

INDUSTRY SEGMENT PROFILE

Composites

EPRI Center for Materials Production

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Introduction

Composite materials are those that are formed by the combination of two or more materials to achieve properties that are superior to those of its constituents. Thus, composite materials are as diverse as porcelain enamel products (glass coated metal), plastic or metal laminated corrugated paper, fiberglass strengthened cement, stainless steel clad carbon steel, fiber reinforced plastics, and steel or glass reinforced rubber (tires).

Composite materials date from the dawn of earliest recorded history. The first known application of composite materials occurred several thousand years ago when the Egyptians started using straw strengthened sun dried clay bricks in construction. Since that time great strides have been made in the development of composite materials. They now offer the promise of new products with extraordinary strength, stiffness, and chemical and temperature resistance.

Engineers who design or use composite materials now generally classify them into one of four categories:

- ◆ Polymer matrix composites
- ◆ Metal matrix composites
- ◆ Ceramic matrix composites
- ◆ Carbon matrix composites

The largest tonnage application for composite materials is in civil engineering structures such as roadways, bridges, and buildings where ceramic (cement) matrix composite materials are used extensively. However, these composite materials are discussed in the cement industry profile and will not be considered here.

The remaining market for composite materials can be separated into two classes: reinforced plastics and advanced composites. With the latter, the military has been the primary customer. A well-defined need for faster and more survivable aircraft and missiles has sparked much innovation and development in the area. Also, the military and civil aerospace were often the only customers who could afford the high prices and long lead times of low volume advanced materials. With respect to civilian applications, reinforced plastics comprise 90 percent of the market, and are based on glass fiber reinforcements in commodity thermosetting resins mainly unsaturated polyesters and their derivatives.

Fiber reinforced plastics (FRP) have been in existence for about fifty years, and will be the focus of this report. They have generally been used to replace traditional materials such as wood, aluminum and steel. Significant advantages over these traditional materials include higher strength, lighter weight, greater corrosion resistance, dimensional stability, higher dielectric strength, and improved design flexibility.

There are four recurring themes that will shape the future of the composite industry: systems solutions, economical manufacturing processes, diverse markets, and new technologies. For maximum return, developments of composite systems must be approached as an integrated process. Decisions regarding designs, processes, and materials must be made synergistically to ensure the production of a high quality saleable product that meets customer's needs.

In the United States, about 3 billion pounds of composite products are manufactured each year. There are approximately 2000 composites manufacturing plants and materials suppliers across the U.S. which, employ more than 150,000 people. About 65% of all composites produced use glass fiber and polyester or vinyl ester resin, and are manufactured using the open molding method. The remaining 35% are produced with high volume manufacturing methods or use advanced materials, such as carbon or aramid fiber.

Common household plastics, such as polyethylene, acrylic, and polystyrene are known as thermoplastics. These materials may be heated and formed - and can be re-heated and returned to the liquid state. Composites typically use thermoset resins which, begin as liquid polymers and are converted to solids during the molding process. This process, known as crosslinking, is irreversible. Because of this, composite materials have increased heat and chemical resistance, higher mechanical properties and greater structural durability than thermoplastics.

The electric utility industry can help the composite industry grow in the 21st century by helping manufacturers of composite materials develop manufacturing processes that are more economical, productive, and efficient. This profile, which concentrates on polymer matrix composites, provides the utility representative with information about the composite industry that should help him aid his composite industry customer toward that goal.

Thumbnail Sketch of Typical Establishment

Composites Raw Material Manufacturer

Average No. of Employees	90
Annual Shipments	\$15 Million
Annual Electricity Consumption	5 million kWh
Electricity Opportunities	Electric heating processes to replace older fossil-fired technologies for improved temperature and process control.
Technology Trend	Automation of high labor content production processes to lower costs. Improved technologies to reduce environmental emissions.
Industry Issues	Lower styrene and VOC emissions in composite processing to accommodate tougher EPA regulations. More complete testing and design standards for inclusion in composite specifications.

Industry Characteristics

The industry is made up of companies manufacturing the following products:

- ◆ Plastics or resin materials for use in composites.
- ◆ Glass fiber, carbon fiber, and aramid fiber in the form of continuous fiber, chopped fiber, fiber rovings, and fiber mat for composite reinforcement.
- ◆ Other fillers or additives for use in composites.
- ◆ Composite preregs. Preregs are defined as a reinforcing material impregnated with resin prior to the molding process and later cured by the application of heat.

The emphasis of this industry profile is on the production of raw materials for the composite industry, rather than on the fabrication of composite parts.

- ◆ Fiberglass for insulation is not included in this report.

In 1999, the estimated value of shipments for FRP composites was \$3.8 billion.

- ◆ Fiber production makes up approximately \$2 billion of this total.
- ◆ Resins comprise approximately \$1.8 billion.

Fiber reinforcements are a principal component in the production of composites.

- ◆ There are approximately 3.5 billion pounds of glass fibers produced worldwide each year for fiber reinforced polymer (FRP) composites, compared to about 30 million pounds of carbon fibers. Aramid fiber production is approximately 10 million pounds annually, though a significant percentage of this fiber is used in non-composite applications such as bulletproof vests.
- ◆ Five manufacturers dominate glass fiber production in North America. Owens Corning controls about 45% of the market, PPG (20%), Vetrotex Certainteed (15%), Sangobain (5%) and Johns Manville (5%).
 - The North American market is 60% of the total world market, or just over 2 billion pounds of glass fiber production annually.
 - The most common types of glass fiber produced are E-glass (\$0.55 to \$0.75/lb), S-glass (\$2.50 to \$2.75/lb), and aerospace grade S-2 glass (\$6/lb). See the glossary included in this report for descriptions of these glass fibers.
- ◆ Leading U.S. industrial grade carbon fiber producers are Zoltek, Acordis-Fortafil, Aldila and Grafil, while Hexcel and BP-Amoco control the aerospace market.
 - Industrial grade carbon fibers are priced at \$8 to \$12/lb.
 - Aerospace grade carbon fibers can range from \$30 to \$200/lb.

- ◆ Dupont is the major producer of high performance aramid fibers (Kevlar).

The **composite matrix** that provides the "glue" to hold the fibers in place is typically an organic or inorganic resin. Composites typically incorporate a thermoset plastic. 80 to 85% of all thermoset FRP composites use a polyester resin. Other common matrices are epoxies (7 to 8%), vinyl esters (3 to 4%), and phenolics (1 to 2%).

The total U.S. FRP composite resin market is estimated at 1.7 billion pounds.

- ◆ Producers of composite resins are aligned according to the type of resin produced.
 - The key polyester resin producers are Reichhold Chemical, Ashland Chemical, Interplastic, Alpha-Owens Corning (AOC), and Cook Composites & Polymers (CCP). Orthophthalic polyester resins make up 50% of the market and are priced at \$0.65 to \$0.70/lb. Isophthalic polyester resins make up 35% of the market and are priced in the \$0.75 to \$0.90/lb range.
 - The key epoxy resin producers are Shell and Dow Chemical. Epoxy resins are generally priced from \$1.00 to \$3.00/lb, but can cost up to \$200/lb for special formulations.
 - The key vinyl ester resin producers are Dow Chemical, Ashland Chemical, Reichhold Chemical, and Interplastic Corporation. Vinyl resins are priced at \$1.00 to 1.25/lb.

There are eight major market segments of fabricated composite parts served by the raw material composite producers.

- ◆ The transportation market (automotive, rail, trucks, and buses) is the largest segment, comprising 32% of the total composite market.
- ◆ The construction market (roofing, infrastructure and infrastructure repair, architectural panels, piping, and bridge decks) occupies 21% of the market.
- ◆ The remaining significant markets are marine applications (10%), electrical/electronic (10%), consumer and recreation (6%), business equipment (6%), aerospace/defense (<1%), and miscellaneous (3%).

Raw materials provided to the composite fabricator include fibers, resins, fillers, additives, pre-pregs, sheet molding composites (SMCs), pultrusions (pulling a fiber/resin composition through a die) and a variety of other components. Composite raw materials are tailored to better fit into downstream fabrication process. Examples of fabrication processes and their market penetration are listed below:

- ◆ More than 50% of all composite fabrication processes are classified as open molding.
- ◆ Approximately 20% use closed molding or a "compressive mold" process.
- ◆ 15% of composite parts are fabricated by filament winding of continuous fiber, followed by a process to impregnate the fibers with resin.
- ◆ Less than 10% use pultrusion.

- ◆ The balance of composite fabrication techniques include vacuum bag or other vacuum forming processes, resin transfer molding (RTM), and centrifugal casting.

National Statistics

Table 1. U.S. FRP Composites Shipments by Market Segment

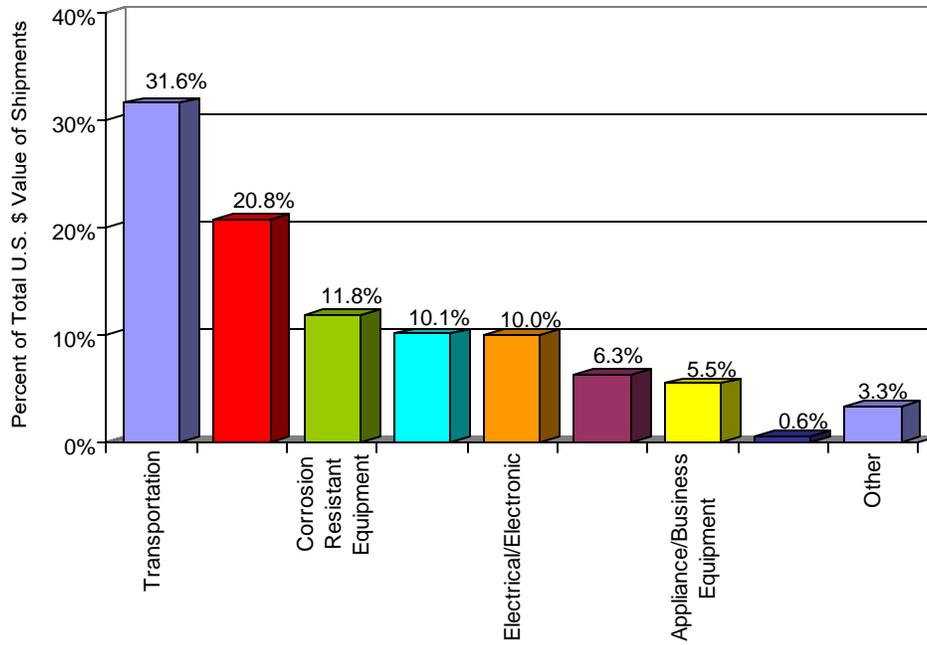
Market	1997 (Millions)	1998 (Millions)	1997-1998 Change	1999 (Millions)	1998-1999 Change
Transportation	\$1,095.2	\$1,139.0	+4.0%	\$1,196.6	+5.0%
Construction	\$689.6	\$740.0	+7.3%	\$781.1	+4.2%
Corrosion Resistant Equipment	\$396.0	\$423.9	+7.0%	\$435.1	+2.6%
Marine	\$353.3	\$364.0	+3.0%	\$377.5	+3.7%
Electrical/Electronic	\$348.2	\$360.3	+3.4%	\$376.6	+4.5%
Consumer & Recreation	\$210.0	\$225.3	+7.3%	\$235.2	+4.4%
Appliance Business Equipment	\$185.0	\$197.7	+6.9%	\$206.8	+4.6%
Aircraft/Aerospace/Defense	\$23.9	\$22.7	-5.0%	\$23.8	+5.0%
Other	\$110.8	\$117.0	+6.0%	\$122.3	+4.5%
Total	\$3,412.0	\$3,589.9	+5.2%	\$3,755.0	+4.6%

Source SPI Composites Institute. Data includes reinforced thermosetting and thermoplastic resin composites, reinforcements and fillers.

Table 2. Key SIC Codes Involved in Composite Raw Materials Production.

SIC Code	Description	Number of Establishments	1997 Value of Shipments	Annual Payroll	Number of Employees
2821	Plastics material & resin mfg.	532	\$44.6 Billion	\$3.1 Billion	61,035
32293	Glass fiber, textile type	22	\$2.0 Billion	\$334 Million	9,157

Figure 1. National Data of End-Uses for Composites, 1999



Industry Data by State

Composite raw material production is not as geographically concentrated as some other manufacturing industries. However, there are some pockets of concentration within both the resin producers and the glass fiber producers due to availability of technical expertise and raw material components.

- ◆ Texas, Pennsylvania, California and New Jersey are key states for the production of plastics materials and resins for composites.
- ◆ Texas, Pennsylvania, South Carolina, and Tennessee have a significant manufacturing presence for the production of glass fibers.
 - The largest glass fiber production facility in the U.S. is the Owens Corning facility in Amarillo, TX.

Competitive Threats

Composite materials are still considered a new technology in many market niches, and therefore require lengthy product approvals.

- ◆ Traditional materials such as steel, aluminum, and concrete have a longer history of materials testing data including life cycle performance.
 - Engineers are reluctant to specify composites for new applications where there is insufficient test data.
 - Engineers tend to rely on design specifications rather than performance specifications. A design specification typically spells out the type of material to be used, whereas a performance specification allows the engineer to choose the material to meet a specified performance level.
 - Composites are less likely to be included in design specifications.
 - A lack of qualification criteria and design standards has hindered some engineers from using FRPs.

Technology advances in lightweight steel and aluminum, particularly in the highly competitive automotive sector, compete with composite applications.

Material recycling requirements by the automobile industry could limit composite applications.

- ◆ Composites are not economically recycled.
 - Technologies for the clean separation of the fiber reinforcement and the matrix have not been fully developed so that the component materials can be reused.

Oil price fluctuations are more likely to have an impact on the cost of composite raw materials (such as resins) due to their higher petrochemical content.

Foreign competition is minimal due to the high ratio of the shipping costs compared to the product value, which is typically \$1/lb for both the fiber reinforcement and the resin matrix.

- ◆ There is considerable foreign competition in carbon fiber production, where the product value is in the range of \$10 to \$200/lb.

Investment Issues

This \$3.7 billion a year industry is considered capital intensive compared to other industries in the manufacturing sector. For purposes of further understanding of these investment issues, U.S. Census data from companies producing Plastics Materials and Resins (SIC 2821) and Pressed and Blown Glass, n.e.c. (SIC 3229) were used.

Composite matrix manufacturers are typically found in SIC 2821.

- ◆ Machinery and equipment assets for SIC 2821 represent nearly 70% of annual shipments.
 - Machinery and equipment assets for most manufacturing industries average between 25% and 50% of annual shipments.
- ◆ Thus, there is \$1 of machinery and equipment assets in place for every \$1.43 in shipments.
- ◆ Buildings and structures assets represent only 1% of shipment value.
- ◆ Approximately 5% of every dollar of shipment value for plastics materials and resins manufacturers (SIC 2821) is reinvested in new capital expenditures each year.

New capital expenditures for textile glass fiber manufacturers (SIC 32293) represented 10% of the value of shipments in 1992, a significant amount and the highest percentage for any pressed and blown glass manufacturers listed in SIC 3229.

- ◆ A total of \$130 million was reinvested in new capital expenditures by 18 textile glass fiber establishments with \$1.3 billion in shipment value in 1992.

National Trends

The defense market was the first segment served by the composite industry, providing applications for military and aerospace parts since the 1960's. Recent cutbacks in defense spending have had a substantial impact on the composites industry, forcing suppliers to drive costs down to compete in a variety of industrial applications.

- ◆ The benefits of composite materials have fueled growth of new applications in markets such as transportation, construction, corrosion-resistance, marine, infrastructure, consumer products, electrical, aircraft and aerospace, appliances and business equipment.

The highest growth segment of FRPs is the construction market.

- ◆ Funding for the Federal Transportation Equity Act for the 21st Century (TEA-21) for fiscal years 1998-2004 increased 44% over its predecessor, the Intermodal Transportation Efficiency Act of 1991 (ISTEA).
 - FRP projects were awarded \$16 million in funding. This represented 70% of all available funding for TEA-21 innovative projects.
- ◆ Seismic retrofit applications include several hundred bridge upgrades in California alone.
 - Carbon fiber/epoxy wraps around bridge columns and beams meet earthquake resistant standards.
- ◆ There are 250 composite bridges and bridge decks in the U.S., and a total of 400 composite bridges worldwide.

Many mass transportation and automotive composite applications are being legislated into reality by energy constraints, tougher environmental laws and safety issues.

- ◆ Despite some initial problems with sheet molding composites (SMCs) in the automotive industry, usage is increasing at a rate of 5% annually.
 - Approximately 250 million pounds of SMCs were used in automotive applications in 1997.
 - Structural components such as fascia supports and grille opening reinforcements account for over 70% of 1997 car and light-truck SMC use.
- ◆ The use of composite materials in marine drive shafts and couplings has gradually increased in the shipping and boat building industries.
 - Composite shafts offer advantages over traditional steel shafts such as reduced weight, corrosion resistance, elastic flexibility, and ease in handling and installation.

Acrylic modified resins such as Ashland Chemical's Modar product are being developed for fire resistance.

- ◆ Other new inorganic formulations and hybridized formulations will address the needs for fire resistance.

The use of phenolic resins in glass and carbon fiber composites is growing, primarily due to their low flame spread, low smoke generation, and low smoke toxicity properties.

- ◆ Applications include mass transit, construction, marine, mine ducting, and offshore structures. These areas traditionally used other resins such as polyesters, vinylesters, and epoxies.
 - More stringent fire resistance requirements are driving this market.
 - In Europe, hand lay-up phenolics composites have been used in mass transit since 1988 after a fire broke out at the King Cross Station, which killed thirty-one people and injured several hundred others.
 - Nomex honeycomb with phenolic pre-pregs are employed to manufacture lightweight composite panels for aerospace applications. The panels are also used in California's Bay Area Rapid Transit (BART) project.
 - Other phenolic composites applications include walls, ceilings, and floors of aircraft interiors.

Pre-pregs (partially cured resin and fiber reinforcement to be fully cured later by a composite fabricator) are the dominant method of buying raw materials for aerospace, sporting goods, and medical device composites.

- ◆ Pre-pregs are more expensive than buying the resin and reinforcement separately, but offer significant quality advantages, including:
 - Better control over the resin/fiber concentrations.
 - Elimination of storage of wet resin and catalyst.
 - Reduction in the amount of styrene emission.
 - Elimination of the manual roller process.
 - Ability to lay-up the material into some shapes that would be difficult with wet systems.
- ◆ Several new types of pre-pregs have been introduced which have solved many of the problems associated with traditional pre-pregs. Most of the new resins are available on a wide variety of reinforcements—fabric, unidirectional tape, mat, braid, and tow using fiberglass, carbon fibers, and aramid fibers.

Advances in winding software control systems have advanced considerably so that rather exotic parts such as 90° pipe elbows, 'T' pipe sections, paddles, and square cross-sections may now be fabricated using filament winding.

Market Structure

This industry manufactures composite raw materials and composites that are used by customers in a wide variety of transportation, construction, industrial, and consumer markets.

Five companies supply more than 90% of the glass fiber reinforcement total industry shipments: Owens Corning (45%), PPG (20%), Vetrotex Certaineed (15%), Sangobain (5%) and Johns Manville (5%) resulting in a concentrated oligopoly.

- ◆ There are 22 establishments listed in SIC 32293 (textile glass fiber) producing \$2.0 billion in sales annually with a total of 9,134 employees.

The Plastics and Resins manufacturers (SIC 2821) tend to be very large, capital intensive companies producing products for the composites industry and other plastics users as well.

- ◆ There is not a specific SIC code for manufacturers that produce composites resins only, and many of the plastics companies within SIC 2821 do not support the composites industry.

According to the U.S. Census figures on SIC 2821:

- ◆ 24% of manufacturers employ less than 20 people.
- ◆ Nearly half the manufacturers employ between 20 and 100 people.
- ◆ 29% of the total employ 100 or more employees.
- ◆ Average employment is 134 people per establishment.
- ◆ Median employment is 50 people per establishment.
- ◆ Market power is more evenly distributed within the plastics and resins manufacturers compared to the glass fiber industry.

Table 3. Number of Establishments by Employment, 1992

Number of Employees	1-19	20-99	100+	Totals
SIC 2821 Establishments	109	211	129	449
Percentage of Total	24%	47%	29%	100%

Source: Census Data

Glossary of Composite Terms

Accelerator — an additive to polyester resin that reacts with catalyst to speed up polymerization. This additive is required in room temperature cured resins. Also called promoter.

Additive — any number of materials used to modify the properties of polymer resins. Categories of additives include reagents, fillers, viscosity modifiers, pigments and others.

Aramid — good strength (450-550 ksi), higher modulus (11.5-27.0 msi), higher cost fiber, very low density (one-half of glass fiber), excellent impact and damage tolerance properties, poor compression and shear strength.

Bag Molding — an airtight film used to apply atmospheric force to a laminate. Also known as vacuum bag molding and pressure bag.

Carbon/Graphite — wide strength range (270-1050 ksi), highest modulus (33-120 msi), highest fiber cost, intermediate density (two-thirds of glass fiber), poor impact or damage tolerance, best tensile strength and stiffness properties.

Catalyst — technically considered an initiator, catalyst is the colloquial name given to the substance added to the resin or gel coat to initiate the cure.

Chopped Strand Mat — a fiberglass reinforcement consisting of short strands of fiber arranged in a random pattern and held together with a binder. Mat is generally used in rolls consisting of 3/4 oz/ft² material to 2-oz/ft material.

Compression Mold — a closed mold, usually of steel, used to form a composite under heat and pressure.

Continuous Filament Strand — a fiber bundle composed of many glass filaments. Also when referring to gun roving; a collection of string like glass fiber or yarn, which is fed through a chopper gun in the spray up process.

Continuous Strand Roving — a bundle of glass filaments fed through a chopper gun in the spray up process.

Continuous Laminating — an automated process for forming panels and sheeting in which fabric or mat is passed through a resin bath, brought together between covering sheets, and passed through a heating zone for cure. Squeeze rolls control thickness and resin content as the various plies are brought together.

E-Glass — good strength (400-500 ksi), low modulus (10.5 msi), lowest cost fiber, available in any forms, widely used in commercial and industrial products, most-used in filament winding.

Epoxy — wide range of resins available, best strength properties, usually heat-cure required, good chemical resistance, higher viscosity systems, higher material cost, applications across broad market segment range.

Fiber Glass — glass which has been extruded into extremely fine filaments. These filaments vary in diameter, and are measured in microns. Glass filaments are treated with special binders and processed similar to textile fibers. These fibers come in many forms such as roving, woven roving, mat and continuous strands.

Filament — a single thread-like fiber of extruded glass. Typically microns in diameter.

Filament Winding — a process which involves winding a resin-saturated strand of glass filament around a rotating mandrel.

Fillers — usually inert organic or inorganic materials which are added to plastics, resins or gel coats to vary the properties, extend volume, or lower the cost of the article being produced.

Gel — the irreversible point at which a polymer changes from a liquid to a semi-solid. Sometimes called the "B" stage.

Gel Coat — a surface coat of a specialized polyester resin, either colored or clear, providing a cosmetic enhancement and weatherability to a fiberglass laminate.

General Purpose Polyester — classified as orthophthalic polyesters, lowest cost systems, widely used in FRP industry, moderate strength and corrosion resistance, room temperature cure.

Hand Lay Up — the process of manually building up layers of fiberglass and resin using hand rollers, brushes and spray equipment.

Improved Polyester — classified as isophthalic polyesters, slightly higher cost, good strength and corrosion resistance, widely used in FRP corrosion applications, room temperature cure.

Isophthalic — a polyester resin based on isophthalic acid, generally higher in properties than a general purpose or orthothatic polyester resin.

Laminate — to place into a mold a series of layers of polymer and reinforcement. The process of applying FRP materials to a mold. To lay up.

Matrix — the liquid component of a composite or laminate.

Orthophthalic or Ortho Resin — a polyester resin based on orthophthalic acid, also known as a general purpose resin (GP).

Phenolic — possess excellent flammability properties (e.g. flame retardant, low smoke emission), higher cost systems, lower elongation, moderate strength, applications involve fire resistant systems structures.

Polyester Resin — the product of an acid-glycol reaction commonly blended with a monomer to create a polymer resin. In its thermosetting form it is the most common resin used in the FRP industry.

Polyvinyl Alcohol (PVA) — a parting film applied to a mold for part releasing.

Prepreg — reinforcing material impregnated with resin prior to the molding process and cured by the application of heat.

Pressure Bag — a membrane that conforms to the inside of a laminate laid up on a mold. The membrane or bag is then inflated under pressure, which consolidates and densifies the laminate.

Pultrusion — a continuous filament-reinforced plastic (FRP) manufacturing process used to produce highly reinforced plastic structural shapes. Unlike filament winding, which places the primary reinforcement in the circumferential (hoop) direction, pultrusion provides the primary reinforcement in the longitudinal direction. The typical pultruded product will exhibit higher mechanical properties in the longitudinal direction (0°) rather than the transverse (crosswise) direction.

Resins (The ‘Glue’) — The glue, or the resin matrix that holds everything together, provides the load transfer mechanism between the fibers that are wound onto the structure.

Roving — a collection of bundles of continuous filaments in untwisted strands. Used in the spray-up (chopping) process.

S-Glass — improved strength (625-665 ksi), higher modulus (12.6 ksi), higher cost fiber, used in aerospace and high performance, pressure vessel applications.

Spray Up — the process of spraying glass fibers, resin and catalyst simultaneously into a mold using a chopper gun.

Thermoplastics — a group of plastic materials that become elastic or melt when heated, and return to their rigid state at room temperature. Examples are PVC, ABS, polystyrene, polycarbonates, nylon, etc.

Thermosets — materials that undergo a chemical crosslinking reaction going from liquid to solid or semi-solid. This reaction is irreversible. Typical thermosets are polyesters, acrylics, epoxies, and phenolics.

Vacuum Bag Molding — process for eliminating voids and forcing out entrapped air and excess resin from lay ups by drawing a vacuum from a plastic film that blankets a laminate.

Vinyl Ester — chemical combination of epoxy and polyester technology, excellent corrosion resistance, higher cost, excellent strength and toughness properties, widely used as corrosion liner in FRP products.

National Energy Consumption Patterns

Natural gas is the primary energy source for producing resins and fiber reinforcements.

- ♦ As shown in Table 4 and 5, electricity accounts for less than 20% of all energy consumption for SIC 2821(Plastics materials and resins) and SIC 3229 (Pressed and blown glass, nec).

Table 4. SIC 2821 Total Energy Consumption 319 Trillion BTU (1994)

Natural Gas & LPG	60%
Electricity	18%
Other (Fuel Oil etc.)	22%

Source: DOE Energy Information Administration

Table 5. SIC 3229 Total Energy Consumption 63 Trillion BTU (1994)

Natural Gas	79%
Electricity	17%
Other (LPG, Fuel Oil etc.)	4%

Source: DOE Energy Information Administration

Typical Electricity Requirements

Even though electricity costs represent less than 20% of total energy costs for composite raw materials producers, these electricity costs still amount to 2% of shipment value, more than double the percentage encountered by most manufacturers.

As shown in Table 5, the Plastics Materials and Resins (SIC 2821) and Pressed and Blown Glass (SIC 3229) manufacturers are considerably more energy intensive and capital intensive compared to other manufacturing operations.

- ◆ The ratio of kWh electricity consumption per dollar of Value Added (VA) for SIC 2821 and SIC 3229 is more than 3 times higher than that for other manufacturers such as automotive parts producers (SIC 3714) and sheet metal work manufacturers (SIC 3444).
- ◆ SIC 2821 is more than 50% higher in capital intensity as SIC 3229 and SIC 3714. SIC 2821 is more than 3 times as capital intensive as SIC 3444.

Table 5. Intensity of Electricity Consumption and Capital Investment

Industry SIC Code	1996 Value Added (\$, Million)	Electricity Purchased (kWh, Million)	kWh/VA	Mach./Equip. Assets (\$, Million)	Mach. & Eq. Assets/ \$ VA
2821	\$15,310.4	18,699.7	1.22	21,194.2	1.38
3229	\$3,898.0	3,653.2	0.94	3,193.2	0.82
3444	\$7,512.7	1,471.6	0.20	2,424.9	0.42
3714	\$44,209.9	15,559.4	0.35	\$26,709.4	0.86

Source: Census Data

Tables 6 and 7 show that electricity end-use varies greatly between the diverse industrial segments of plastics materials (SIC 2821) and pressed and blown glass (SIC 3229), though electricity for machine drives is the major use for both SIC codes.

- ◆ More than 63% of electricity end-use in SIC 2821 is by machine drive manufacturing.
- ◆ Approximately 43% of electricity end-use in SIC 3229 is by machine drive.
- ◆ Approximately 32% of electricity end-use in SIC 3229 is consumed by process heating.

Table 6. SIC 2821 Plastic Materials and Resins Major Electricity End-Uses (1994)

End Use	Percent of Total
Machine Drive	63.5%
Electro-Chemical Processes	10.9%
Process Cooling	9.5%
HVAC	4.4%
Facility Lighting	3.6%
Process Heating	2.8%
Facility Support, Other	5.3%

Source: DOE Energy Information Administration

Table 7. SIC 3229 Pressed and Blown Glass Major Electricity End-Uses (1994)

End Use	Percent of Total
Machine Drive	43.0%
Process Heating	32.0%
HVAC	7.8%
Facility Lighting	7.5%
Facility Support, Other	9.7%

Source: DOE Energy Information Administration

Manufacturing Process Issues

The production of the key raw material components of composites, resins and fiber reinforcement, is characterized by high capital cost processing.

- ◆ Polyester resins make up over 80% of the matrix materials found in composites.
 - Complex polymer esters are created by the condensation reaction of a glycol (ethylene, polypropylene) with an unsaturated acid. The esters are further reacted with a saturated acid (orthophthalic or isophthalic acid) to form a polymeric backbone to which a reactive solvent (typically styrene monomer) is added.
 - The resulting thermoset polymer has a crosslinked molecular structure that cannot be reversed by heat.
 - Through the use of additives and chemical adaptations, polyester resins can be further tailored to meet special performance requirements such as low shrinkage, low molding pressures, reduced density, flame retardance and UV resistance. Other chemical additives improve resin handling, extend shelf life, or speed cure.
- ◆ Processes such as compression molding combine polyester resins ("wet" materials) with reinforcing fibers to produce composites.
 - Other matrix resins include phenolics, vinylesters, hybrid resin systems, and epoxies.
- ◆ Pelletizers convert polymers into uniform shapes and sizes that offer a convenient feedstock for the extruding and pultruding machines that produce composites.

Glass fiber represents 90% of all composite reinforcements. Glass fiber production begins with silica sand, the basic building block of any glass. Other ingredients are borates and trace amounts of specialty chemicals.

- ◆ The materials are blended together in a bulk quantity, called the "batch." The blended mix is then fed into the furnace where the ingredients dissolve into molten glass.
- ◆ The molten glass flows to numerous high heat-resistant platinum trays, which have thousands of small, precisely drilled tubular openings, called "bushings." This thin stream of molten glass is pulled and attenuated (drawn down) to a precise diameter, then quenched or cooled by air and water to fix this diameter and create a filament.
- ◆ The hair-like filaments are coated with an aqueous chemical mixture called a "sizing," which protects the filaments from each other during processing and handling, and ensures good adhesion of the glass fiber to the resin.
- ◆ After the sizing is applied, filaments are gathered together into twine-like strands that go through further processing steps, depending on the type of reinforcement being made.

- In most cases, the strand is wound onto high-speed winders that collect the continuous fiber glass into balls or "doffs".

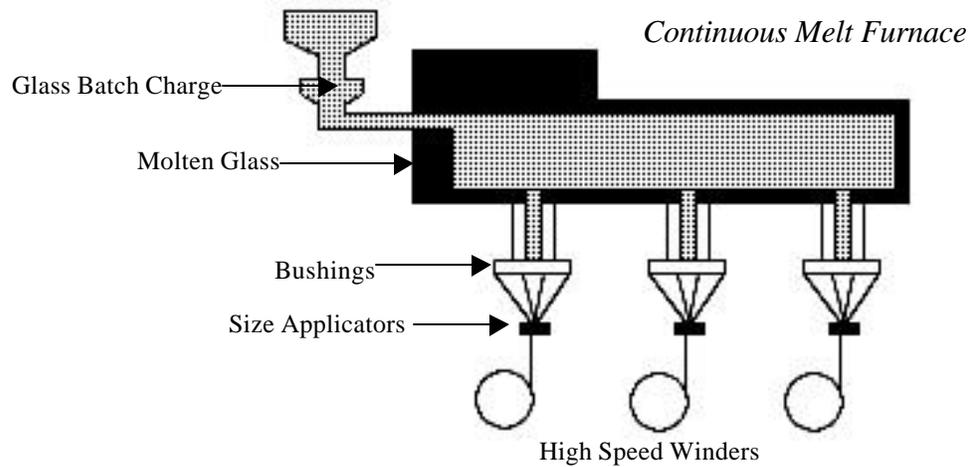


Figure 2. Glass Fiber Production

- ♦ E-glass and S-glass have slightly different compositions, with S-glass being more expensive and having higher strength and stiffness. S-2 glass has the same composition as S-glass, but includes substantive paperwork to meet aerospace requirements.

Pre-preg winding is an alternate approach to provide a higher value product to the composite fabricator.

- ♦ The resin supplier provides the roving or tow fiber in spools that already have a carefully controlled resin content saturated throughout the fiber. The vendor does this by passing the dry fiber through a resin tank at the vendor's facility.
- ♦ After wetting out the fiber roving or tow, the resin is partially cured (called B-staging) with heat and respooled for delivery to the filament winding manufacturer.
- ♦ Pre-pregs are cured under heat (120-180°C) and pressure (50-500 psi) to prepare laminates.
- ♦ Pre-preg windings have a limited shelf life, typically not more than one year.

The packaging of the resins and fiber reinforcement are determined by the downstream fabrication process requirements.

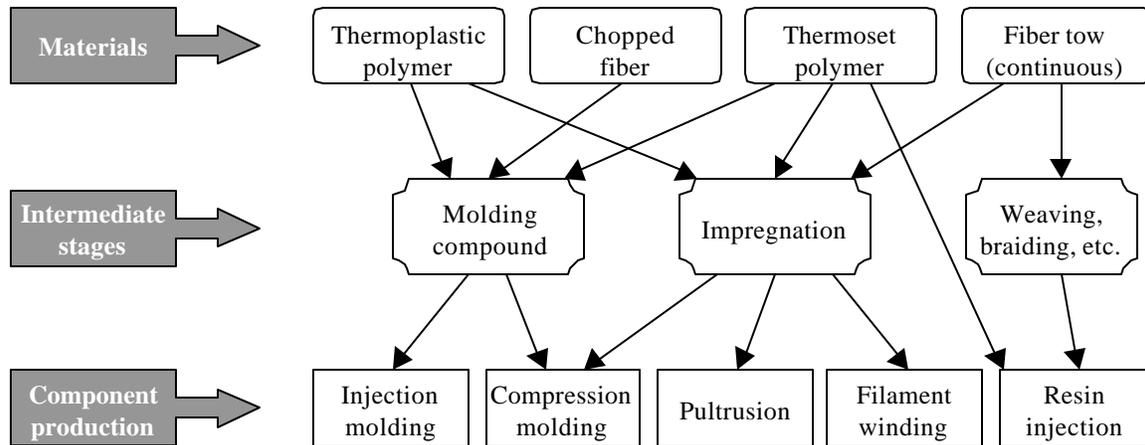


Figure 3. Composites Manufacturing Processes

In the basic processing route shown in Figure 3, low viscosity resin is impregnated into arrays of dry fiber.

- ◆ The open mold process is the simplest and most common technique to create a composite. Though it is very labor intensive, it can be found in many industries including boat building and a variety of residential fixtures such as bathtubs, shower enclosures, etc.
 - A typical procedure is a wet lay-up method in which the fibers, usually in the form of a mat on a polished mold, are impregnated with resin by rolling or spraying.
 - Curing usually takes place at ambient temperature.
 - Recent developments include co-spraying of liquids so that mixing occurs as the liquids are introduced to the fibers.
- ◆ Filament winding has been compared to "wrapping a whole bunch of string around a spool and taking the spool out late".
 - The 'spool' essentially is the internal part, referred to as the mandrel that forms the shape of the filament wound structure.
 - The 'string' is the reinforcing fiber that is systematically wound around the mandrel until it totally covers the surface area to the depth desired by the designer.
 - In order to keep the string in place, the fiber reinforcement is saturated with the 'glue,' or resin, which eventually cures and binds the fibers in place.
- ◆ In the pultrusion process, fiber reinforcements are pulled through a guide plate that aids in locating the reinforcing materials correctly in the final pultruded part.
 - The aligned materials are then passed through a resin impregnation chamber that contains the polymer solution.

- The polymer solution impregnating the reinforcements acts as a glue connecting the various components of the reinforcement. The polymer solution (sometimes known as resin mix) contains the polymer resin in addition to filler, catalyst, and other additives that enhance the performance of the pultruded structural shape.
- Most pultrusion processors use an electrical or oil-heated system with one to four separate heating zones on the die surface. The number of heating zones is dictated by the speed of the process, type of resin to be cured, length of the die, and type of heating source. More heat zones increase speed.
- In another variation, a radio-frequency heating unit is placed after the resin impregnation step and before the curing die. This is a form of preheating the composite and is very useful in accelerating the curing reaction for pultruded composites consisting of only longitudinal glass reinforcement. Carbon fiber reinforcement cannot be heated in a radio-frequency unit because of potential fire hazards.
- ♦ Resin Transfer Molding (RTM) is used for the production of automobile body parts, tennis racquets and a variety of industrial and recreational products.
 - Fibers are pre-placed in position and enclosed in a die.
 - A low viscosity, pre-catalyzed resin is injected into the mold at relatively pressure.
 - The mold is usually made of metal for good heat transfer. It is sometimes evacuated to encourage good infiltration.
- ♦ Vacuum Infusion Processing (VIP) is suitable for all commercial fibers, cores, and any resin in the range of 50 cps to 1000 cps viscosity.
 - Vacuum infusion captures 90% of the fumes and forces (infuses) resin through dry layers of fiberglass, thus eliminating the voids that can be found in 10% of traditional wetted-out lay-ups.

Table 8. Application of Thermoset Filament Winding Systems

Private Industry	Typical Application	Typical Resin Systems
Corrosion	Underground Storage Tanks, Aboveground Storage Tanks	Polyester (Ortho- and Iso-phthalic), Vinyl Ester
	Piping Systems, Stack Liners, Ducting Systems	Polyester (Ortho- and Iso-phthalic), Vinyl Ester, Epoxy, Phenolic
Oil Field	Piping Systems, Drive Shafts, Tubular Structures	Epoxy, Phenolic
Paper and Pulp	Paper Rollers, Piping Systems, Ducting Systems	Vinyl Ester, Epoxy
Infrastructure and Civil Engineering	Column Wrapping, Tubular Support Structures, Power Poles, Light Standards	Polyester (Ortho- and Iso-phthalic), Vinyl Ester, Epoxy
Commercial Pressure Vessels	Water Heaters, Solar Heaters, Reverse Osmosis Tanks, Filter Tanks, SCBA (Self-Contained Breathing Apparatus) Tanks, CNG (Compressed Natural Gas) Tanks	Polyester (Ortho- and Iso-phthalic), Vinyl Ester, Epoxy
Aerospace	Rocket Motor Cases, Drive Shafts, Launch Tubes, Aircraft Fuselage, High Pressure Tanks, Fuel Tanks	Epoxy, Bismaleimide (BMI), Phenolic, Vinyl Ester
Marine	Drive Shafts, Mast and Boom Structures	Epoxy
Sports and Recreation	Golf Shafts, Bicycle Tubular Structures, Wind Surfing Masts, Ski Poles, Amusement Rides	Epoxy

Technology Trends

Resin and fiber reinforcement manufacturers are refining their products to allow fabricators to more easily process their raw materials into composites. This will allow the industry to expand composite applications by reducing manufacturing costs.

- ◆ Low shrink thermoset resin formulations are being developed to enable fabricators to abandon some of the arcane production practices needed to compensate for current resin characteristics.
 - With the exception of one or two recent developments, most of the polyester resins used in the composites industry were developed 20 to 40 years ago. Resin manufacturers now recognize the need to invest more fully in product innovations.
 - A large percentage of current off-the-shelf resin formulations will become obsolete under practices specified in Maximum Allowable Control Technology (MACT).
- ◆ Resin specific styrene suppressants are being developed that eliminate secondary bonding problems.
 - If the bonding issue can be addressed, the use of suppressant technology will be far more useful to a wider segment of the industry.
 - Styrene suppressant additives are tremendously effective in reducing emissions.
 - A suppressant that works well with a specific resin may not be effective in an orthophthalic resin, or an additive that works well with an isophthalic resin may be less effective with another formulation.
- ◆ The next generation of thermoset resins will be low emitting Hazardous Air Particulate (HAP), and have wider handling parameters than current materials.
 - Efforts are underway to pull together packages of resins, suppressants, and required handling procedures from a systems perspective for fabricators.
- ◆ Epoxy resins may replace the current dominant resin (polyester) in production open molding.
 - Non-atomized flow applicators are perfectly capable of handling many epoxies, and would solve the problem that epoxies don't spray well.

Nanocomposites are expected to find significant applications in stronger but lighter weight automotive parts, enhanced gas-barrier properties in packaging, and improved flame-retardance.

Gel coats are being developed that are more tolerant of thickness variation so that low-tech brush or roller application could be used in place of atomized spraying.

- ◆ The non-atomized dispensing of gel coat will reduce environmental emissions.

- ◆ Gel coat manufacturers have made some real progress in developing low monomer products, with specialized formulations available in the 28% -33% range. Low emitting or non-HAP gel coats will play a major role in environmental regulatory compliance.

Ciba Specialty Chemicals and Boeing developed a soft-tooling technique for the fast fabrication of close-tolerance composite parts at a cost up to 70% less than conventional mold making methods.

- ◆ Low Cost Tooling for Composites (LCTC) utilizes seamless epoxy patties to build lay-up tools. The epoxy compound is oven-cured and can then be quickly CNC machined to produce lightweight, extremely accurate, dimensionally stable tools for fabricating prepreg prototypes and short-run parts in an autoclave.

Equipment manufacturers are developing better resin spray gun and flow applicators to reduce overspray and lower emissions.

- ◆ Current equipment, including the gun, lines and force needed to pull the lines, is too heavy. The lines are too stiff to allow the precise gun control required for high quality application. New equipment reduces system weight and makes fluid lines more flexible.

Continued development of non-atomized fluid tip flow applicators in place of spray technology.

- ◆ Lower environmental emissions
- ◆ Innovations involving the use of fluid impingement technology, dynamic mechanical fluid tips, or the use of ultrasonic energy to reduce particle agglomeration characteristic of multiple orifice flow nozzles

Oriented Flow Chop could be the next major advancement in open mold fabrication. One aspect of flow chopping is that the electrostatic charge at the gun seems to be higher, and more difficult to disperse, as compared to traditional spray application.

- ◆ If the chop alignment could be enhanced, it would be possible to apply fiber oriented in one direction.
- ◆ Each ply of chop could be oriented in a specific direction, thus providing similar mechanical properties as the fabrics used in hand lay-up.

Better process monitoring equipment is being developed to enhance product quality.

- ◆ The integration of accurate flow meters in application equipment, coupled with easily accessible bar code technology, will allow operators to apply *exactly* the right of material to a variety of mold sizes and shapes.

There will be a general phasing out of high monomer resins, except in applications where they are absolutely required.

- ◆ Either by regulation, or by waning customer ability to use traditional formulations, many long time workhorse formulations will go by the wayside by 2003 – 2005.

Environmental Regulations and Issues

The resin producers and fiber reinforcement manufacturers fall within industries that are highly visible to the EPA.

- ◆ Composite resin manufacturers are primarily listed under SICs 2821 and 2819.
 - The chemicals sector (SIC 28) reported the largest quantity (798 million pounds in 1997) of Toxic Release Inventory (TRI) data for both on-site and off-site releases.
 - TRI releases within the chemical industry make up 31% of total reported releases.
 - Though composite resin producers contribute only a small percentage to this total, they face significant EPA regulations that they must comply with.
- ◆ Glass fiber manufacturers are primarily listed in SIC 3229.
 - The Stone/Clay/Glass sector (SIC 32) reported 108 million pounds of TRI releases in 1997, or approximately 1.7% of total reported releases.
- ◆ Plastics manufacturers (SIC 30) reported 109 million pounds of TRI releases in 1997, or approximately 4.2% of total reported releases.

Resin manufactures are facing MACT compliance limitations, molding plant permit limitations, and compliance with industry exposure standards.

Styrene production is one of the dominant environmental issues affecting the composites industry. Styrene emissions have so far cost the industry millions of dollars *before* the MACT regulation is even in place.

- ◆ The EPA has set out to minimize styrene emissions by forcing the resin producers to supply resins that will emit less styrene when used downstream in the fabricator's manufacturing process.
- ◆ Highly filled resin systems have been successful in reducing styrene emissions. In Table 9, the same resin was used in three different configurations: As an unfilled resin; as a filler loading of 30% by weight (low filler); and as a filler loading of 60% by weight (high filler). The resultant emissions are as follows:

Table 9. Comparison of Resin System Fillers on Styrene Reduction.

Resin System	Filler Load by Weight	Emissions % of Available Styrene (AS)	Emissions % of Resin Weight (RW)	Emissions (lb./gal)	Emissions % of Resin as Applied	Control Efficiency
No Filler	0%	20.1 %	9.2 %	.82	9.2 %	90.8 %
Low Filler	30%	18.9 %	8.8 %	.69	6.2 %	93.8 %
High Filler	60%	18.5 %	9.0 %	.47	3.6 %	96.4 %

- The non-filled resin system produced 9.2% emissions by weight, while the low filled system produced 6.2%, and the highly filled system produced 3.6% emissions. The actual effect of the highly filled resin was to reduce emissions by 60.8%.

Occupational Safety and Health Administration (OSHA) has a permissible exposure limit (PEL) for airborne particulates not otherwise regulated, which includes fibrous glass.

- ♦ OSHA does not have a specific PEL for the substance nor does the agency regulate it as a carcinogen. OSHA does not ‘ban’ substances, but sets PEL.

In March 1998, EPA withdrew the AP-42 emission factors for the open molding of composites, citing the availability of more accurate emission information being developed by industry.

- ♦ The AP-42 factors for composites have long served as the primary emission factor reference for state regulators and composites manufacturers. Emission factors are especially important for open molders, since most emissions from open molding are difficult to measure, and therefore stack testing is expensive, difficult to reproduce, and seldom used.
- ♦ EPA’s withdrawal of the AP-42 factors for open molding has left facilities and regulators unsure of how to estimate emissions for permitting, compliance demonstrations, TRI reporting, and other purposes.
- ♦ AP-42 factors remain valid for all composite fabrication processes other than open molding.

The Unified Emissions Factors (UEF) are the likely replacement for AP-42 factors in open molding and are based on several independent studies of emissions from open molding processes.

- ♦ Tables are available which state the emission rate in pounds of styrene emitted per ton of resin or gel coat processed.
- ♦ The UEFs account for the impact on emissions of certain process variables: monomer content in resins and gel coats, resin application technology, vapor suppressants, worker training, and open versus covered cure.

Opportunities for Increased Electricity Use

Replacement of gas fired melting in more tightly controlled temperature applications.

"Pinch" technologies for optimizing heat flow in resin production plants. "Pinch" technologies are a means to combine heat processes within a production facility to maximize thermal efficiency.

- ◆ Chemical processing plants that have 3 or 4 heat exchangers or more are good candidates to optimize heat transfer within their production plant via "pinch" technologies.
- ◆ Plants that produce their own utilities, such as steam, are also good opportunities for "pinch" technologies.
 - "Pinch" technologies usually incorporate the addition of motors and fans to move the process heat around where it can be utilized most efficiently in the production process.

Improved drying/curing processes.

- ◆ Radio frequency drying of plastics resins.
- ◆ Radiant heat lamps for melting thermoplastic resins during filament winding.
- ◆ Radiant heat lamps for curing thermosetting resins

Motors to run fans and pumps for improved air quality and ventilation systems.

Electric material handling equipment, such as conveyors, and electric fork lifts

Vacuum processing applications for composite parts.

Aqueous cleaning using various heaters for drying parts after washing.

- ◆ Replaces solvent based cleaning and minimizes VOC emissions.

Areas of Decreased Electricity Use

Energy efficient motors and drives.

Energy efficient shop lighting.

More efficient compressed air systems.

Opportunities for Electric Utilities

Utilities should target mid size establishments and be sure that technology advances and business strategies fit with the industry leaders.

Though most of the energy used in this industry is used for machine drives and process heating, there are specific opportunities using electrotechnologies to improve manufacturing efficiencies.

- ◆ Capital investment should target replacing worn out equipment with new technology.
 - Compressor upgrades.
 - Vacuum processing.
- ◆ Opportunities to replace gas fired melting technology with electric melting, particularly for requirements needing precise temperature control.
- ◆ Opportunities to use vacuum thermal processing in high quality applications to minimize impurities and formation of voids in composite structures.

Industry Associations and Periodicals

The following trade associations are resources for industry information and possible collaborative efforts.

- ♦ **Society of the Plastics Industry (SPI)**, 1801 K Street NW, Washington, DC 20006, PH: (202) 974-5200, FAX: (202) 296-7005, www.socplas.org
- ♦ **Composites Fabricators Association**, 1655 N. Ft. Meyer Drive, Suite 510, Arlington, VA 22209, PH: (703) 525-0511, FAX: (703) 525-0743, www.cfa-hq.org
- ♦ **Center for Composite Materials**, University of Delaware, PH: (302) 831-8702, FAX: (302) 831-8525, www.ccm.udel.edu
- ♦ **ASM International**, Materials Park, OH 44073-0002, PH: (440) 338-5151, FAX: (440) 338-4634, www.asm-intl.org
- ♦ **Chemical Manufacturers Association**, 1300 Wilson Boulevard, Arlington, VA 22209, PH: (703) 741-5000, FAX: (703) 741-6000, www.cmahq.org
- ♦ **SAMPE**, PO Box 2459, Covina, CA 91722, PH: (626) 331-0616, FAX: (626) 332-8929, www.sampe.org
- ♦ **Society of Plastics Engineers**, 14 Fairfield Drive, Brookfield, CT 06804-0403, PH: (203) 775-0471, FAX: (203) 775-8490, www.4spe.org
- ♦ **American Society of Civil Engineers**, 1801 Alexander Bell Drive, Reston, VA 20191, PH: (703) 295-6300, FAX: (703) 295-6222, www.asce.org
- ♦ **American Chemical Society**, 1155 16th Street NW, Washington, DC 20036, PH: (202) 872-4600, www.acs.org

The following trade publications are resources for industry information.

- ♦ *Engineering News-Record*, Two Penn Plaza, 9th Floor, New York, NY 10121, PH: (212) 904-3249, www.enr.com
- ♦ *Civil Engineering*, 1801 Alexander Bell Drive, Reston, VA 20191, PH: (703) 295-6300, FAX: (703) 295-6222, www.asce.org
- ♦ *Advanced Materials and Processes*, Materials Park, OH 44073-0002, PH: (440) 338-5151, FAX: (440) 338-4634, www.asm-intl.org, Design News
- ♦ *Cahners Business Information*, 275 Washington Street, Newton, MA 02458-1630, PH: (617) 558-4660, FAX: (617) 558-4402, www.manufacturing.net/magazine/dn.com
- ♦ *Polymer Composites*, 14 Fairfield Drive, Brookfield, CT 06804-0403, PH: (203) 775-0471, FAX: (203) 775-8490, www.4spe.org

- ♦ *MIL 17 Composite Materials Handbook*, Center for Composite Materials, University of Delaware, PH: (302) 831-8702, FAX: (302) 831-8525, www.ccm.udel.edu
- ♦ *Machine Design*, Penton Publications, 1100 Superior Avenue, Cleveland, OH 44114, PH: (216) 696-7000, www.machinedesign.com

For Further Information Contact:

The EPRI Center for Materials Production

1251 Dublin Rd

Columbus, OH 43215

Voice: 614/255-2590

FAX: 614/291-2867

cmp@tarateccorp.com

00000000001000135