficulties, as well as the technical challenges of blending used polymer with virgin polymer without compromising mechanical properties. PCR consists of many different types of plastics; sorting these plastics into homogeneous groups is tedious since any given product, such as a clear beverage container, can be made with different polymers. Manually sorting PCR results in unacceptable error rates because different polymer types have a similar appearance. As a result, automated processes that sort by chemical identity are increasing in popularity.

Another troublesome aspect of recycling is treatment of the PCR prior to its incorporation into the manufacturing process. There are three basic points in the production stream at which PCR can be introduced (shown in Figure 6). Although the effort and cost of processing PCR increases with each step of breaking it down into simpler components, the more the PCR is cleaned and purified, the easier it is to incorporate.

The simplest method of reusing plastics, both in terms of expense and energy use, is to clean and pelletize (or "shred") the PCR, then feed it into the production stream. In the cleaning process, bulk plastics (e.g., flattened beverage containers) are washed in an aqueous solution; density differences between different polymer types allow a rough sorting of resins according to buoyancy characteristics. The washing process removes surface contaminants, but does not untangle molecular ties; therefore, inks and adhesives can be separated out, while pigments and fillers tend to remain inside the molecular matrix. After pelletizing, the polymers are either introduced into the production stream or sent for further treatment. This method produces polymers with a relatively high level of contamination. Applications for polymers at this level of treatment are restricted to filler and low-end products such as trash bags. While this process is relatively low cost, the limitations in use of the resulting polymer supply must be taken into account. As a result, this process is often used as simply the preliminary step to further treatment.

Another process option is to melt PCR down into its component polymers. When the plastic is liquefied, many of the contaminants can be filtered out, and the polymer types can be isolated according to density. While melting PCR is more energy-intensive than shredding it, the increased polymer purity affords greater confidence in predicting the mechanical properties of the recycled resin and in determining the best ratios of virgin and recycled polymers. Like the washing and pelletizing method, this technique can be used by itself or as a preliminary step for more advanced treatments.

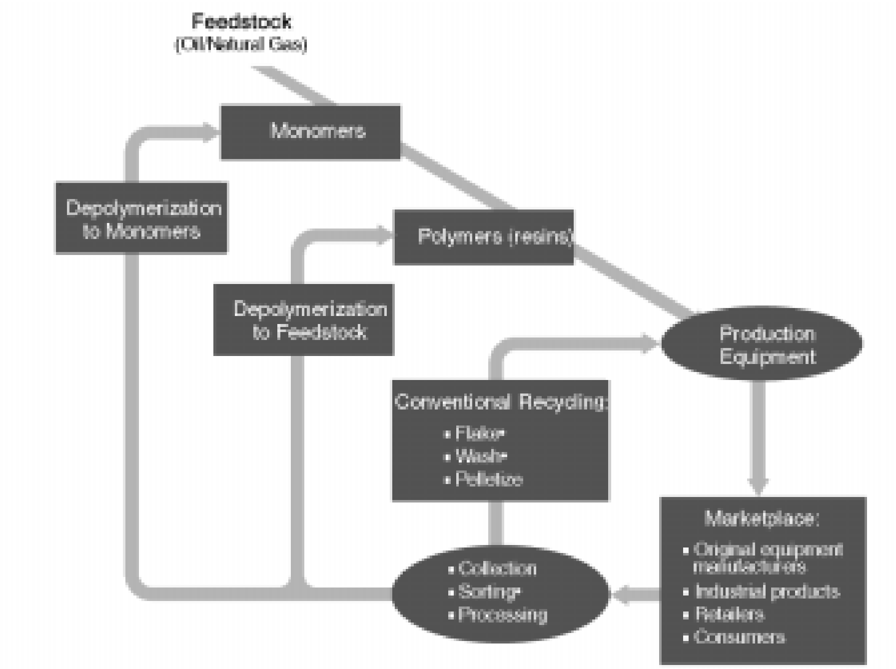


Figure 6
Plastics Recycling Process

The most sophisticated and energy-intensive recycling technique breaks PCR down into its constituent monomers. This method requires chemical dissolution of the polymers through hydrolysis or pyrolysis to yield their building-block components. This process is necessary for the recovery of polymers, such as polyesters and polyurethanes, formed by “irreversible” reactions. It provides the best recovery of chemical components of plastics and overcomes the problems associated with reusing contaminated polymers. Reversing the polymerization process can be carried further by reducing the monomers to the form of petrochemical feedstock, which then can be used for applications other than plastics products manufacturing. The primary benefit of this process is the quality of the processed recyclate. By recovering the building-block monomers and reusing these components to form polymers, the quality of the product is as high as that achieved with virgin polymers. Because this process offers many advantages, several major corporations are developing the technology in their R&D labs to position themselves for future market opportunities.

Technology Solutions

Automated sorting devices that use IR energy to determine the chemical identity of plastic compounds are effective and are becoming popular with waste management companies and plastics manufacturers that must incorporate recyclate in their processes but want to maintain high end-product quality. IR sorters rely on the unique signature of reflected IR energy that characterizes each polymer type. As each unit of PCR passes through a scanner, it is identified, and a mechanical plunger or a stream of compressed air pushes it into the appropriate collection stream. Although plastics products manufacturers typically receive sorted PCR from waste management companies and are not currently engaged in the direct processing of collected recyclate, sorters may provide an attractive opportunity for vertical integration of the recycling/ manufacturing process. As the regulatory environment applies more pressure on plastics products manufacturers to participate in and encourage consumer recycling, automatic IR sorters may be a wise equipment investment. IR sorters may also be useful as a quality control measure to ensure sufficient purity of PCR stock received from a waste management company prior to introducing it into the production stream.

Systems that wash shredded PCR with aqueous solutions to remove surface contaminants typically also dry the material. Technologies such as radio-frequency drying and IR drying are also used in preparing washed PCR for reuse.

Need

Minimize Chlorine Health Risk

PVC is a commonly used component in many plastic products. It is used extensively in plastics from construction piping to consumer items such as shampoo bottles and trash receptacles. Exposure to chlorine is a human health concern. Environmental advocates in Europe assert that the manufacture of PVC creates a chlorine health hazard. Industry advocates disagree; they opine that chlorine is not a public health risk and that, even if it were, incineration of chlorine-containing products—not manufacturing—is the largest source of public exposure.

As a result of this health concern, the European Community (EC) has adopted relatively strict controls on PVC manufacturing and incineration in an attempt to limit chlorine emissions. Many industry observers assert that the benefits of PVC outweigh the link between PVC and a possible human health impact. Although this debate is ongoing, EC regulations may portend similar regulations here. Also, if the EC decides to restrict or ban PVC production, use, or incineration, the regulation could have an effect on U.S. companies exporting PVC products to EC member countries. Most notably, a ban on chlorine would have a major impact on the share of plastics in the construction supply market.

Technology Solutions

No electric technology solutions are currently available to replace chlorine or PVC.

3

TECHNOLOGY SOLUTIONS

This section describes each of the technology solutions identified in the previous section. Each technology is summarized, linked by end-use application to a business need, and categorized as an "electrotechnology" or an "efficiency technology." Electrotechnologies are selected new or alternative electric equipment options. In many plastic product manufacturing applications, the electrotechnologies can increase productivity or operating product quality, reduce operating costs, and/or address environmental issues. Efficiency technologies, in contrast, offer opportunities to decrease energy use, but typically have little or no direct impact on production.

Each electrotechnology is described more completely in Section 4, Electrotechnology Profiles. Vendors of these electrotechnologies, sources of information on efficiency technologies, and trade associations are listed in Section 5, Resources.

In this section, the technologies are grouped and discussed by end use, beginning with "Motors and Drives," the end use that represents the greatest percentage of total electricity use in the plastics products industry. Table 3 summarizes the technology solutions.

Table 3
Electrotechnology Solutions to Plastics Products Business Needs

End Use	Solution Type	Technology Type	Business Needs: Increase Productivity/ Product Quality	Business Needs: Reduce Operating Costs	Business Needs: Address Environmental Issues
Motors and Drives	Efficiency Technology	Energy-Efficient Electric Motors		■	
Motors and Drives	Efficiency Technology	Adjustable Speed Drives	■	■	
Motors and Drives	Efficiency Technology	All-Electric Injection Molding Machines	■	■	
Process Heating	Electrotechnology	Indirect Resistance Heating of Plastics			■
Process Heating	Electrotechnology	Radio-Frequency Heating and Drying of Plastics	■	■	■
Process Heating	Electrotechnology	Electric Infrared Heating of Plastics	■	■	■
Process Heating	Electrotechnology	Fusion Welding of Plastics	■	■	■
Lighting	Efficiency Technology	Energy-Efficient Indoor Lighting		■	
Lighting	Electrotechnology	Energy-Efficient Outdoor Lighting	■	■	

Motors and Drives

Machine drive accounts for 51% of the electricity used in plastics products manufacturing. This electricity powers a range of production equipment, including motors driving injection molding machines, pumps for cooling and hydraulic systems, and motors driving materials handling equipment. The extensive use of motors and drives represents opportunities for energy-efficient electric motors, ASDs, and high-efficiency production equipment.

Since motors and drives account for such a large percentage of the electricity consumed in the plastics products industry, motor system efficiency can significantly influence the overall energy efficiency of a facility.

Efficiency Technology Solution
Energy-Efficient Electric Motors

Energy-efficient motors (also known as high-or premium-efficiency motors) are typically 2–6% more efficient than their standard counterparts and cost 15–30% more than standard motors. Over a typical 10-year operating life, a motor can consume electricity valued at over 50 times the initial cost of the motor. As a result, energy-efficient motors are extremely cost-effective, with simple payback on investment of less than 2 years when compared to a standard-efficiency motor. The payback is generally attractive unless electricity prices are very low or a motor is operated infrequently.

Energy-efficient motors offer more than just reduced electricity consumption. They are typically manufactured to closer tolerances, use better materials, and offer more robust construction than standard motors. This higher quality translates into improved reliability and reduced maintenance requirements.

Efficiency Technology Solution
Adjustable Speed Drives

ASDs, also known as variable speed drives, utilize electronic control of the motor current frequency to raise and lower the speed of a motor in accordance with the demands of the load. Reducing the frequency of the current to a motor below 60 hertz slows the motor, thereby eliminating energy use that otherwise would be wasted. In conventional motors, the motor speed remains constant when the load decreases, causing power factor to drop and the motor to run inefficiently.

Historically, motor systems requiring variable output have been controlled with dampers or valves that apply back pressure on the system. Unfortunately, in many applications, such as centrifugal pumps and fans, this form of load control is relatively ineffective. Centrifugal pumps and fans typically respond to system pressure changes with corrections in flow; consequently, bypass and recirculation lines are used to handle excess flow, which results in wasteful energy consumption. In contrast, ASDs manipulate the electrical supply such that motor speed, rather than back pressure, reacts to the system requirements. In general, controlling motor speed can provide higher motor efficiencies and power factors over a broad range of system operating conditions.

Power Factor

A key influence on motor efficiency is the time relation between the electric current and voltage draw. Known as "power factor," the difference between a motor's current and voltage significantly affects its effectiveness in converting electrical power to mechanical power. An under-loaded conventional motor typically has a low power factor, perhaps as low as 40%; a motor operating near its design rating has a power factor close to 80%.

It is difficult to design a motor system in which all motors are loaded at their design rating at all times. Inconsistencies in processes, fluctuations in rates, and production line stoppages and surges all change motor loads and, since motors are sized to handle their highest normal operating load, conventional motors frequently operate with low power factors.

Power factor can be increased by reducing or eliminating the use of oversized motors, avoiding control techniques that rely on "unloading" a motor and keeping it running, and installing capacitors to correct the problem.

Production Equipment

The equipment used to manufacture plastic products is typically driven by hydraulic systems that are pressurized by motor-driven pumps. Hydraulic systems are characterized by slow, steady, controllable equipment motion and are capable of generating the large forces required by compression molding and injection molding processes. Hydraulic system pumps are well-suited for electric motors because their torque/speed demands match the capabilities of conventional ac synchronous motors. Hydraulic pumps spin at speeds of 300–1800 rpm and can generate pressures over 2000 psi which, when applied to large surface areas, create the high forces necessary for plastics production.

The principal drawbacks of a hydraulic system are higher equipment maintenance, intermittent operation (creating potential power surges), and energy losses due to fluid heating and seal leakage. A hydraulic system uses oil because it does not compress, has low viscosity, and has good heat rejection ability; however, oil requires changing, sometimes after a limited number of hours. In addition, since hydraulic systems undergo continuous pressure changes, seals fatigue and must be replaced periodically. As a hydraulic system ages, the seals permit increased fluid leakage, which can degrade system efficiency and create higher operating stress on the pumps. Inefficient hydraulic system operation also can have a negative impact on production equipment performance and generate added heat that can burden a facility's HVAC system.

Efficiency Technology Solution
All-Electric Injection Molding Machines

All-electric injection molding machines offer improved performance over conventional, hydraulically operated plastic product manufacturing equipment. Although more expensive than conventional molding machines, industry experts believe all-electric injection molding machines will dominate the market in the near future, perhaps within

10 years. Until recently, the high torques needed to directly drive injection molding equipment have exceeded the capacity of synchronous motors. The development of brushless dc motors has solved this direct-drive challenge. With high torque, low-speed operating characteristics, brushless dc motors provide a good solution to the operating and maintenance challenges posed by hydraulically driven equipment.

The advantages of all-electric molding machines include improved process control and more efficient, quieter operation. The energy losses attributed to fluid heating and seal leakage are avoided, and the subsequent decrease in energy consumption lowers the cooling load on a facility's HVAC system. All-electric injection molding equipment has a 98% power factor, much higher than the 30– 80% power factor offered by conventional motors used in hydraulic system applications. The high power factor of the all-electric injection molding equipment reflects the efficiency with which these machines operate.

Process Heating

Process heating equipment consumes 19% of the electricity used in the plastics products industry. The applications of process heating include

- liquefying polymers during injection molding,
- curing thermosets,
- preheating plastic preforms and fillers,
- drying resin prior to use, and
- bonding thermoplastics.

Due to the differences among these applications, as well as the varying requirements of different polymers and final products, manufacturers of plastics products use several different types of heating equipment. In injection molding and compression molding applications, heat is typically supplied by a boiler producing steam at medium pressure (400–500 psi) or by electric indirect resistance heaters. In some manufacturing facilities, one central boiler provides steam heat for molding machines and for space heating; smaller facilities, however, tend to rely on indirect resistance heating for production services.

Process heating is also used to dry resins prior to feeding them into production. Moisture expands under heat and can create problems in most molding and forming processes. Moisture can also displace polymers and interfere with curing by absorbing heat. Polymers such as nylon and polyethylene terephthalate (PET) are relatively hygroscopic and require special drying prior to being molded or extruded. This type of application typically uses convective heating provided by electricity or gas.

Several methods can be used to dry hygroscopic polymers prior to feeding them into the manufacturing process. These methods include passing them through a convective oven, conditioning them in a dehumidification chamber, and exposing them to radio-frequency (RF) or infrared (IR) energy. Convective ovens require careful temperature control to avoid resin coagulation. At temperatures above 200–250ºF, resins begin to clump, which can interfere with feeding. The primary disadvantage of a dehumidification chamber is that the moisture removal process takes several hours, which can impede flexibility and potentially cause significant delays in production.

Getting plastic parts to bond is a critical step in the manufacture of many products. Frequently, bonding is the slowest step of a production process due to the material handling, alignment, and fusion or curing time required for a bond to form. Fusion welding is a process heating application that connects parts by heating the plastic at the interface and forcing the parts together, thereby allowing polymers from each part to flow together and bond. Upon cooling, these bonds are often nearly as strong as the original polymers. RF and electric indirect resistance heating technologies also can be used in bonding, though in limited applications. RF is typically only used in high-volume, continuous-process sealing applications (e.g., creating laminates) that can justify the significant purchase cost of the equipment. Electric indirect resistance is generally used in low-grade fusion applications.

IR heating is used primarily to preheat plastics prior to thermoforming. IR heaters are efficient and responsive; by transferring energy directly to the items in production, they lose little energy to the surroundings. They also have short ramp-up times, so they can be switched on and off in response to the pace of production, further minimizing energy use. Plastic preforms that are preheated require less time in a mold to form or cure; consequently, IR systems offer an efficient, relatively inexpensive opportunity to increase productivity.

Electrotechnology Solution
Indirect Resistance Heating of Plastics

Indirect resistance heating is the dominant heating method in the plastics products industry and is used primarily in heating resins for molding. Its compact size and accurate temperature control contribute to its popularity as the heating source for injection molding, thermoforming, and compression molding equipment. Resistance heating elements fit well around injection molding cylinders and other molding equipment, promoting accurate heat transfer and responsive temperature control. Recognizing that plastics are inherently poor thermal conductors, careful control of the surface temperature of a mold is necessary to prevent overheating.

Indirect resistance heating elements are relatively easy to maintain. The elements are inexpensive and can usually be replaced with little difficulty. The heaters do not require special power supplies or elaborate control systems. Upgrades, modifications, and retooling efforts are also relatively simple, providing good flexibility. Because indirect resistance heating provides a high degree of control, it is readily compatible with other heating methods. For example, RF heating can be used effectively as a complement to electric resistance heating to preheat polymers in a mold and reduce the chance of overheating high-risk regions.

Electrotechnology Solution
Radio-Frequency Heating and Drying of Plastics

RF energy is a primary method of preheating plastic preforms. Preforms are plastics that are stamped, cut, or bent so that they roughly fit a mold. Preheating these preforms improves productivity by making the plastic more flexible prior to molding. The good penetration qualities that characterize RF energy are well-suited to preheating applications. RF energy can reduce the cycle time for molding 25– 30%, decrease the molding pressure 30–40%, and lower the mold temperature 15–30ºF, thereby significantly improving productivity and reducing operating costs.

RF heating also can be used to preheat the filler in many plastics applications, as well as to facilitate the curing of high-quality thermoset molds. Filler expands the volume of a resin, reduces unit material costs, and provides added physical qualities to the polymer. Unfortunately, many molding processes tend to lessen the strength and flexibility of a filler as it goes through the process. Preheating the filler decreases the viscosity of the mixture as it travels through the molding process; this improves the strength and flexibility of the filler. Additional benefits of preheating filler are a reduction in machine wear and an improvement in energy efficiency. A warm polymer/filler blend is less abrasive to the injection screw surfaces and requires less power to press into the mold. The less viscous fluid also improves filler dispersal throughout a blend, enhancing the overall appearance and strength of the final product.

The favorable penetrating qualities of RF energy also can be exploited to resolve curing problems with thermoset mold shapes that inhibit proper heat transfer. Thermoset curing conventionally relies on heat conducted inward from the mold surfaces to raise the temperature of the polymer enough to begin cross-linking. Plastics are inherently poor conductors of heat; the outside of a plastic tends to overheat before the inner regions reach the required temperature for curing. RF heating resolves this because its heat penetrates to warm a polymer evenly throughout a mold. The mold can then be heated to the curing temperature with less risk of overheating. Another application of RF heating is for bonding layers of plastic to form laminates. The speed of RF heating and the ability to carefully control the amount and placement of heat facilitates formation of a uniform bond between plastic surfaces. The high speed of RF heating technology surpasses the speed of any other heating method.

RF drying also removes water from pelletized resin quickly and effectively prior to manufacturing. Water molecules are polar; they align themselves according to the influence of an electromagnetic field. By creating an electromagnetic field that alternates between 2 MHz and 200 MHz, RF drying causes the rapid movement and subsequent heating of water molecules, thus causing evaporation.

RF drying also contributes to production improvements through more efficient use of energy, shorter production times, and increased control over the final moisture content of a product. As water evaporates out of a plastic, the plastic responds less to the RF energy and heats up less. This relationship between moisture content and energy absorption prevents overheating of a resin and allows RF to effectively dehydrate resins that have uneven moisture profiles.

A significant drawback to RF equipment is its purchase cost. The complicated electronics required for RF drives the cost of equipment above that of many other drying alternatives. However, RF drying is a quick, accurate method of dehumidification that avoids the problem of overheating a polymer or creating production bottlenecks. Therefore, the production benefits afforded by this technology can create attractive competitive advantages.

Electrotechnology Solution
Electric Infrared Heating of Plastics

Electric IR heating can improve productivity in many preheating applications. IR energy is a form of radiation that includes wavelengths just longer than visible light. Within the IR band, certain wavelengths are capable of warming plastic to a depth sufficient for most purposes without overheating the surface. IR radiation also transfers energy directly from the emitter to the target, thus reducing the energy losses associated with conventional gas heating.

IR heating is characterized by negligible ramp-up time and quick energy transfer, making it a good match for automated production processes. IR heaters can be quickly energized and deenergized by signals from the production line, avoiding wasteful heater burn time during brief production stoppages. While less penetrating than RF energy, IR energy transfers heat deeper than both convection and conduction heating methods.

IR heating is most commonly used to preheat flat shapes such as film and sheet and is particularly effective in thermoforming applications. IR heating increases throughput by decreasing the amount of heat transfer necessary during the molding task. In addition, preheated plastics typically require less compressive force during forming, lowering both task times and equipment wear. Similar to RF heating and drying, IR heating can be used to dry resin pellets, removing moisture that would otherwise interfere with the molding and curing process. It also can be used to remove moisture from PCR prior to incorporating it into the production process.

Electrotechnology Solution
Fusion Welding of Plastics

Improved fusion techniques such as ultrasonic, vibration, and induction welding can rapidly heat the bonding surfaces of plastics. These electrotechnologies can significantly reduce bonding task times and increase overall productivity. In addition, they result in high-strength bonds that are aesthetically more attractive than bonds achieved by conventional methods.

- Ultrasonic Welding. Ultrasonic welding is currently the most popular bonding method for thermoplastic parts due to its relatively low purchase and operating costs, short task time, and its successful history with a variety of products. Using high frequencies of 20–40 kHz, ultrasonic welding bonds plastic parts through vibration. The vibrations create friction where the parts interface, thereby heating the surrounding plastic. The parts are then forced together at a pressure of about 60 psi so that the heated plastics flow together to form an interlinked molecular network that solidifies when cooled. The resulting bond is clean and precise. Because the heat-affected zone is so small, small parts can be rapidly assembled with high-quality results.
- Vibration Welding. Vibration welding is similar to ultrasonic welding in that the parts to be bonded are vibrated to create heat that melts the plastic at the interface surface, and the parts are then joined at a pressure of about 60 psi. However, vibration welding is characterized by lower frequencies and is more tolerant of surface contamination. The vibrations created (25–400 Hz) are applicable to fewer joint geometries and polymer types, but are tolerant of moisture contamination, making this process especially suitable for hygroscopic polymers such as nylon.
- Induction (Electromagnetic) Welding. Electromagnetic welding is a form of induction bonding that uses a higher-frequency magnetic field (1.8–8 MHz). The bonding agent acts much like a double-sided strip of adhesive tape. It contains iron particles that, when exposed to a magnetic field, vibrate and create heat. This heat melts the plastic on either side of the parts that then flow together, cool, and form a bond.

Process Cooling

Process cooling accounts for approximately 8% of the electricity used in the production of plastics products. Cooling is primarily required to remove heat from a mold to facilitate curing of the polymer. Cooling jackets and piping that contain circulating water typically provide process cooling. The effectiveness with which molds are cooled can have a significant impact on productivity. Although quick heat removal promotes short production cycles, it can cause severe thermal stress, which must be avoided to prevent equipment damage. Control of the cooling water temperature is provided by bypass lines and flow control valves. The heat transferred to the cooling water is generally removed by a chiller using the refrigeration cycle for heat rejection. Depending on the size of the system, the chiller can reject the heat to the plant or to the outdoors (the latter requires a fan-cooled heat exchanger or a cooling tower).

Most process cooling is provided by electrical refrigeration systems; opportunities to improve the efficiency of existing systems center around advances in compressor design. Newer compressors have improved system efficiencies, and all are adapted to use hydrochlorofluorocarbon refrigerants. Although compressor replacement can increase efficiency and save energy, it is difficult to justify such an upgrade on this basis alone. However, for plastics products manufacturers with old CFC-based cooling systems, making the changeover to more environmentally responsible refrigerants can provide an opportunity for compressor improvement.

Lighting

Lighting accounts for 7% of the electricity consumed in plastics production. Adequate lighting is essential to productivity, product quality, and worker safety. Three types of lighting systems dominate in plastics products manufacturing facilities: incandescent, fluorescent, and high-intensity discharge (HID). Incandescent lighting systems are common in low-ceiling areas such as hallways and restrooms but are the least energy-efficient. Fluorescent lights typically appear as 4-foot-long tubes used in two-, three-, or four-tube fixtures; they are used in offices and sometimes in production and loading dock areas. They are more efficient and have longer operating lives than incandescent lamps. HID lights are often one-tube fixtures; they are characterized by high illumination levels, long life, and low maintenance costs. HID lights are practical options for high-ceiling areas, which characterize many warehouse-type production areas.

Outdoor lighting is also provided primarily by HID lamps due to their good illumination, energy-efficiency, and low maintenance requirements. HID lights include mercury vapor, metal halide, and high-pressure sodium lights. Of these, mercury vapor lights are the least efficient.

Efficiency Technology Solution
Energy-Efficient Indoor Lighting

The most efficient form of fluorescent lighting available today is the T-8 fluorescent lamp with an electronic ballast. Conversion from a magnetic (T-12, 40-watt) ballast to an electronic (T-8, 32-watt) ballast can be accomplished by either retrofitting an existing fixture or installing a new fixture designed for T-8 lamps, at a cost of roughly $40 and $100, respectively.

Ceiling-mounted incandescent lamps can be successfully replaced with compact fluorescent lights when the ceiling height is less than 12 feet, such as in offices or hallways. HID lights are more efficient and have longer lives than both fluorescent and incandescent lights; of these, mercury vapor lights provide considerably less light per watt than their metal halide and high-pressure sodium counterparts and are good candidates for replacement.

Electrotechnology Solution
Energy-Efficient Outdoor Lighting

Outdoor lighting is also part of a plastics products manufacturing plant's energy bill. Existing applications for outdoor lighting range from incandescent lights on facility signs to mercury vapor lights in parking lots and driveways. These lighting systems normally represent only a small portion of a facility's energy bill because they are on for limited periods of time and because they seldom contribute to a facility's peak electrical demand. This means there may be small savings potential from energy conservation projects. More significant benefits may accrue through increasing outdoor lighting to reduce the potential for crime and increase employee safety.

Heating, Ventilation, and Air Conditioning

HVAC systems consume 7% of the electricity used by plastics products manufacturers. Although this energy use represents a comparatively small amount of the total operating costs, HVAC is important because control of the ambient conditions within a plant is critical to productivity and product quality. Moisture, in the production area interferes with polymer curing because the resins absorb moisture, and moisture condenses on the mold surface. Prior to being fed into the production process, polymers typically are dried to remove any water a resin absorbed during shipment. Maintaining low ambient humidity lessens the resin dehumidification burden; it does not eliminate the need for process drying entirely.

The most significant production problem caused by high relative humidity is condensation on mold surfaces. Molds are generally cooled with chilled water to solidify the plastic during curing. The ability to cool molds quickly significantly influences productivity; consequently, mold surfaces are frequently chilled to temperatures that approach the dew point of the production area. Since moisture on mold surfaces interferes with product quality, production areas should be dehumidified, usually by the HVAC system, to inhibit condensation.

The net result of keeping the dew point temperature of the ambient air low is often an air temperature too low for worker comfort, such that it must be reheated prior to being returned to the production areas. This overcooled air often is reheated with the incoming process air stream in a heat recovery heat exchanger.

For facility space heating, plastics products manufacturers often tap energy from the boiler that produces steam for mold heating. Heat can be captured from the boiler using heat exchangers that directly access a steam line or pull waste heat from a condensate line. Production facilities that do not use steam for mold heating must rely on conventional heating systems; however, there may be opportunities for energy transfer within the facility. For example, production areas that require cooling and dehumidification to prevent condensation problems can act as a heat source for other areas of the facility. Heat recovery heat pumps and heat exchangers could be considered as energy-efficient investments; however, it is difficult to justify their purchase on energy savings alone. Improved working conditions, lower defect rates, and decreased maintenance costs also should be considered in justifying HVAC system upgrades.

4

ELECTROTECHNOLOGY PROFILES

This section provides profiles of the electrotechnologies identified in Sections 2 and 3. Each profile explains the technology, its advantages and disadvantages, commercial status, and costs. The profiles have been designed as stand-alone descriptions so they can be utilized separately from this guide. Turn to Section 5 for a list of equipment vendors that can provide further information as needed.

Indirect Resistance Heating of Plastics

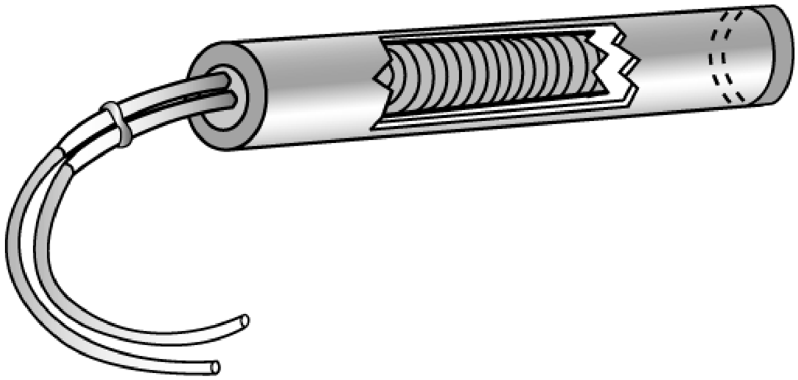
Basic Principle

Indirect resistance heating offers the plastics industry a safe, efficient, reliable, and clean method for heating resins. Indirect heating systems are easy to control and operate over a wide temperature range. These systems are the most commonly used heating method in the plastics industry. They are especially used to heat thermoplastic resins for molding. In the basic injection molding process, a measured quantity of melted resin is injected under high pressure into a relatively cold steel mold, where the plastic material solidifies into the shape of the mold cavity.

System Description

In indirect resistance heating, a current is passed through a resistance heating element that transfers heat to the subject material by radiation, convection, and/or conduction. The dominant indirect resistance heating technology in the plastics industry is an electric cartridge heater (also known as an “encased resistance heater”).

The electric cartridge heater consists of an electric wire or ribbon resistance element surrounded by an electrical insulator that is enclosed in a metallic tube. The outer covering provides mechanical and chemical protection. The cartridge heater is inserted into a slot or hole in the platen (mold cavity) to provide heat through electrical resistance that is then transferred to the mold through the thermal conductivity of the metal platen. These heaters can be designed to operate at whatever voltage a plant has available.



Electric Cartridge Electric Resistance Heater

Advantages

- High energy efficiency: Virtually all of the applied energy is converted to useful heat.
- Flexibility: Operating temperature can be varied.
- Ease of control: Automatic temperature control can be achieved through the use of microprocessors and solid-state switches.
- Better working conditions: The absence of combustion blower noise and hot flue gases makes a plant cleaner and cooler and improves worker safety.
- Cost savings: Indirect resistance heaters are fairly inexpensive, reliable, durable, and compact.

Disadvantage

- Frequent replacement: Cartridge heaters have a service life of 3–12 months. This is due to failure of the resistance element. Failure occurs because temperature control in the platen is achieved by switching the heaters on and off.

Commercial Status

Resistance heating and melting have been used in the plastics products industry for many years in both thermoplastic and thermoset applications. In 1954, the first cartridge heater was patented. Cartridge heaters are now available in many lengths, diameters, and heat output sizes and therefore can be fitted to a variety of heating requirements.

Cost and Electrical Requirements

The cost of an electric cartridge heater is determined mostly by size and operating temperature. Systems are available in 25–18,000 watt sizes; the respective size-to-power relationship is 0.022–0.4 kW per square inch of cartridge. A 75-watt unit usually costs $10–$30; a 4600-watt unit costs $100–$450.

Electric Cartridge System Characteristics

Dimensions	Diameter: 0.12–1.0" Length: 1–36"
Power Rating	0.025–18 kW
Key Inputs	
Power	Electricity
Other	None
Key Outputs	
Solid Waste	None
Air Emissions	None
Water Effluent	None
Cost	
Purchase	$10–$1000
Installation	Minimal
Other Supplies	none

Radio-Frequency Heating and Drying of Plastics

Basic Principle

Radio-frequency (RF) drying and heating uses RF waves to heat nonconductive materials (such as plastics and water) that contain polar molecules. RF energy is a rapidly alternating electromagnetic field. Polar molecules react to the field's rapidly changing polarity by moving around, creating heat in a manner similar to friction. Since many thermoplastics and thermosets have polar qualities, RF heating is an effective drying and heating technology for a large number of plastics applications.

However, not all polymers respond well to RF energy. The material must possess a certain level of electrical resistance and dielectric strength to withstand rapid heating from a strong electric field. The ability of a material to dissipate an electromagnetic charge is called "dielectric loss" and is measured by the dielectric loss constant. Polymers with a low dielectric loss constant (less than 0.1) do not react to the field sufficiently to heat quickly; polymers with a high dielectric loss constant (greater than 1) react so well that they tend to overheat. Simple aliphatic hydrocarbon polymers, such as polyethylene, polypropylene, and nonpolar polystyrene, exhibit a low dielectric loss, thus are not good candidates for RF heating. On the other hand, polymers such as polyurethane, polyvinyl chloride (PVC), and nylons exhibit strong dielectric losses and are readily heated by RF fields.

System Description

Some common applications of RF heating include sealing layers of plastic to form laminates, preheating preforms, preheating filler, facilitating the curing of thermoset molds, and drying pelletized resin. Plastic sealing relies on the speed and controllability of RF to produce a uniform bond between plastic surfaces. Since sheets have a uniform geometric profile, the field created by RF energy is consistent and can be adjusted to an intensity sufficient to fuse the sheets together as they pass through the heater at comparatively high speed (up to 12 feet per minute in some cases). This high-speed sealing promotes a level of productivity that far surpasses any other heating method. Also, RF sealing is versatile enough to bond different types of polymers and metals to plastics.

RF heating is also used to preheat preforms prior to thermoforming and compression molding. Preforms are plastic shapes that roughly fit a mold and are heated, liquefied, and pressed during thermoforming or compression molding. Preheating these preforms quickens the mold processing time by making the preform more pliable and lessening the amount of heat that must be transferred to them while in the mold. Thick preforms are difficult to effectively preheat with surface heating methods. The penetrating characteristics of RF energy provide advantages over convective and infrared heating techniques, which primarily heat the surface of the plastics. Since plastic is typically a poor thermal conductor, heat is not rapidly transferred internally. RF energy, however, penetrates the plastics and thoroughly warms the preforms to provide a pliability that improves the molding process.

Similarly, RF heating can preheat the filler used in many plastics applications and facilitate the curing of high-quality thermoset molds. Preheating filler—an additive that expands the volume of a resin—lessens the viscosity of the mixture, thereby improving its strength and flexibility. Preheating also reduces wear and tear on machinery and improves the energy efficiency of the plastic product manufacturing process because it requires less power to press the thermoset material into the mold. The penetrating qualities of RF are also advantageous for thermoset mold curing. Because plastics are poor conductors of heat, thermosets tend to overheat on the outside before the inner regions reach a high enough temperature for curing. RF heating penetrates and warms plastics evenly, reducing the potential for overheating.

RF energy can also be used to dry pelletized resin. Many resins absorb moisture and must be dried prior to being fed into production equipment. Since water is exceptionally polar, it responds favorably to RF energy; consequently, high moisture levels in pelletized resin create high dielectric loss characteristics that promote rapid heating. As the moisture in the resin heats up, it evaporates. A physical principle of dielectric circuits (including capacitors) dictates that low dielectric losses create low electrical impedances on the power supply. As the dielectric loss characteristics of a resin decrease (which occurs as the resin dries), less energy is pulled from the RF field. This effect creates a self-limiting drying process: relatively wet resin consumes a large amount of energy from the RF field; however, this energy draw decreases as the resin dries. This principle also applies to resins with a variable moisture profile. When exposed to RF energy, the wetter areas of a resin feedstock absorb more energy than the drier areas; this promotes uniform drying and minimizes the risk of overheating. Recognizing that many resins coagulate at high temperatures (200–250°F), precise control of the drying process is critical to avoid feed problems.

A typical RF heating unit consists of a power supply, oscillator, and a set of electrodes. The power supply provides the high voltages needed for the oscillator to generate high-frequency energy (2–100 MHz). The electrode system receives the high-frequency energy and converts the power to RF waves. Because the same frequencies are used for radio communication, RF heaters must be shielded to avoid radio interference.

Radio-Frequency Heating and Drying System Characteristics

Dimensions	Length: 15–40' Height: 5–10' Width: 5–10'
Power Rating	1–1000 kW
Energy Consumption	52,000 kWh annually*
Key Inputs	
Power	Electricity
Other	Oscillator tube replacement
Key Outputs	
Solid Waste	None
Air Emissions	None
Water Effluent	None
Cost	
Capital	\$1000–\$2,500,000
Operating and Maintenance	\$200–\$10,000

* Assuming a 50-kW unit used 4 h/d, 5 d/wk, 52 wk/yr.

Advantages

- Rapid, uniform, heating/drying: Heat is generated uniformly throughout the material; unlike with a convective process, no time is needed for the heat to flow into the material from the surface. The resulting decrease in drying time can allow a plant to increase productivity and even upgrade from batch to automated continuous processing.
- Reduced cycle time for molding: Preheating preforms prior to molding can reduce the molding cycle time 25–30%. Use of RF preheating also reduces molding pressure and lowers the mold temperature, significantly improving productivity and reducing operating costs.
- Improved product quality: Since the product does not need to be exposed to high temperatures for long periods of time, RF heating and drying reduces the potential for product damage and often enhances product quality.
- Less equipment maintenance: RF preheating of filler material decreases the viscosity of this mixture, thereby allowing lower mold temperatures and pressures and decreasing wear on the dynamic surfaces of the screw and the barrel.
- Better filler mixture: In injection molding applications, RF preheating of filler material promotes better mixing of filler and resin, which improves the properties of the final product.
- More efficient use of energy and space: Units are compact and efficient and can often save space and reduce energy costs since they require virtually no startup or cooldown time.

Disadvantages

- High initial capital cost: RF heaters have high purchase costs; however, improvements in throughput, product quality, and energy use can provide short payback periods for high-volume applications.
- Must be shielded: RF heaters use the same frequencies used for radio communications, thus units must be shielded to avoid interference. Although RF equipment must be shielded, it typically requires less floor space than conventional heaters.

Commercial Status

RF technology has been used commercially in the United States for more than 50 years and is highly reliable. Continuous (conveyor) and batch (operator removes the product from the exposure area when processing is complete) systems are available from a variety of vendors for numerous applications. Vendors usually specialize in specific applications (e.g., specific polymers and/or end products).

Cost and Electrical Requirements

One of the major disadvantages of an RF system is the initial capital cost. Capital costs are \$1000–\$4000 per kW of power output: smaller systems (1–200 kW) cost \$2500–\$4000 per kW, and larger systems (300–1000 kW) cost \$1000–\$2500 per kW. A typical 210-kW system costs approximately \$570,000.

About 60% of the power input to the generator actually reaches the product. As a result, the power required is about 1.7 times the power reaching the product (the generator output). Thus, a generator with an output of 210 kW would require a power input of about 350 kW.

Electric Infrared Heating of Plastics

Basic Principle

Infrared (IR) energy is part of the electromagnetic spectrum and occurs between visible light and radio waves (0.75–1000 microns). Electric IR energy is produced by heating an emitter of IR radiation. The radiation is then absorbed at the surface by the substance at which it is directed, causing its molecules to vibrate and generate heat. Since the energy radiates directly to the substance, there is no need for convective airflow, minimizing energy losses and eliminating the need for air handling equipment. Additionally, IR lamps heat up relatively quickly; consequently, they can be deenergized between batches and during production stoppages.

System Description

A typical electric IR system includes quartz lamps and reflectors. Industrial systems are configured to expose production work to a bank of lamps fixed at a particular height, position, or angle, or placed in moveable arches. Portable arm-mounted lamps are available for smaller applications. An electric IR system reaches full power in less than 1 second and can be accurately regulated with simple controls. This responsiveness allows IR heaters to effectively complement an automated production line.

Applications of IR heating systems in plastics manufacturing include preheating plastic preforms and drying pelletized resin. Plastic preforms are shapes that are roughly the size of the production mold; they are used primarily in thermoforming and compression molding processes. Preheating the preforms facilitates molding by softening the plastic and lessening the time and energy required for the mold to reach the temperature necessary for curing.

Similarly, drying resin improves the production process by removing moisture that would otherwise interfere with molding and curing. IR energy relies on adequate surface area exposure to effectively transfer heat. Since resin is usually pelletized and therefore has a relatively high surface area per unit volume, IR energy is ideally suited for this application. This characteristic is exceptionally useful for processes that incorporate postconsumer recyclate (PCR) into the production stream. Most PCR is washed using aqueous techniques; therefore, moisture removal is essential.

Alternate methods of preheating include convection heaters (both gas-fired and electric), electric resistance heaters, and radio-frequency (RF) equipment. IR heaters offer the advantages of quick and accurate heating with relatively moderate purchase costs. RF heaters typically provide more penetrating energy; however, the complexity of the associated electronics pushes the cost of RF heating equipment well above that of IR systems.

In an electric IR system, 85–90% of the energy used is converted to radiation, and 50–70% of the energy is absorbed by the product. By contrast, a gas IR system transfers only 20–25% of the energy it uses to the product and produces emissions of its own.

Electric IR Heating System Characteristics

Dimensions	IR heaters are modular units of 6–10" and can be built up incrementally and configured to meet the needs of any specific application.
Power Rating	8–15 kW per square foot
Energy Consumption	4160 kWh annually*
Key Inputs	
Power	Electricity
Other	None
Key Outputs	
Solid Waste	None
Air Emissions	None
Water Effluent	None
Cost	
Purchase	$1000–$250,000
Installation	Minimal
Other Supplies	None

* Assuming an 8-kW unit used 2h/d, 5d/wk, 52wk/yr.

Advantages

- Quick and efficient heating: Process time can be reduced 50–80% in comparison to convective ovens.
- Short ramp-up time: The responsiveness of IR heaters minimizes energy loss between batches and during production stoppages.
- Excellent results with pelletized resin: The large surface area of pelletized resin promotes effective heat transfer with IR emitters, thus improving polymer drying.
- Easily incorporated into existing production lines: The modular characteristics of IR equipment allow quick integration with existing production lines.
- Little system support required: Air handling equipment, gas lines, and cooling water systems are unnecessary.
- Compact size: IR ovens, due to their increased energy intensity and efficiency, are generally much smaller than convection ovens and require less floor space.
- Long life and low maintenance: Electric IR emitters have a long life and require little routine maintenance. Bulb change-outs are infrequent and can be performed quickly.

Disadvantages

- Higher initial capital cost: IR systems have higher purchase costs than conventional heating methods; however, improvements in efficiency and productivity often result in short payback periods.
- Heat is transferred primarily to the surface of the target: IR energy does not have the penetrating qualities of RF systems. IR heating is limited by the ability of the target material to conduct heat away from the surface.

Commercial Status

A variety of IR systems are available through numerous vendors. Systems can be obtained with heating element temperatures of 600–4000°F, thereby producing radiation of 1–6 microns. Vendors can also provide IR systems with precise controls capable of achieving highly accurate process temperatures. Plastics manufacturers use IR heating for preheating and drying; temperatures less than 200°F are common.

Cost and Electrical Requirements

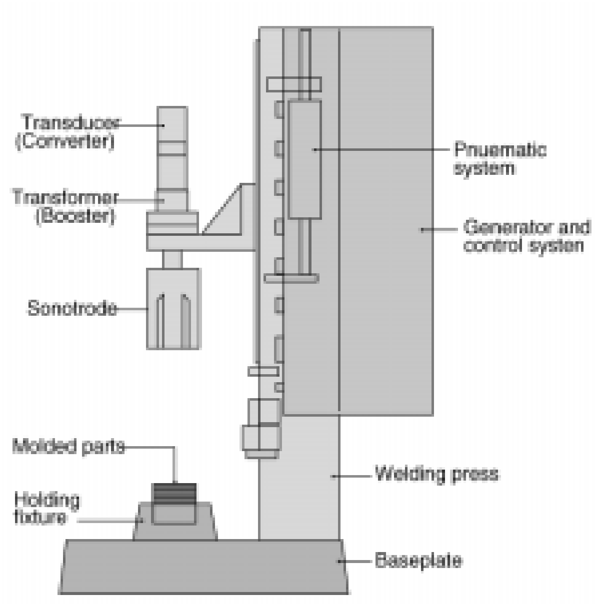
IR systems are usually custom-designed to meet specific applications; the price varies with the design. A basic IR spot heater or panel heater with two or three quartz emitters generally costs $1000–$2500. Small custom-designed ovens cost $10,000–$250,000.

IR ovens typically cost 10–20% less than gas convection ovens for the same application and features. This is due to the elimination of required gas safety controls as well as the reduction or elimination of air handling equipment.

Fusion Welding of Plastics

Basic Principle

The growth in the number of applications for plastics is attributable to advances in their mechanical properties and manufacturability. As production challenges—such as the need for cost-effective bonding of parts—are resolved, plastics become attractive substitutes for many materials. Fusion welding is an example of a production improvement; it offers high-strength bonds, aesthetically appealing finishes, and is quick to perform. Fusion welding exploits the qualities of thermoplastic polymers by melting the plastic at the interface of two parts, forcing the parts together under an applied pressure, then allowing the molten joint to cool and solidify. Conventional bonding methods rely on adhesives and mechanical fasteners to join parts; however, these methods take longer and produce a less attractive joint.



Ultrasonic Welding Machine

Fusion welding utilizes vibrational and electromagnetic energy to create the heat necessary to melt plastic. There are three basic fusion welding techniques: vibration welding, ultrasonic welding, and induction (electromagnetic) welding.

In vibration and ultrasonic welding, vibrational energy is created by forcing the parts together and then applying acoustic frequency or ultrasonic waves to the assembly. In induction welding, electromagnetic energy is used to excite a ferrous bonding agent that reacts to the alternating field and heats the surrounding plastic. The melted plastic flows together under an applied force. The bonds formed by fusion welding are close in strength to the parent plastic, and the localized heating creates joints with a smooth finish.

System Description

Ultrasonic Welding. Ultrasonic welding creates vibrational frequencies of 20–40 kHz in the two plastic parts being pressed together. The vibrations, generated by sonotrode (or horn), cause the parts to heat up such that the greatest heat is generated at the joint surfaces. The plastic melts and flows together, creating new molecular bonds that solidify upon cooling. Ultrasonic welding has a short process time, typically less than 1.5 seconds, followed by a brief cooling.

Ultrasonic welding is the most prevalent welding technique for thermoplastic parts. Its quick, clean welds do not require extensive preparation, and the process can be readily automated. Since the technique does not use a surface agent, it is appropriate for sterile applications (e.g., no contaminants allowed). Additionally, the strength and purity of the welds enable them to withstand aggressive postproduction sterilization processes and harsh chemicals. For these reasons, ultrasonic welding is used widely in the production of medical equipment, appliances, and optical equipment.

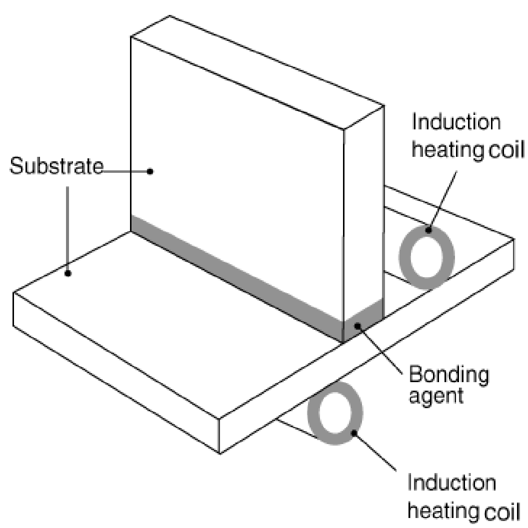
The effectiveness of ultrasonic welding is dependent on the physical properties of the polymers being joined as well as the physical shape of the parts. Polymers that dissipate energy well are not good candidates; rather, hard plastics, such as polystyrenes, are the easiest to bond ultrasonically. The thickness of the part is also a key factor. Parts thicker than 0.25 inch at the bond site tend to dissipate too much energy to create the necessary heat.

Vibration Welding. Vibration welding is similar to ultrasonic welding in that vibrational energy is used to melt plastic at the bond interface. The difference is that vibration welding moves parts across one another at frequencies of 25–400 Hz. The shape of the joint has a critical impact on the effectiveness of the weld; large, simple, planar surfaces provide the best applications. Vibration welding offers short process times (similar to ultrasonic welding) and is tolerant of surface contamination. However, since it leaves “flash,” or a visible seam, along the joint (which must be hidden or removed), vibration welds are not as clean as their ultrasonic counterparts.

Vibration welding, however, is superior to ultrasonic welding in joining thick sections (e.g., parts more than 1 inch thick) and can be used on a broader range of polymers. Also, the heat-affected zone is relatively small. While ultrasonic welding tends to heat both parts, vibration welding localizes the heat at the joint. The versatility of vibration welding is reflected by the number of process variables, such as clamping pressure and vibrational frequency and amplitude, all of which are determined by the characteristics of the joint. Selecting the correct process parameters depends heavily on the geometry of the joint and polymer properties.

Induction Welding. Induction welding requires the application of a bonding agent along the surfaces of the parts to be joined. The bonding agent contains ferrous particles which, when exposed to an alternating magnetic field, vibrate and generate heat. The heat melts the surrounding plastic, and the plastic from each part flows together under the force of compression. The frequency of the magnetic field varies according to the needs of the application. For most applications, frequencies of 1.8–4 MHz are sufficient; however, for large, energy-intensive applications, which are characterized by water-cooled electrodes, frequencies of 4–8 MHz are necessary.

The use of a bonding agent offers several advantages and drawbacks. These advantages include ensuring that only specific areas along a part interface are welded, welding joints that have complicated geometries and thick dimensions, and joining incompatible polymer types that do not bond well with vibration welding techniques. Additionally, induction welding can bond plastic to different types of substrates such as glass and wood. The drawbacks include extra production steps to apply the bonding agent color-match the bonding agent to the parent plastic(s).



Induction Welding

Advantages

- Relatively tolerant of surface contamination: Expensive and time-consuming joint preparations are not necessary.
- Does not require ventilation: No adhesives are used; therefore, no solvent vapors are emitted.
- Shortens task times: The quick, precise application of heat results in rapid bonding and short cooling periods. The process times for all types of fusion welding are typically less than those for adhesive bonding because curing is not necessary.
- Results in strong bonds: Fusion welding produces strong, impact-resistant joints. Joints produced by ultrasonic or vibration welding include only the parent plastic, which means the bond does not compromise the service capabilities of the product.
- Lends itself to automation: Fusion welding equipment can be readily incorporated into an automated production process.
- Produces a small heat-affected zone: Vibration welding and induction welding heat the plastic only along localized regions, which minimizes distortion of the bonding parts.
- Provides a reversible weld (induction welding): In many applications, the bonding agent can be reheated to release the weld. This provides a maintenance and repair benefit that can significantly improve the initial value and reusability of a product.

Disadvantages

- Limited by geometry in some applications: Each fusion welding technique is limited with respect to the geometry of the joint. Ultrasonic welding is ineffective on thick sections, vibration welding requires planar joints, and induction welding requires electrode access close to the joint. Typically, at least one fusion welding technique is effective for any given application.
- Limited by polymer types in some applications: Ultrasonic welding is ineffective on polymers that quickly dissipate energy. However, vibration welding and induction welding are applicable to a much broader range of materials and can often be used when ultrasonic welding is impractical.
- Requires a bonding agent (induction welding): Induction welding requires an additional production step to apply a bonding agent. In a well-designed production process, this task can be automated, or the bonding agent can be applied in the molding process.

Fusion Welding System Characteristics

	Ultrasonic Welding	Vibration Welding	Induction Welding
Dimensions	Width: 10–48" Depth: 10–48" Height: 15–40"	Width: 20–60" Depth: 20–60" Height: 30–72"	Width: 20–60" Depth: 20–60" Height: 30–72"
Power Rating	0.3–4 kW	0.5–5 kW	2–5 kW
Key Inputs Power Other	 Electricity None	 Electricity None	 Electricity None
Key Outputs	Vibrational energy, heat	Vibrational energy, heat	Electromagnetic energy, heat
Capital Cost	$1000–$10,000	$5000–$100,000	$5000–$100,000

Commercial Status

Ultrasonic welding has a 25-year record of success in the plastics industry and promises to remain an attractive bonding technique as thermoplastic polymers are used in new applications. Competitive pressures on manufacturers to improve productivity should promote the use of ultrasonic welding equipment.

Similarly, vibration welding is an established technology used by the industry for over 20 years. Since this method is effective with large objects and can weld multiple objects concurrently, the automotive industry in particular is expanding its use of vibration welding as it expands its use of plastics in general.

Induction welding is commercially proven and is used on products of a range of sizes and polymer types. The equipment configuration is often custom-designed to ensure sufficient coverage by the electromagnetic field.

Cost and Electrical Requirements

The fusion welding techniques offer a cost-effective solution to many design and production problems. The costs of fusion equipment vary according to the application; however, installation is relatively uncomplicated, and requirements for support services such as cooling are minimal. Since the process costs for existing fastening techniques vary widely, a payback period for fusion welding equipment must be calculated on a case-by-case basis.

Outdoor Lighting

Basic Principle

Many small businesses benefit from enhanced outdoor lighting through reduced potential for crime, increased employee safety, and improved visibility and attractiveness of the facility.

These benefits are obtained for a relatively small operating cost because, in most cases, outdoor lighting does not contribute to a facility's peak electrical demand. This means that the average energy cost for outdoor lighting (in terms of cents/kWh) is typically less than the energy cost of other improvements.

There are three principal methods for using outdoor lighting in small businesses:

1. Signage on the exterior of the building or illuminated signs near the building to generate attention for the building or the small business

2. General lighting in parking lots, driveways, parking garages, and walkways

3. Facade lighting to increase the visibility of the structure and surrounding architectural features and landscaping

Different lighting technologies are typically used for different applications. Existing lighting systems can often be retrofitted or replaced by energy-efficient lighting systems. In addition, existing lighting systems can be supplemented with new lighting systems to increase safety, security, visibility, and name recognition.

Typical Outdoor Lighting Applications

Type of Light	Exterior Signage	Parking Garages	Parking Lots/ Driveways	Walkways	Facade and Landscaping
Incandescent	■			■	■
Compact Fluorescent		■		■	■
Fluorescent	■	■		■	■
Metal Halide		■	■	■	■
High-Pressure Sodium			■		
Mercury Vapor			■		

Note: Additional applications are possible for each of the lighting types, but the chart identifies the most efficient applications for each of the light sources. Low-pressure sodium lamps are not normally used in small businesses because of their poor color quality.

System Description

Mercury vapor, high-pressure sodium (HPS), and metal halide lamps are referred to as high-intensity discharge (HID) lamps. Metal halide lamps and HPS lamps provide approximately 100 and 140 lumens per watt, respectively, while mercury vapor lamps provide up to 60 lumens per watt. Mercury vapor lamps emit a blue-green light, while HPS lamps emit a yellow-orange light. Metal halide lamps emit a predominately white light. Most HID lamps require a spacing-to-mounting height ratio of 1.0–1.9, which means that the spacing is roughly one to two times the pole height.

Each HID lamp requires a specific ballast to drive the lamp; however, some manufacturers offer metal halide and HPS lamps that can be operated by a mercury vapor lamp ballast. This allows easier conversion from inefficient mercury vapor lamps to higher-efficiency metal halide and HPS lamps. HID lamps are available in a variety of wattages from 35–1500. The HID ballast adds approximately 8–15% to the wattage of the lamp.

Fluorescent lamps are also used as outdoor lighting sources for small businesses. Conventional 4-foot and 8-foot tubes are used in many parking garages and covered walkways. Compact fluorescent lamps are also becoming popular as replacements to incandescent lamps in stairways. Newer T-8 lamps and electronic ballasts are approximately 30% more energy-efficient than older 40-watt T-12 lamps with magnetic ballasts.

Incandescent lamps are the least efficient form of outdoor lighting. However, incandescent lamps are still used as spotlights on signs and as floodlights on building facades and landscaping. The short lifetime of incandescent lamps often has a bigger impact on operating costs than does the additional energy use. Common controls used for outdoor lighting systems include time clocks, photocells, and programmable controllers.

Advantages

Well-designed outdoor lighting systems can offer the following advantages:

- Increased perception of comfort and friendliness
- Increased security for customers and employees
- Reduced number of accidents in driveways, parking areas, and walkways
- Increased visibility for the facility and the small business

Typical Lamp Characteristics for Outdoor Applications

Type of Lamp	Typical Wattages	Initial Lumens/Watt	Avg Rated Life (h)
Incandescent	60–1,500	15–24	50–2,500
Compact Fluorescent	12–35	25–75	8,000–12,000
Fluorescent	20–215	50–100	9,000–20,000
Metal Halide	175–1,500	69–115	10,000–20,000
High-Pressure Sodium	35–1,000	51–140	7,500–24,000
Mercury Vapor	40–1,000	24–60	12,000–24,000

Note: Initial lumens/watt includes ballast losses.

Disadvantages

Other than installation and operating costs, there are no overall disadvantages of outdoor lighting. However, specific lamps do have weaknesses:

- HID lamps require 2–7 minutes to warm up before reaching full output.
- Metal halide lamps require up to 15 minutes to cool before restrike.
- Special low-temperature fluorescent lamps are required in cold climates to maintain a relatively constant lumen output when temperatures are below freezing.

Commercial Status

All of the lamps described above are readily available from a variety of manufacturers. However, mercury vapor and older T-12 fluorescent lamps are being phased out of production.

Gradual improvements have been made in the efficiency of outdoor lighting systems. In addition, color-corrected HPS lamps are available, as well as improved metal halide lamps that contain incandescent or fluorescent lamps that come on if the power is interrupted.

EPRI Information

Additional information on lighting technologies is available from the EPRI Lighting Information Office, (800) 525-8555.

5

RESOURCES

This section contains three lists: 1) equipment suppliers for the electrotechnologies profiled in this guide, by equipment type; 2) EPRI information sources on efficiency technologies; and 3) plastics industry trade associations. Information used to compile these lists was based on a combination of a telephone survey, published reports, directories, buyer's guides, and technical journals. The information was current at the time of publication and is expected to change over time.

Indirect Resistance Heating

Equipment Suppliers

ARI
381 ARI Court, Addison, IL 60101
(708) 953-9100, fax: (708) 953-0590

Akinsun Heat Company, Inc.
1531 Burgundy Pkwy., Streamwood, IL 60107
(630) 289-9393, fax: (630) 289-9506

Argus International
P.O. Box 38-M, Hopewell, NJ 08525
(609) 466-1677, fax: (609) 466-4111

CM Furnaces, Inc.
103 Dewey St., Bloomfield, NJ 07003
(201) 338-6500, fax: (201) 338-1625

Casso-Solar Corporation
P.O. Box 163, U.S. Rte 202, Pomona, NY 10970
(914) 354-2500, fax: (914) 362-1856

Chromalox
641 Alpha Drive, Pittsburgh, PA 15238
(412) 967-3900, fax: (412) 967-5148

CooperHeat, Inc.
1021 Centennial Ave., Piscataway, NJ 08854
(800) 526-4233, fax: (908) 981-0850

Dalton Electric Heating Company
28 Hayward St., Ipswich, MA 01938
(508) 356-9844, fax: (508) 356-9846

Electric Furnace Company
435 West Wilson St., Salem, OH 44460
(216) 332-4661, fax: (216) 332-1853

Electro Heat Systems, Inc.
P.O. Box 1529, Acme Road, Butler, PA 16003
(412) 228-3530, fax: (412) 283-6570

Glenn Electric Heater Corporation
2111 East 30th St., Erie, PA 16510
(814) 898-4000, fax: (814) 898-1719

Glo-Quartz Electric Heater Company
7084 Maple St., Mentor, OH 44060
(216) 255-9701, fax: (216) 255-7852

HED Industries, Inc.
Highway 31, P.O. Box 246, Ringoes, NJ 08551
(609) 466-1900, fax: (609) 466-9608

IHS-INDUCTOHEAT
5009 Rondo Drive, Fort Worth, TX 76106
(817) 625-5577, fax: (817) 625-1872

Inductoheat, Inc.
32251 North Avis Drive, Madison Heights, MI 48071
(800) 624-6297, fax: (810) 589-1062

Industrial Heating & Finishing Company
P.O. Box 129, Pelham, AL 35124
(205) 663-9595, fax: (205) 663-9608

Infratrol Manufacturing Corporation
646 S. 29th St., Milwaukee, WI 53234-0290
(414) 671-7140, fax: (414) 671-5088

Lindberg/Cycle Dyne
304 Hart St., Watertown, WI 53094
(800) 234-4468, fax: (414) 261-0925

Lufran, Inc.
10200 Wellman Rd., Streetsboro, OH 44241
(216) 655-9797, fax: (216) 656-3500

Process Heating Corporation
547 Hartford Turnpike, Shrewsbury, MA 01545
(508) 842-5200, fax: (508) 842-9418

Process Thermal Dynamics
304 G 50th Ave., Alexandria, MN 56308
(612) 762-2077, fax: (612) 762-1319

Radiant Energy Systems
458 Hamburg Turnpike, Wayne, NJ 07470
(201) 942-7767, fax: (201) 942-5581

Reliant Heating & Control, Inc.
1305 Highway 174, P.O. Box 330, Colfax, CA 95713
(916) 888-0722, fax: (916) 346-2289

Therma-Tron-X, Inc.
1155 S. Neenah Avenue, Sturgeon Bay, WI 54235
(414) 743-6568, fax: (414) 743-5486

Watlow Electric Mfg. Company
12001 Lackland Rd., St. Louis, MO 63146
(314) 878-4600, fax: (314) 878-6814

Radio-Frequency Heating and Drying of Plastics

Equipment Suppliers

Ameritherm, Inc.
P.O. Box 901, Scottsville, NY 14546
(716) 889-9000, fax: (716) 889-4030

Callanan Company
1844 Brummel Drive, Elk Grove, IL 60007
(847) 364-4242, fax: (847) 364-4373

IHS-INDUCTOHEAT
5009 Rondo Drive, Fort Worth, TX 76106
(817) 625-5577, fax: (817) 625-1872

Kaber Manufacturing Corporation
140 Schmitt Blvd., Farmingdale, NY 11735
(516) 694-6857, fax: (516) 694-6846

LaRose Radio Frequency Systems, Inc.
150 Dover Rd., Minis, MA 02054
(508) 376-0850, (617) 762-4900, fax: (617) 762-4952

Nemeth Engineering Associates, Inc.
5901 W. Highway 22, Crestwood, KY 40014
(502) 241-1502, fax: (502) 241-5907

PSC
21761 Tungsten Rd., Cleveland, OH 44117
(216) 531-3375, fax: (216) 531-6751

Radio Frequency Co., Inc.
P.O. Box 158, 150 Dover Rd., Millis, MA 02054
(617) 762-4900, fax: (617) 762-4952

Thermex Thermatron
60 Spense Street, Bayshore, NY 11706
(516) 231- 7800, fax: (516) 231- 5399

Electric IR Heating

Equipment Suppliers

Aitken Products, Inc.,
P.O. Box 151, 566 North Eagle St., Geneva, OH 44041
(216) 466-5711, fax: (216) 466-5716

Americure, Inc.
2353 W. Lincoln St., Phoenix, AZ 85009
(602) 253-3130,

Argus International
P.O. Box 38-M, Hopewell, NJ 08525
(609) 466-1677, fax: (609) 466-4111

BGK
4131 Pheasant Ridge Dr., N.E., Minneapolis, MN 55449
(612) 784-0466, fax: (612) 784-1362

Cleveland Process Corporation
127 S.W. Fifth Ave., Homestead, FL 33030
(800) 241-0412, fax: (305) 248-4371

Dry-Clime Corporation
P.O. Box 146, State Rd. 46 W., Greensburg, IN 47240
(812) 663-4141, fax: (812) 663-4202

Edwin Trisk Systems
670 New York Street, Memphis, TN 38104
(800) 261-7976, fax: (901) 274-8355

Eraser Company, Inc.
Olivia Drive, P.O. Box 4961, Syracuse, NY 13221
(315) 454-3237, fax: (315) 454-3090

Future Cure
29313 Clemins, Westlake, OH 44145
(800) 722-4664, fax: (216) 835-1578

Fostoria Industries, Inc.
1200 N. Main St., Box 986, Fostoria, OH 44830
(419) 435-9201, fax: (419) 435-0842

Glenro, Inc.
39 McBride Ave., Paterson, NJ 07501
(800) 922-0106, fax: (201) 279-9103

Infratech Corporation
1634 Industrial Park St., Covina, CA 91722
(818) 331-9400

Infratrol Manufacturing Corporation
646 S. 29th St., Milwaukee, WI 53234
(414) 671-7140, fax: (414) 671-5088

IRT Systems
89 Connie Crescent, Concord, Ontario, L4K 1L3, Canada
(800) 387-3639, fax: (905) 669-1171

Prime Heat
1946 John Towers, El Cajon, CA 92020
(619) 449-6623, fax: (619) 449-9844

Process Thermal Dynamics
304 G 50th Ave., Alexandria, MN 56308
(612) 762-2077, fax: (612) 762-1319

Radiant Energy Systems
458 Hamburg Turnpike, Wayne, NJ 07470
(201) 942-7767, fax: (201) 942-5581

Solaronics
704 Woodward, Rochester, MI 48307
(810) 651-5333, fax: (810) 651-0357

Tech Systems
1030 N. Lincoln St.., Greensburg, IN 47240
(812) 663-4720, fax: (812) 663-4799

Watlow Electric Manufacturing Company
12001 Lackland Rd., St. Louis, MO 63146
(314) 878-4600, fax: (314) 878-6814

Fusion Welding of Plastics

Equipment Suppliers

Ultrasonic and Vibration Welding Systems

Branson Ultrasonics Corporation
41 Eagle Road, Danbury, CT 06813-1961
(203) 796-0400,

Bryant Assembly Technologies, Inc.
230 Pepe's Farm Rd., Milford, CT 06460
(800) 937-2900

Electromagnetic Welding Systems

Emabond Systems
49 Walnut Street, Norwood, NJ 07648
(201) 767-7400

Herman Ultrasonics
630 Estes Ave., Schaumburg, IL 60193
(708) 980-7344

Sonics & Materials, Inc.
100 Kenosia Ave., Danbury, CT 06810
(203) 744-4400

Ultra Sonic Seal Co.
368 Turner Way, Aston, PA 19014
(215) 497-5150

Outdoor Lighting

Equipment Suppliers

Bairnco Corp.,
2251 Lucien Way, No. 300, Maitland, FL 32751
(407) 875-2222, fax: (407) 875-3398

Bieber Lighting Corp.
970 W. Manchester Blvd., Inglewood, CA 90301
(213) 776-4744, fax: (310) 216-0333

Bulbtronic, Inc.
45 Banfi Plaza, Farmingdale, NY 11735
(800) 647-2852, (516) 249-2272, fax: (516) 249-6066

Carlon (Lanson & Sessions Co.)
25701 Science Park Dr., Cleveland, OH 44122
(216) 831-4000, fax: (216) 831-5579

Cooper Lighting Group
400 Busse Rd., Elk Grove Village, IL 60007-2195
(847) 956-8400, fax: (847) 956-1475

Crouse-Hinds Co.
Lighting Production Div., P.O. Box 4999, Syracuse, NY 13221
(315) 477-8185

Doane, L.C., Co.
55 Plains Rd., P.O. Box 975, Essex, CT 06428
(203) 767-8295, fax: (203) 767-1397

Duro-Test Corp.
9 Law Dr., Fairfield, NJ 07004
(201) 808-1800, fax: (201) 808-6622

Federal APD, Inc., Federal Signal Corp.
24700 Crestview Ct, Farmington Hills, MI 48335
(800) 521-9330, (810) 477-2700, fax: (810) 477-0742

Gardco Lighting
2661 Alvarado St., San Leandro, CA 94577
(510) 357-6900, fax: (510) 357-3088

G.E. Company
3135 Easton Turnpike, Fairfield, CT 06431
(800) 626-2004, fax: (518) 869-2828

Hapco Division of Kearney-National, Inc.
P.O. Box 547-KN, Abingdon, VA 24210
(540) 628-7171, fax: (540) 628-7707

Litetronics International
4101 W. 123rd St., Alsip, IL 60658
(708) 389-8000 ext 195, fax: (708) 371-0627

Mason, L.E., Co.
98 Business St., Boston, MA 02136
(617) 361-1710, fax: (617) 361-6876

Philips Lighting Co.
200 Franklin Sq. Dr., Somerset, NJ 08875
(908) 563-3000, (800) 631-1259, fax: (908) 563-3975

Rig-A-Light
P.O. Box 12942, Houston, TX 77217
(713) 943-0340, fax: (713) 943-8354

Sterner Lighting Systems
351 Lewis Ave., Winisted, MN 55395
(320) 485-2141, fax: (320) 485-2899

Thomas and Betts
Corporate Headquarters, Memphis, TN 38119
(800) 888-0211, fax: (800) 888-1366

Unique Solution, Division of Holophane Corp.
515 McKinley Ave., Newark, OH 43055
(614) 349-4194, fax: (800) 346-5923

Information on Efficiency Technologies

This list provides EPRI resources on efficiency technologies identified in the guide. Copies of these publications can be ordered through the EPRI Distribution Center, (510) 934-4212.

Adjustable Speed Drives

Medium-Voltage Adjustable Speed Drives: A Basic Specification Guide, BR-104420, May 1995.

Adjustable Speed Drives: Application Guide, TR-101140, December 1992.

Environmental Benefits of Adjustable Speed Drive Applications, TR-100200, July 1992.

Adjustable Speed Drive Directory, Third Edition, CU-7544, January 1992.

Energy-Efficient Lighting

Proceedings—Efficient Lighting 1993: A Lighting Symposium for Electric Utility Lighting and DSM Professionals, TR-105963, January 1996.

Electronic Ballasts, BR-101886, May 1993.

High-Intensity Discharge Lighting, BR-101739, May 1993.

Advanced Lighting Technologies Application Guidelines: 1990, TR-101022-R1, May 1993.

Lighting Fundamentals Handbook, TR-101710, March 1993.

Commercial Lighting Efficiency Resource Book, CU-7427, September 1991.

Additional information on lighting can be obtained from the EPRI Lighting Information Office, (800) 525-8555.

Energy-Efficient Motors

Assessment of Electric Motor Technology: Present Status, Future Trends, and R&D Needs, TR-101264, December 1992.

Electric Motors, TR-100423, June 1992.

Trade Associations

American Plastics Council

1275 K Street, N.W., Suite 400, Washington, DC 20005
(202) 371-5319, fax: (202) 371-5679

This organization represents plastics industry processors and suppliers.

Plastic and Metal Products Manufacturers Association

225 W. 34th Street, New York, NY 10122
(212) 564-2500

Formerly the Plastic Products Manufacturers Association, Inc.

Plastic Bag Association

355 Lexington Ave, 17th Floor, New York, NY 10017-6603
(212) 661-4261, fax: (212) 370-9047

Members are U.S. and Canadian manufacturers of plastic bags for retail use.

Plastic Bottle Institute

1275 K Street, N.W., Suite 400, Washington, DC 20005
(202) 371-5200, fax: (202) 371-1022

Members are manufacturers of plastic bottles. This organization is a division of the Society of the Plastics Industry.

Plastic Drum Institute

1275 K Street, N.W., Suite 400, Washington, DC 20005
(202) 371-5200, fax: (202) 371-1022

Members are manufacturers of plastic drums. This organization is a division of the Society of the Plastics Industry.

Plastic Shipping Container Institute

1411 Opus Place, Suite 111, Downers Grove, IL 60515
(312) 969-4500, fax: (312) 969-4752

Members are manufacturers of plastic shipping containers.

Society of Plastics Engineers

14 Fairfield Drive, Brookfield, CT 06804-0403
(203) 775-0471, fax: (203) 775-8490

Members are individual plastics engineers.

Society of the Plastics Industry

1275 K Street, N.W., Suite 400, Washington, DC 20005
(202) 371-5200, fax: (202) 371-1022

This organization promotes the application and use of plastics and is the principal representative of the plastics industry.

Thermoforming Institute

1275 K Street, N.W., Suite 400, Washington, DC 20005
(202) 371-5395, fax: (202) 371-0865

A division of the Society of the Plastics Industry.