Plastics Product Manufacturing (NAICS 3261)

Industry Brief

Industry Snapshot

The plastics product manufacturing industry encompasses companies engaged in processing new or recycled plastic resins into a wide variety of intermediate or final products. Accordingly, the industry uses a wide variety of processes such as compression molding, extrusion molding, injection molding, blow molding, and casting – all of which rely on motors and drives, as well as process heating and cooling.

The 1995 edition of this document[1] covered the miscellaneous plastic products industry (SIC 308). With the advent of the NAICS (North American Industry Classification System) as the standard for classifying business establishments, the industries falling previously under SIC 308 have generally been reclassified into NAICS 3261 – Plastics Products Manufacturing, as shown in Table 1.

The plastics products manufacturing industry continues to grow when measured by value of shipments, even as the numbers of establishments and employees decline. Between 1997 and 2007 the number of establishments and employees fell 13% and 15%, respectively, while value of shipments grew 37% (see Table 3). Because of their unique combinations of chemical, physical, and electrical properties, plastics are highly versatile raw materials. They can be shaped into a multitude of finished products quickly and easily. Plastics have displaced many traditional metal, wood, and glass components in products around the world.

Plastic is polymeric organic material. When it is heated it becomes a malleable fluid that takes on any desired shape. Plastics are generally divided into two categories: thermosets and thermoplastics.

- **Thermoset** plastics cure permanently to a hardened state. Once cured, thermosets cannot be remelted and remolded, so they cannot be recycled, except as filler material. The cure is achieved through heat, chemical reaction, or irradiation such as electron beam processing. Thermoset plastics include Bakelite, melamine, epoxies, and polyimide.
- **Thermoplastics** are plastics that liquefy when heated and, when cooled, generally remain elastic and flexible. Thermoplastics can endure multiple melting/freezing cycles and can be reshaped each time. As a result, they are recyclable. Thermoplastics include polyethylene, polypropylene, polycarbonate, polyester, polystyrene, and polyvinylchloride. Thermoplastics are the most common type of plastic, representing about 90% of national production.

Table 1
NAICS Codes and Industry Descriptions for Plastics Product Manufacturing

NAICS Code	Description
32611	Plastics Packaging Materials and Unlaminated Film and Sheet Manufacturing
32612	Plastics Pipe, Pipe Fitting, and Unlaminated Profile Shape Manufacturing
32613	Laminated Plastics Plate, Sheet (except Packaging), and Shape Manufacturing
32614	Polystyrene Foam Product Manufacturing
32615	Urethane and Other Foam Product (except Polystyrene) Manufacturing
32616	Plastics Bottle Manufacturing
32619	Other Plastics Product Manufacturing

The raw materials needed to make most plastics come from petroleum and natural gas. They typically consist of a base resin to which a variety of fillers, plasticizers, pigments, and other additives are added to achieve specific results and characteristics.

Plastic products can be produced using a range of processing techniques. The various processes are distinguished by the way the processor melts the plastic granules or powder and by the way the plastic products are formed. The most common processing methods are described below.

- **Injection molding** is the most common method of forming thermoplastic materials in a wide variety of sizes. It entails the use of both heat and pressure to convert plastic pellets or granules into molded shapes.

  Granular plastic is gravity-fed from a hopper into a barrel. Within the barrel, an auger slowly moves the granules forward, forcing the plastic into a heated chamber where it melts. The auger forces the melted plastic through a nozzle and into a mold cavity where it cools and hardens into the shape of the mold. Once cool, the mold opens, releasing the plastic part. The process is then repeated.

The operation is primarily hydraulic, with much of the operation powered by electrically-driven pumps. Injection molding also involves the use of electric motor-driven augers and process heating systems, which can be electric or gas-fueled.

- **Extrusion molding** is a high-volume method of creating plastic objects having a fixed cross-sectional profile, such as plastic sheeting and films, pipes and tubing, rods, adhesive tape, and window frames.

  Similar to injection molding, granular plastic is gravity-fed from a hopper into a barrel. Within the barrel, an auger slowly moves the granules forward, forcing the plastic into a heated chamber where it melts. The auger then forces the melted plastic through a die with the desired cross-section to give the plastic its final shape. The continuous plastic piece is then cooled, often using a water bath.

  Again, similar to injection molding, extrusion molding is primarily hydraulic, with much of the operation powered by electrically-driven pumps. In addition, extrusion molding uses electric motor-driven augers and electric or gas-fueled process heating.

- **Compression molding** is a high-volume method of molding that uses heat and high-pressure to form partially cured thermosetting resins. The molding material – in the form of granules or a soft, pre-formed piece – is placed directly into a heated mold. As the mold closes, the material is forced into the shape of the mold. Once the material has cured, the mold opens and the plastic part is ejected.

  The operation is primarily hydraulic, with much of the operation powered by electrically-driven pumps. It also involves electric or gas-fueled process heating.

- **Blow molding** is a method of forming hollow plastic parts such as hoses, bottles, jugs, jars, and other containers. There are three primary types of blow molding: extrusion blow molding, injection blow molding, and stretch blow molding.

  Each type of blow molding involves a process where granular plastic is fed from a hopper into a barrel where an auger drives the plastic into a heated chamber. The melted plastic is fed through an extruder to form a tubular shape with a hole at one end through which compressed air can pass. The tubular shape is then clamped into a mold and air is pumped into it. The air pressure then pushes the plastic outward into the mold. Once the plastic has cooled, the mold opens up and the part is ejected.

  In addition to electrically-driven pumps for hydraulics and augers to drive the plastic through the extruder, blow molding also involves the use of electrically-driven compressors for compressed air, and electric or gas-fueled process heating.

- **Thermoforming** is the process of heating thermoplastic sheet until it is pliable, and then stretching it over a single-sided mold until it cools and solidifies to the desired shape. The plastic can be heated using convection or radiant heat. Thermoforming is the most common method of high-volume, continuous thermoforming of plastic sheet products.

  Plastic sheet is fed from a roll through an oven heated to the forming temperature. After heating, the sheet is pressed onto a mold using vacuum pressure, air pressure, or mechanical force. Once cool, excess material is trimmed from the sheet and the part is released from the mold.

  Thin-gauge products manufactured using the thermoforming technique include disposable cups, containers, lids, trays, blister pack covers, clamshells, and other products for the medical, food, and retail industries. Thick-gauge products include vehicle door and dashboard panels, refrigerator liners, utility vehicle beds, and plastic pallets.

- **Rotational molding**, also known as rotomolding, uses rotational forces rather than pressure to form mostly hollow parts. It begins with a measured quantity of granular plastic loaded into the mold. The mold is heated as it begins to rotate, which disperses the plastic over the interior walls of the mold. To maintain the thickness throughout the part, the mold continues to rotate until the mold and the part have cooled. Once cooled, the mold is opened and the part released.

  Rotation molding is particularly practical for large, hollow products, such as tanks, which are difficult to mold using other methods. The downside of rotational molding is its long cycle times, which are protracted due to the need to allow the entire mold to cool prior to product release.

  The molds are rotated with electric motors and heated in either electric or gas ovens.

According to the most recent business census data, the U.S. plastics product manufacturing industry consists of 12,150 firms with combined annual revenues of about $170 billion.[2] Those firms employ over 700,000 people. The industry is somewhat fragmented in that the four largest companies generate 5% of total industry revenue and the 50 largest companies generate about 31% of total industry revenues.

In terms of industry revenues, the top five states are California, Ohio, Texas, Illinois, and Michigan, which together represent over one-third of total industry revenues. The second tier of states includes Pennsylvania, Indiana, North Carolina, Wisconsin, and Georgia. The top ten states combined reflect 53% of the industry's total revenues. Figure 1 shows that except for California and Texas, the top ten states are in the Midwest and Southeast. The Los Angeles and New York metropolitan areas together represent 9% of the nation's plastics product manufacturing revenues.

In terms of the number of establishments, California is home to one-ninth of the plastics product manufacturing establishments. The top ten revenue states are home to 55% of the plastics product manufacturing establishments. The Los Angeles and New York metropolitan areas together represent 12% of the nation's plastics product manufacturing establishments.

Figure 1
Top 10 States in Plastics Products Manufacturing – Total Value of Shipments
Source: U.S. Census Bureau, American Fact Finder 2007.

Table 2 shows the top ten states for plastics product manufacturing facilities by value of 2007 shipments, number of employees, and number of establishments. California ranks first in all three categories and represented over 8% of industry shipments in 2007.

Virginia has the highest value of shipments per establishment at $29.2 million per year, while Colorado the lowest at $6.1 million. South Carolina has the highest value of shipments per employee at $344,000, which is 13% higher than Mississippi, the next highest state. Oregon has the lowest value of shipments per employee at $194,000 per employee.

Figure 2 shows the major end-use markets for plastics in the U.S.. Packaging – such as bottles, film, cups, etc. – is the greatest share at 9.7 million tons or 25% of total shipments. Close behind at 8.6 million tons (22% of total shipments) is building and construction end-uses, which includes pipe, siding, insulation, etc. Exported plastic products are 4.4 million tons or one-ninth of total U.S. production.

Table 2
Plastics Product Manufacturing – Top 10 States: Value of Shipments, Number of Employees, and Number of Establishments – 2007

	Total Value of Shipments		**Number of Employees**		**Number of Establishments**	
State	($1,000)	Rank	Count	Rank	Count	Rank
California	14,178,819	1	61,737	1	1,353	1
Ohio	12,631,374	2	54,299	2	802	2
Texas	12,117,162	3	42,773	5	751	3
Illinois	11,694,708	4	45,475	4	634	5
Michigan	9,822,659	5	47,086	3	642	4
Pennsylvania	9,449,765	6	39,001	6	572	6
Indiana	8,089,486	7	34,613	7	458	9
North Carolina	7,320,456	8	28,345	9	400	11
Wisconsin	6,928,537	9	28,492	8	435	10
Georgia	6,391,383	10	21,518	11	355	13
Total U.S.	**170,467,731**	**–**	**700,000**	**–**	**12,136**	**–**

Source: U.S. Census Bureau, American Fact Finder 2007.

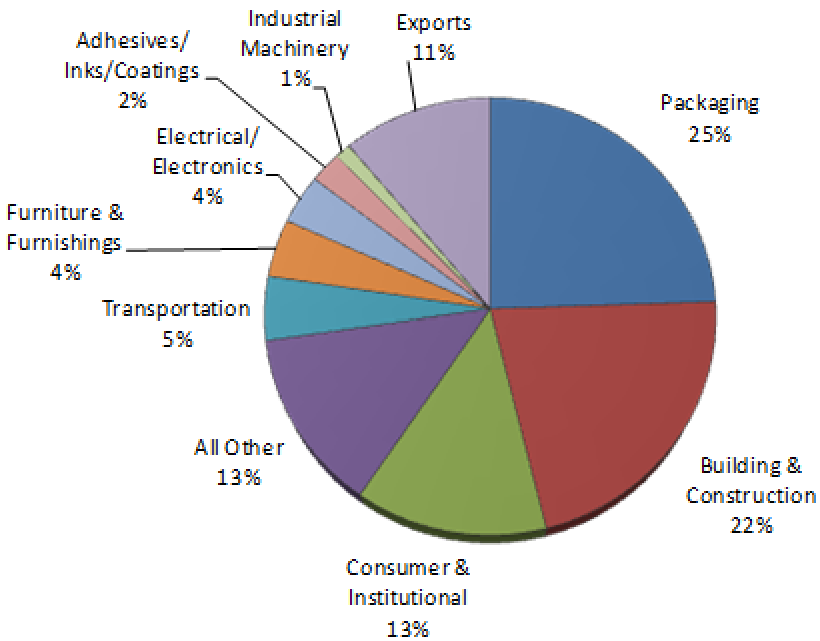

Figure 2
Share of Total Value of Shipments by Sub-Industry, 2007
Source: Kuhlke, Bill and Dr. Tom Walsh. World Plastics Market Review, http://www.polymerplace.com/articles/World%20Plastics%20Review.pdf

Competitive Landscape

The Global economic downturn has had an adverse impact on the demand for plastic products and U.S. manufacturers continue to face rapidly increasing foreign as well as domestic competition. Capital expenditures, which have been flat through the downtown in the industry, should increase when global economic conditions improve. Table 3 compares the size of the plastics product industry in 1997 to that in 2007. Since the beginning of the downturn, decreases in plastic feedstock inventories and energy prices have allowed plastics products manufacturers to adjust to more favorable prices.

Table 3
Comparative Size of the U.S. Plastics Product Manufacturing Industry: 1997 vs. 2007

Year	Establishments	Value of Shipments ($1,000)	Annual Payroll ($1,000)	Paid Employees
1997	14,012	$124,445,374	$23,029,570	820,707
2007	12,141	$170,520,915	$26,329,298	700,224
Absolute Change '97-'07	-1,871	$46,075,541	$3,299,728	-120,483
Percent Change '97-'07	-13.4%	37.0%	14.3%	-14.7%

Source: U.S. Bureau of the Census, American Fact Finder 2007.

Research continues at a rapid pace to develop the next generation of plastic resins that will incorporate nano-, bio-, and composite technologies. These advances and the demand for the research that produces them can be attributed to a strong demand for plastics used in a variety of end uses, such as motor vehicles, construction, consumer goods, packaging, and electric/electronic equipment.

The plastics product manufacturing industry is the seventh largest manufacturing industry in the U.S.[3] The following firms are the ten largest in the U.S. in terms of sales and represent a variety of molding processes:[4]

- Amcor Rigid Plastics
- Bemis Co. Inc.
- Berry Plastics
- Graham Packaging Co.
- IAC Group
- JM Eagle
- Pactiv
- Plastipak Packaging Inc.
- Sealed Air Corp.
- Sigma Plastics Group

Industry Outlook

Domestic employment in the plastics product manufacturing sector will continue its long-term decline from its peak in 2000. The Bureau of Labor Statistics forecasts a 6% decrease in employment between 2008 and 2018 for the sector.[5]

A 2002 study by the U.S. Bureau of the Census found that the value per ton of plastics products was 3.8 times higher than for all industrial commodities shipped.[6] This is because plastics products tend to be very light and have a comparatively high value-to-weight ratio. Because of their high ratio, plastic products are shipped farther on average than industrial products in general. This sustains the conclusion of most plastics products manufacturers who find that physical proximity to raw material inputs is less important than energy costs and transportation efficiency.

Plastics are widely used in both industry and in consumer products. Therefore, the plastics product manufacturing industry is highly dependent on the health of the U.S. economy. According to the International Trade Administration of the U.S. Department of Commerce, the top policy and regulatory issues for the U.S. plastics product manufacturing industry are:

- The need for capital, since many small- and medium-sized U.S. manufacturers do not have the capital to invest in new machinery or technological innovations.
- The need to reduce the costs of doing business (healthcare, litigation, tort reform, energy prices, intellectual property rights).
- The need for an even playing field – regarding China, in particular, and what the U.S. industry sees as currency manipulation and unfair trade practices.

Industry leaders can improve corporate profitability by reducing overcapacities and shifting product lines from specialties to base grades plus additives. Reducing overcapacities could be accomplished by closing non-competitive plants and relying on good market research to locate and build only large, economical plants.[7]

Energy Use Characteristics

The Energy Information Administration's (EIA's) Manufacturing Energy Consumption Survey (MECS) provides energy end-use data for NAICS 326 Plastics and Rubber Products as a whole, but does not allocate end-use data to NAICS 3261 Plastics Products Manufacturing alone. As such, it is very difficult to accurately characterize or quantify the energy use of industries under the NAICS 3261 code. However, as a whole, the plastics and rubber products industry (NAICS 326) consumed 336 trillion Btu of energy in 2006. Of that, 54% was consumed as electricity and 38% as natural gas. The remaining 8% was split between distillates, fuel oil, propane, coal, and other fuels.

Although a large amount of electricity is consumed, the plastics and rubber products industry is not particularly energy-intensive. As illustrated in Figure 3, an estimated 51% of electricity is consumed by machine drives, 16% goes to process heating, and 11% of total electricity used goes to HVAC. These three end-uses represent 78% of the electricity consumption in the plastics and rubber products industry. The majority of the machine drive electricity is used for compressed air, hydraulics, and augers.

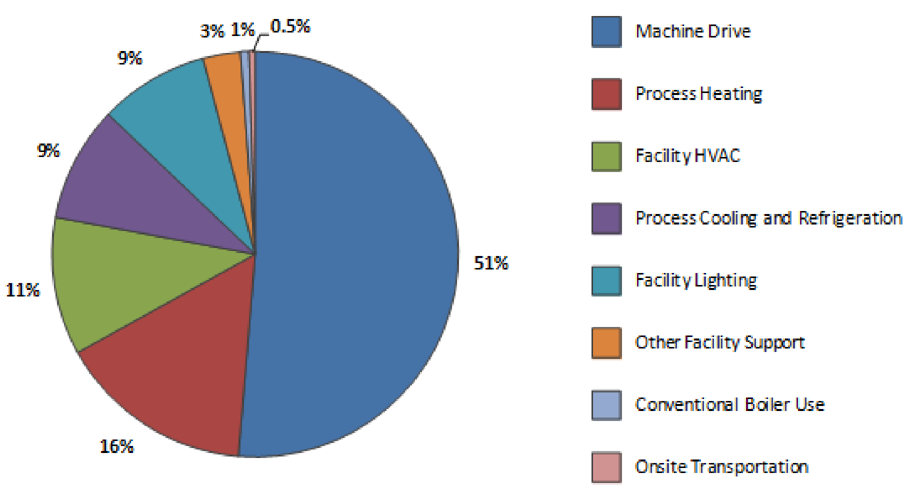

Figure 3
Electric End-Uses for NAICS Industry 326: Plastics and Rubber Products
Source: U.S. Energy Information Administration, Manufacturing Energy Consumption Survey, 2006.

The U.S. Census Bureau provides data on electricity consumption and energy costs for the plastics products manufacturing industry (NAICS 3261) and sub-segments NAICS 32611 to 32619. Total electricity costs for NAICS 3261 in 2007 were $3.2 billion for 51,838 GWh consumed ($0.062/kWh). Electricity costs per kWh and electric intensity were highest in the plastic bottle manufacturing industry (NAICS 32616). Electricity purchases were greatest in the other plastics products industry (NAICS 32619). Electricity expenditures averaged four times that for other fuels and averaged 4.5% of total materials cost for the industry. The industry averaged 0.63 kWh per dollar of value added. Statistics regarding energy costs and consumption are summarized for each sub-industry in Table 4.

Efficient Electric Technology Alternatives

Several electric technology options are available for plastics products manufacturers that can help them improve the energy efficiency of their operations. The following discussion begins by presenting a number of well-established technologies that have been adopted to some extent by the plastics products manufacturing industry, but still show potential for greater adoption. The discussion continues with some lesser-known technologies that have limited or no market penetration in the industry, but which show considerable promise for improving operations. We conclude with technologies that are still under development, but could be available commercially within the next decade.

Due to the fact that machine drives consume over half of the electricity consumed by plastics products manufacturing firms, it is obvious that it is with motors and drives that the greatest opportunities for energy savings lie.

Established Technologies

High Efficiency Motors

Due to the enormity of energy use by motors in plastics product manufacturing, improving motor efficiency can have substantial benefits in terms of reduced operating costs. Replacing standard efficiency motors with premium or high efficiency motors, which are generally 2% to 8% more efficient, can lead to significant

Table 4
Energy Costs for NAICS 3261 and Sub-Industries – 2007

NAICS 3261 Sub-Industries	Cost of Electricity ($Million)	Cost of Other Fuels ($Million)	Energy as % of Material Cost	Electricity Consumed (GWh)	Intensity (kWh/$ Value Added)
32611	$678.8	$227.2	4.6%	11,510.1	0.76
32612	$250.1	$50.3	3.9%	4,173.7	0.66
32613	$52.0	$39.7	5.4%	838.9	0.41
32614	$152.1	$111.3	5.7%	2,423.3	0.68
32615	$81.3	$44.9	2.2%	1,288.4	0.31
32616	$465.2	$23.5	7.3%	7,053.6	1.38
32619	$1,524.8	$310.9	4.2%	24,549.8	0.53
NAICS 3261 Totals	**$3,204.3**	**$807.8**	**4.5%**	**51,837.7**	**0.63**

Source: U.S. Census Bureau, American Fact Finder 2007.

energy savings. In general, high efficiency motors should replace failed standard efficiency motors that are used for 4,000 hours per year or more. Too often, however, motors are run until they fail and then replaced with a motor on hand of the same or higher rated horsepower to avoid equipment downtime. This replacement strategy often leads to the installation of oversized motors. Additionally, facilities may not install premium efficiency motors due to misconceptions about durability.

Of the lifetime cost of owning a motor, only about 1% to 5% is the initial purchase cost; the remaining 95% to 99% is energy cost. Therefore spending a bit more to purchase a higher efficiency motor will return lower operating costs over the life of the motor. When purchasing a motor, the most energy-efficient and affordable motor possible should be chosen. Premium efficiency motors can cost about 20% more, but have a payback period of less than four years with one-shift operation and a cost of $0.05/kWh. Payback will be even shorter for a 24-hour, seven-day-per-week operation, or a facility with higher electricity costs.

Proper motor sizing is important, too. For optimum efficiency, motors should be sized to operate with a load factor between 65% and 100%. Oversizing results in less efficient motor operation. For example, a motor operating at a 35% load is less efficient than a smaller motor that is matched to the same load.

Adjustable Speed Drives

Adjustable speed drives (ASDs) enable a continuous range of electric motor speed control, thereby matching motor speed with load. Variable frequency drives (VFDs), the most common type of ASD, meet process requirements by adjusting the frequency and voltage of the power supplied to an AC motor to allow it to operate over a large range of speeds.

ASDs can be applied to existing motor-driven equipment to improve the efficiency of the drive portion of the system. Alternatively, ASDs can be installed along with new motor-driven equipment in retrofit or new construction applications to optimize the efficiency and operation of the entire motor-driven system. ASDs are applicable to a wide variety of motor-driven applications, such as pumps, fans, compressors, and a myriad of process loads such as augers, presses, rotational molds, etc. They are best suited to applications that require partial loads for long periods of time.

In general, annual energy savings from ASDs range from a couple percent to as high as 50%. ASDs applied to pumps and fans generally yield savings on the order of 30-35%; ASDs on material handling equipment and machinery often result in savings of about 7%; and ASDs on compressors and refrigeration systems typically achieve savings of 18-23%. Figure 4 illustrates how energy consumed by a motor is reduced by almost one-half with a 20% reduction in motor speed due to the cubic relationship between the two values.

The installed cost for an ASD depends on several factors including the size and type of drive, the size and complexity of the installation, and whether or not the ASD is installed on existing equipment or as a package with new motor-driven equipment. Generally, the cost per horsepower decreases with an increase in drive size. Installation costs are on the order of $100-300/hp for typical applications (~5-50 hp). However, large-scale ASDs (~500 hp) may cost as little as $50/hp and small-scale ASDs (~1hp) may cost as much as $500/hp. Payback periods generally range from one to three years.

All-Electric Injection Molding Machine

The equipment used to manufacture plastics 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 necessary by compression and injection molding machines. Hydraulic systems are well-suited for electric motors because their torque and speed demand match the capabilities of conventional AC synchronous motors.

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. In addition, 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 can have a negative impact on production equipment performance and generate added heat that can burden a facility's HVAC system.

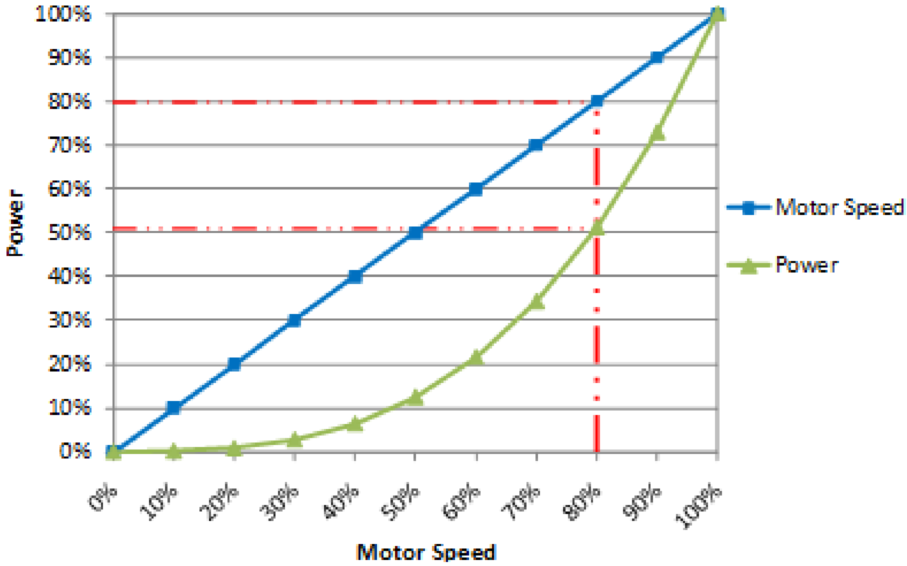

Figure 4
Cubic Relationship between Power and Motor Speed

All-electric injection molding machines offer improved performance over conventional, hydraulically-operated plastic product manufacturing machines. 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 ten years.

The major difference between an all-electric injection machine and a hydraulic injection machine is the construction of the drive system. The standard injection machine uses hydraulic power to operate the auger screw with both rotary (for melting) and linear motion (for injecting), and to operate the clamp unit. The hydraulic power is created using pumps driven by AC (alternating current) induction motors.

All-electric machines eliminate the hydraulic power altogether. The all-electric machine uses an AC or brushless DC (direct current) variable speed servo motor for each individual component of the machine. In addition to more precision and process control, all-electric injection machines use at least 50% less energy than hydraulic machines. Other advantages of all-electric machines include greater reliability, less maintenance, quieter operation, and cleanliness. 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.

The major drawback to all-electric machines is that the initial capital cost investment is approximately 15-20% more than hydraulic machines.

Process Heating Technologies

Process heating equipment consumes 16% of the electricity used in plastics product manufacturing plants. Process heating applications include heating, drying, liquefying, curing, and bonding.

There are three process heating technologies that are currently in use in the plastics product industry, but could be better established. These include radio-frequency drying and heating, infrared heating, and fusion welding.

Radio-Frequency Drying and Heating

Radio-frequency (RF) waves heat nonconductive materials (such as plastic) that contain polar molecules. Since many types of plastics contain polar molecules, RF is an effective drying and heating technology for a large number of plastics, including polyurethane, polyvinyl chloride (PVC), and nylons.

RF heating works best for regular-shaped objects and large objects. Objects with many curves and edges or with uneven thicknesses may not heat uniformly.

RF energy is commonly used to preheat plastic preforms prior to thermoforming and compression molding. Preforms are plastics that are stamped, cut, or bent so that they roughly fit a mold. Preheating preforms improves productivity by making the plastic more flexible prior to molding. RF heating is preferred with thick preforms, because they are difficult to effectively preheat with surface heating methods.

RF energy can reduce the cycle time for molding 25-30%, decrease the molding pressure 30-40%, and lower the mold temperatures 15-30°F, thereby significantly improving productivity and reducing operating costs.

Other uses of RF include preheating fillers, curing thermosets, drying resins, and bonding. RF systems can be used as stand-alone units or in conjunction with conventional systems. RF heating equipment also requires approximately one-third the floor space of conventional units.

One of the major disadvantages of an RF system is the initial capital cost. RF heating equipment costs will vary significantly depending on the size, sophistication, and automation of the system. Capital costs are approximately $1,000 to $4,000 per kW of power output, with larger systems costing less per kW of output. A typical 210 kW system costs approximately $550,000.

Infrared Heating

Infrared (IR) heating is most commonly used to preheat flat shapes such as film and sheet and is particularly effective in thermoforming applications. Certain wavelengths of IR radiation are capable of warming plastic to a depth sufficient for most purposes without overheating the surface.

IR heating is characterized by short ramp-up time and quick energy transfer. The responsiveness of IR heaters minimizes energy loss between batches and during production stoppages. 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.

Alternate methods of preheating include convection heaters (both gas-fired and electric), electric resistance heaters, and 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.

IR systems are usually custom-designed to meet specific applications, so their prices vary with the design. Prices can start at $50-$150 per square foot of heater. A basic IR spot heater or panel heater with two or three quartz emitters generally costs $1,000-$2,500. Small custom designed ovens range in costs from $10,000 to $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

Fusion welding is a generic term describing a number of techniques used to bond thermoplastics. This technology offers an alternative to the use of screws, adhesives, or mechanical fasteners. It is particularly appropriate for joining polyethylene, polypropylene, and other low-surface energy materials that are difficult to bond with adhesive.

Fusion welding offers high-strength bonds, aesthetically appealing finishes, and is quick to perform. It can significantly reduce bonding task times and increase overall productivity. Fusion bonding has been known for many years and in recent years, the field has become very dynamic, with new process developments and equipment design.

Three common fusion welding technologies include laser welding, hot plate welding, and spin welding.

- **Laser welding** is a relatively new high-speed, non-contact welding technology. Some materials are transparent to laser energy, so laser energy can pass through until it meets a laser-absorbing material. This produces a strong, but invisible weld.

- **Hot plate welding** has been around for a number of years. A heated platen melts the joining surfaces of two thermoplastic parts after which the two parts are pressed together until a bond forms.

- **Spin welding** is a process that uses rotational friction to melt circular thermoplastic parts together. One plastic part is held stationary, while the other part is rotated against it under pressure. Advantages of spin welding include high-quality permanent joints, hermetic seals, lower equipment costs, ease of assembly, energy-efficient operation, no ventilation required, and immediate handling.

The costs of fusion equipment vary according to the technique and the application; however installation is relatively uncomplicated, and requirements for support services such as cooling are minimal. Equipment costs for spin welding are lower than for hot plate welding, in general. Spin welding costs can range from $15,000 to $50,000. Hot plate welding costs can range from $40,000 to $100,000. Laser welding costs vary greatly depending on the application.

Energy-Efficient Lighting

Lighting represents about 9% of electricity use in plastics products manufacturing and typically consists of high-bay fixtures.[8] The purpose of lighting is to provide a safe and efficient working environment, so it is important that the levels of lighting be appropriate, but not wasteful. Lighting levels in industrial facilities are often found to be higher than necessary. Table 5 shows the lighting levels recommended for areas typically found in industrial facilities. Table 6 lists the maximum power levels in watts per square foot for a variety of industrial spaces.

Table 5
Recommended Lighting Levels for Various Area Types

Area Type	Light Level (foot-candles)[9]
Material processing – Coarse	10
Material processing – Medium	30
Component production – Large	30
Component production – Medium	50
Assembly – Simple	50
Shipping and receiving	50
Control panel/Computer viewing	30 (vertical)

Source: Highbay Industrial Lighting Knowhow

Table 6
Power Limits for Industrial Spaces

Whole Building Method	Watts/Sq Ft
Manufacturing facility	2.2
Warehouse	1.2
Space Method	**Watts/Sq Ft**
General lighting high-bay	3.0
Active storage/bulky	1.1
Transition/Corridors	0.7
Equipment room	0.8
Workshop	2.5
Control room	0.5

Source: ASHRAE/IESNA Standard 90.1-1999

Commonly used lamps can be categorized into three types: incandescent, fluorescent, and high-intensity discharge (HID). There is a significant amount of literature available about these technologies and their relative efficacies. Facilities that increase the efficiency of lighting not only decrease lighting electricity use, but they also reduce space cooling and ventilation loads because more efficient lights produce less waste heat. A common rule-of-thumb is one watt of air conditioning savings results from every three watts of lighting power reductions. This rule is changing over time as CFLs and LEDs replace incandescent lamps in even greater numbers.

High-bay spaces are typically lit by high intensity discharge (HID) fixtures such as metal halide (MH) lamps. High pressure sodium (HPS) lamps have been losing favor in HID high-bay applications due to the yellow light they emit. Lately, more lamp manufacturers have introduced advanced high-output fluorescent systems as alternatives to HID lamps for illuminating high-bay spaces. At one manufacturing facility, replacing MH lamps with T5 high-output fluorescent lamps reduced lighting energy consumption and demand by 20%. Depending on the type of facility, the necessary lighting levels, and the type of existing lamps, retro-fitting high-bay spaces with high-output fluorescent lamps can lead to savings as high as 70%.

Emerging Technologies

The technologies in the following table are currently commercialized, although their market penetrations are still very low.

Technology	Description	Application
Gas assisted molding	This injection molding process uses pressurized nitrogen to force softened plastic into the mold. The pressurized gas is injected inside the molded part, replacing plastic volume with a gas induced void. This has several benefits, including the elimination of part distortion caused by post-molding contraction, less material use, smaller press sizes, and shorter cycle times.	Injection molding
All-electric blow molders	All-electric blow molders have similar advantages over hydraulics as all-electric injection molding machines: energy savings, quietness, cleanliness, more precision and control, and faster cycle times. All-electric models are more expensive than conventional hydraulic machines; however, the price premium on all-electric models has fallen from about 30% five years ago to between 5% and 20% today. The premium for bigger machines requiring larger motors is closer to 30%. For that reason, manufacturers are offering hybrid models that combine hydraulics with electric motors.	Blow molding
Mold-efficient cooling and heating (MECH)	MECH is an "ovenless" direct mold-heating and cooling approach to rotational molding. Rotational molding typically wastes over 90% of its energy input for heating and cooling, while the manufactured product typically requires 20% more material. The MECH system replaces conventional oven and cooling chambers by incorporating those functions in the mold itself. Electric heating panels are cemented to the outside of the mold shell and covered with an outer insulation panel with air-cooling channels. The mold is cooled by a high volume of conditioned air blown over the entire outer surface of the mold. Benefits reportedly include energy cost reductions as high as 80% and the ability to use real-time process-monitoring without fear of overheating sophisticated electronics.	Rotational molding
Magnetically-coupled ASDs	A type of adjustable-speed drive where the connection between the motor and its load is a gap of air, rather than a physical connection. The torque is transferred by rare-earth magnets on one side to induce magnetic fields on the other. The amount of torque transferred is varied by controlling the width of the air gap. The benefits are greater tolerance for misalignment, little impact on power quality, reduced vibration, and longer equipment life. Energy and demand impacts would be similar to standard ASDs.	Pumps, fans, compressors, etc.
Industrial heat pumps	There are many opportunities for waste heat recovery in plastics product manufacturing facilities. Using industrial heat pumps to leverage waste heat from space or machinery cooling for use in other process heating applications is extremely energy-efficient relative to other electric or fossil-fueled process heating technologies.	Process heating, process drying, process water heating, space heating
LED lighting	LEDs can have very high efficacy, much longer life than conventional lighting technologies, and are dimmable.	Task lighting and illuminating small areas with intense light.

Developing Technologies

The technologies in the following table are not yet available commercially. Their current status varies between laboratory development and technology demonstration.

Technology – Status	Description	Application
Ultra-efficient and power-dense electric motors – In development	As shown above in Figure 3, machine drives consume about 51% of all electrical energy consumed by the plastics product manufacturing industry. Induction motors represent nearly all constant-speed motors and most variable-speed motors. Currently, most induction motors meet either the EPACT 1992 minimum efficiency requirements or the higher NEMA "premium" efficiency standards. New motor technology under development will result in motors with 30% lower losses while being 30% smaller and 30% lighter.	Target applications include pumps, fans, and compressors in the 20-50 hp range. An estimated 90% of industrial applications will be suitable.
Powder injection molding (PIM)	PIM is an alternative to machining and investment casting of automotive items. It is an interdisciplinary injection molding technique that combines metallurgy with plastics molding. Products made using the PIM process take advantage of the material flexibility of powder metallurgy and the design flexibility of plastics molding. PIM has several advantages over traditional metalworking, including no scrap and can produce parts that are difficult to machine.	Automotive parts and assemblies

Other Process Improvements

In addition to the efficient electric technologies presented in the previous section, there are six process improvements with the potential to add value to plastics product manufacturing facilities.

- **Reduced Compressed Air System Pressure** – Compressed air is used extensively in plastics product manufacturing for many pneumatically-operated or air-cooled systems. Electric motors operate compressors that increase the pressure of air. Distribution systems take that compressed air to the various points of use with, ideally, minimal pressure loss.

  There is a direct relationship between compressed air system operating pressure and energy consumption, since it takes more energy to maintain a higher pressure. Therefore, reducing system pressure can lead to energy savings. A rule-of-thumb states that for systems operating around 100 psi, every decrease of 2 psi in operating pressure will reduce energy costs by 1%. The issue is to determine whether system pressure is too high and therefore appropriate for reduction. Other benefits of reduced system pressure include reduced leakage rates, increased system capacity, and longer component life.

  Compressed air systems are often operated at higher pressures than necessary for several reasons, including the comparatively wide control band used on most compressors and the belief that extra pressure provides a cushion against pressure drops. Pressure drops are the result of the compressed air losing pressure as it travels from the compressor through the various system components (e.g., aftercoolers, separators, air driers, valves, and filters) to the point of use. Pressure drops can be mitigated by thoughtful system design and selection of components, including:

  1. Avoiding the addition of new components and end-uses in a jumbled manner,
  2. Keeping filters and other components clean,
  3. Selecting components that minimize pressure drop,
  4. Providing the shortest path for the distribution system between compressor and end-use, and
  5. Placement of storage tanks and pressure regulators closer to larger end-uses.

- **Compressed Air Leak Sealing** – A commonly-cited figure is that 20% to 30% of the energy expended to compress air is lost through leaks in the system. Even a well-maintained compressed air system can leak as much as 10% of its compressor's output. Leaks also contribute to system operating troubles, such as irregular system pressure, the need to oversize compressors, and decreased service life of compressed air system equipment. Leaks can occur anywhere in the system, but are most commonly found in couplings, hoses, fittings, quick-connects, valves, and point-of-use equipment.

  Rates of leakage are a function of supply pressure and are proportional to the square of the diameter of the hole. For example, at a system pressure of 90 psig, a hole with a diameter of 1/32nd inch will leak 1.5 CFM. Assuming an electricity cost of \$0.05/kWh, electricity consumption of 18 kW/100 CFM, and 7,000 operating hours per year, a single air leak 1/32nd inch in diameter will waste about \$58 per year.

  The best method for detecting leaks is to use an ultrasonic acoustic detector. These portable tools use directional microphones to locate the source of the high frequency sound caused by air leaks. While easy to use, ultrasonic detectors are very expensive and best used by trained personnel. They are often able to estimate the rate of leakage based on the volume and frequency of the sound emitted by the leak.

The final step is the establishment of a leak prevention program, of which there are two types. The first is the "leak tag" program in which leaks are marked with a tag when they are identified and repaired at a later time. The second is the "seek and repair" program in which leaks are fixed as soon as they are identified.

- **Eliminate Inappropriate Compressed Air Uses** – Compressed air may be one of the most expensive forms of energy found in a manufacturing facility. But, because it's clean and readily available, it is often used inappropriately for applications for which better options are available. Potentially inappropriate uses include personal cooling, equipment cooling, vacuum generation, and idle or abandoned equipment.

  The typical overall efficiency of compressed air systems is 1-15%. Therefore, as a general rule, compressed air should be used only if safety enhancements, significant productivity gains, or labor reductions result.

- **Power Factor Correction** – Inductive loads like transformers, electric motors, and HID and fluorescent lighting may cause a low power factor. A low power factor may result in increased power consumption and increased electricity costs. A low power factor can be improved by minimizing idling of electric motors, avoiding operating equipment above its rated voltage, replacing standard efficiency motors with premium-efficiency motors, and installing capacitors on AC circuits to decrease the magnitude of reactive power in the system.

- **Minimizing Voltage Unbalances** – Voltage unbalances degrade the performance and shorten the life of three-phase motors. A voltage unbalance causes a current unbalance, which will result in torque pulsations, increased vibration and mechanical stress, increased losses, and motor overheating. All these work to reduce winding insulation life. Voltage unbalances can be caused by incorrect operation of power factor correction equipment, an unbalanced transformer bank, or an open circuit. A rule of thumb is that the voltage unbalance at the motor terminals should not exceed 1%. Even a 1% unbalance will reduce motor efficiency at part load operation, while a 2.5% unbalance will reduce motor efficiency at full load operation.

  For a 100 hp motor operating 8,000 hours per year, a correction of the voltage unbalance from 2.5% down to 1% will result in electricity savings of 9,500 kWh or almost $500 at an electricity rate of $0.05/kWh.

- **Disconnect Ballasts in Delamped Fixtures** – Delamping is a technique often used to reduce lighting levels in over-illuminated areas. It involves removing some or all of the lamps in a fluorescent fixture. The problem is that the ballast in the fixture is still powered even after lamp removal, with electronic ballasts drawing up to 10 watts.

  It is important to determine how the ballast is wired before delamping. Electronic ballasts can be wired either in series or in parallel. If the ballast is wired in series, then all the lamps connected to the ballast must be removed. If this is not done, the lamps still sharing the ballast may flicker or produce less light and life lamp will be negatively impacted. If the ballast is wired in parallel, then it is not necessary to remove all the lamps connected to the ballast.

Benefits Of Expanding End-Use Applications Of Electricity

The previous two sections identified efficient electric technologies and process improvements that will save electricity. Several of the opportunities presented above decrease electricity requirements by using electricity more efficiently. A few such examples include adjustable speed drives, electric process heating technologies, and high efficiency motors. Several of the opportunities presented may be alternatives to natural gas-fired technologies, depending on what is already in use at a given facility. Examples include some of the suggested process heating technologies, such as electric IR heating.

Expanding end-use applications of electricity can yield four main types of benefits, as described below.

Energy Savings

Highly efficient electric alternatives (e.g., electric process heating) can decrease primary energy use[10] relative to fossil-fueled alternatives (e.g., natural gas-fired process heating) as well as more commonly used electric technologies. For example, electric IR heating transfers about twice as much energy to the product as gas IR heating. The result is significant energy and cost savings.

Reductions in Greenhouse Gas Emissions

Decreasing primary energy use correspondingly reduces greenhouse gas (GHG) emissions associated with the combustion of fossil fuels. That is, if a natural gas process heating technology were replaced with a very efficient electric process heating technology so that primary energy use was reduced, GHG emissions would also be reduced.

Switching to electric processes can also shift GHG and other air emissions from the end-use site to an off-site power plant, making control of emissions more viable. However, this depends on how and where the electricity is generated. For plastics product manufacturers that obtain much of their electricity from traditional power plants, switching from fossil fuels such as natural gas to electricity shifts the emissions off-site.

Process Improvements

Many electric technologies offer improved productivity for plastics product manufacturers by improving the production process. For example, RF drying and heating reduces cycle times for plastics molding by 25-30%. Shorter molding times lead to increased throughput, which increases production efficiency and lowers production costs. All-electric injection molding provides more precise molding and process control through the use of variable speed motors. Besides energy savings, all-electric injection molding is more reliable, requires less maintenance, operates more quietly, and is cleaner.

Economic Advantages

Energy savings, improved product quality, and increased productivity all translate to cost savings for plastics product manufacturers. Electric technologies also offer the ability to take advantage of off-peak rates for certain processes, which can further reduce operating costs. Depending on local tax laws, there may be tax advantages to investing in energy-efficient technologies as well.

Additional Resources

The Industrial Technologies Program (ITP) of the U.S. Department of Energy's Energy Efficiency and Renewable Energy Program is the lead government program working to increase the energy efficiency of U.S. industry. The ITP has several industry- and technology-specific profiles as well as a library of brochures, fact sheets, and databases with information on current technology R&D efforts. The ITP can be found at http://www1.eere.energy.gov/industry/index.html.

The Industrial Assessment Centers (IAC) Database is a collection of all the publicly available assessment and recommendation data. This includes information on the type of facility assessed (size, industry, energy usage, etc.) and details of resulting recommendations (type, energy & dollars savings etc.). The IAC database for the plastics product manufacturing industry can be found at http://iac.rutgers.edu/database/naics/3261.

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Notes

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8. "High-bay" lighting is typically found in facilities with ceilings higher than 25 feet.

9. For comparison, an overcast day would produce about 100 foot-candles of illumination.

10. Primary energy is energy before any transformation to secondary or tertiary forms of energy. Primary energy includes any losses due to generation, transmission, or other system inefficiencies. This is distinct from delivered energy, which is only energy delivered to the point of use, which does not take losses into account.

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1024690 January 2012

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