Workable Solutions to Environmental Concerns Facing Composites Fabricators

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abstract

Manufacturers of organic matrix composites face a number of mounting environmental concerns. Because a variety of hazardous materials are used in production of composites, manufacturers are concerned with stiffening regulations and increasing liabilities. Cost efficient waste and pollution reduction programs can be established for composites fabricators, if a long-term view toward managing resources is accepted. Management must look beyond simple one step solutions which sidestep or deal with basic problems. Consideration must be given to selecting approaches which interact with all areas including basic production strategies, facility design, and management strategies. Cost-efficient approaches are best developed through careful attention to refining material flow patterns, conserving materials, eliminating waste, utilizing new technologies, separating incompatible operations, eliminating liabilities, and controlling inventory.

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WORKABLE SOLUTIONS TO ENVIRONMENTAL CONCERNS FACING COMPOSITE FABRICATORS

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Introduction

Because of the materials used in production of organic matrix composites, the industry can expect increased emphasis on safety and pollution reduction issues. Federal and state regulations are undergoing constant revision in terms of new approaches to managing potentially hazardous materials, waste disposal, atmospheric emissions, and worker safety. Environmental and safety terms such as "cradle to grave" and "right to know" have become increasingly important to manufacturing professionals. Implementation of pollution reduction and safety strategies is often an outgrowth of problems created by regulatory and enforcement demands. Decisions affecting materials selection, processing technologies, facility layout, and even the geographic location of the production facility are increasingly influenced by environmental and safety concerns.

Potential environmental and safety problems exist in practically all manufacturing and service facilities. Problems faced by the composites industry are typical of those found in other industries. Resin systems, catalysts, dust, solvents, and other chemicals pose potential health and environmental problems and necessitate the establishment of systems for eliminating or minimizing dangers and liabilities. Waste generation may also be a major problem, especially where part or all of the waste may be classified as hazardous. Maintenance of acceptable internal and external air quality is also a serious problems. Even a company's system of management becomes more complicated and expensive. Meeting environmental and safety standards can represent major expenses in terms of direct operations and overhead. On the positive side, some producers have found that well planned pollution reduction strategies actually prove to be cost effective.

A study of efficient and effective pollution and waste reduction strategies for this industry was commissioned by the North Carolina Pollution Prevention Pays Program in January, 1986. This study was commissioned with the primary goal of developing specific recommendations for that part of the industry dealing with open molding processes. Funding was made available, because the capability for producing and maintaining of composite structures was viewed as an important element of the state's and the nation's economic and strategic well being and because there is urgent need to solve or minimize environmental and safety problems which exist in many operations. To ignore safety and environmental issues facing this industry jeopardizes the safety of the environment, endangers the health of the workforce, will ultimately lead to the loss of jobs, and severely reduces the nation's ability to competitively produce many high performance products. In June, 1987, a pollution reduction manual was published for the Pollution Prevention Pays Program. A number of the successful strategies and approaches outlined in the findings of this report are reviewed in this paper.

Background

Solutions to environmental problems may be as complex as the industry itself. Operations involving the molding, forming, and repair of composite materials are carried out at many locations and under a great variety of circumstances. While some enterprises operate facilities which are dedicated almost exclusively to the production and marketing of major composite components, other firms may accommodate processes aimed only at the production or repair of small accessories or parts. Operations range from small one man job shops to large production facilities with thousands of employees. Major differences also exist with regard to
basic materials processing technologies and the types of materials used. No one set of recommendations or management system can meet the needs of this diverse industry. Each facility has its own unique circumstances which must be considered in developing workable solutions.

Epoxies and a variety of other thermosetting resins have traditionally served as matrix systems for organic matrix lay-ups. Each family of resins pose slightly different problems in terms of chemical content and potential dangers. Resin delivery may be accomplished through a variety of approaches including spray application, impregnators, and brush or roller. For many applications, fabricators prefer to work with reinforcing materials which have been preimpregnated with resins. Resin systems also contain fillers, activators, and other additives which can contribute to potential environmental and safety problems. Typical problems associated with using resins include atmospheric emissions, toxic vapors, fire, explosions, and generation of hazardous waste. Even with an emerging trend toward the use of thermoplastic matrix systems, some of these problems are likely to remain.

A number of different materials are widely used as reinforcements for organic matrix composites. Glass, graphite, and aramid are the most common. Fiber reinforcing may take the form of filaments, woven roll stock, non woven roll stock, or short chopped fibers. Where open molds and spray delivery of resin are used, some hand rolling is almost essential for removing voids and insuring proper integration of resin and reinforcing material. Post molding operations frequently generate dust and other particulate matter which may pose safety problems. In particular, there is increased discussion of theories related to potential health problems which may be caused by exposure to fiberglass particles.

| • Use and Storage of Potentially Hazardous Chemicals |
| Resins |
| Solvents |
| Catalysts |
| • Emission of Vapors and Odors |
| • High Levels of Worker Contact With Chemicals |
| • High Levels of Worker Contact With Vapors |
| • Production, Storage, and Disposal of Contaminated Waste |
| • High Levels of Worker Contact With Dust |

TABLE 1: POTENTIAL ENVIRONMENTAL AND SAFETY PROBLEMS

The process of developing solutions to environmental problems is further complicated because many different fabrication technologies are employed. Some variation in processing can be traced to the diversity of products produced. For example, approaches used in the production of a high pressure storage tank are different than the approaches used to mold a seating unit. Approaches to producing basically similar products may also vary because of differences in facilities, organizational production concepts, and product performance requirements. Lay-out of the physical facilities also influence approaches to dealing with environmental issues. Where high production outputs are required, larger companies can develop facilities which have specific areas and streamlined production equipment for each unique operation. Smaller organizations may find it necessary to mix operations within the same production area. Fabricators must also deal with other potential environmental and regulatory problems associated with hazardous materials storage, contaminated solvents, waste disposal, flammable liquids and vapors, and dust. Development of a comprehensive approach for dealing with
environmental and safety concerns, requires that each unique facility, process, and material be evaluated in terms of existing and potential problems.

Establishing Pollution Reduction Strategies

In establishing a pollution reduction program, administrators must be willing to take a long-term view of managing resources. In many cases, approaches to facility and process development for the composites industry can be categorized as being short-sighted. Operations have been set up in open general purpose structures with little regard for anything other than executing basic lay-up and secondary finishing operations. Many pollution-related problems, created by these approaches, can be minimized through refining basic production and facility design. Profitable pollution reduction approaches can only be developed when careful attention is paid to selection of processing strategies, refining material flow patterns, conserving materials, conserving utilities, separating incompatible operations, and controlling inventory.

Planning for future contingencies will be essential to the economic well-being of the industry. The materials used in the molding processes are under constant scrutiny by health and environmental agencies. There seems to be little doubt that future regulations regarding in-plant and out-of-plant air quality, worker exposure, and waste management will be tougher. Processing equipment and facility designs should be selected with potentially tougher regulations in mind. Where possible, alternate materials and processing approaches should be explored. At a minimum, existing facilities and equipment should be fine tuned to bring potential environmental problems under control.

When calculating the overall effects of implementing a pollution reduction strategy, it is often difficult to get a clear picture of the actual costs and benefits of all available alternatives. The following cost factors must be included in order to obtain an accurate analysis: capital equipment, equipment operation, virgin solvent, transportation of virgin and waste solvents, hazardous waste disposal, overhead for record keeping, fees for obtaining any required permits, and legal liabilities. These cost factors must be carefully weighed against productivity needs, available assets, incentives, and disincentives.

A number of incentives for implementing pollution reduction strategies are provided by federal, state, and local governments as well as by private agencies. Incentives may be offered by the State and Federal Government to insure against unfair competition from noncomplying companies, provide relief for heavily impacted companies, and encourage compliance with state and federal requirements. These incentives may take the form of property tax exemptions, tax exempt industrial development bonds, accelerated amortization, reduced franchise taxes on certain waste recovery property, and matching funds for implementation of selected waste reduction strategies. Incentives may also be offered by local governments or industrial development agencies for the purpose of attracting or retaining industries. Maintenance of goodwill and image can also be essential in maintaining or enhancing the status and influence of the company in the eyes of the public and special interest groups. Companies should also be interested in limiting foreseen and unforeseen long-term liabilities.

A number of regulatory factors dictate an interest in waste and pollution reduction strategies. According to the code of federal regulations, all industrial installations are legally obligated to properly handle, ship, store, and dispose of hazardous materials and waste. In addition, there are regulations specifically issued for the protection of employees in the workplace. A few important regulations are listed in Table 2.
TABLE 2: SELECTED POLLUTION AND SAFETY RELATED REGULATIONS

For a conscientious company, environmental concerns have to be addressed with respect to the discharge of pollutants into the air or nearby rivers and streams. In addition, proper disposal of waste on the land should also be assured. Because air pollution, water pollution, and the accumulation of hazardous and toxic waste have created conditions which have adversely affected environmental quality, federal and state governments have promulgated regulations for the prevention of environmental degradation. A severe penalty and possible imprisonment can be imposed under these regulations. Both state and federal agencies have responsibility for the enforcement of environmental legislation.

Long-term liability may be the most important factor in the decision making processes which relate to pollution reduction strategies. This is true when considering worker safety, as well as the relationship of materials and processes to the environment. The Resource Conservation and Recovery Act (RCRA), “cradle-to-grave” philosophy, as well as lawsuits being carried out under Comprehensive Environmental Response Compensation and Liability Act (Superfund), should attract the attention of management in the composites industry. Even companies that legally and properly disposed of hazardous waste in the past are now having to absorb cleanup costs for those materials. Lawsuits have forced companies to pay the cost of removing their wastes from licensed landfills and disposing of them in a manner that meets current standards.

In addition to the outside environment, which deals with factors related to environmental quality, there is another part of the environment in which people work, i.e., the work environment. Because the emphasis on worker protection is different from that of environmental protection, regulation and standards are also different.

Hazardous materials and processes create a number of concerns regarding worker health and safety. Existing and emerging regulations must be considered when selecting equipment, designing production processes, and choosing materials. Many of the materials used are highly flammable, harmful to tissue, respiratory irritants, and toxic in other ways. There is potential for immediate worker injury and for long-term health problems. Chemicals used in resins and solvents, along with dust created by grinding operations, make the industry a prime target for fines and lawsuits related to short-term and long-term worker health issues.

Regulatory agencies and legal statutes provide a number of disincentives for failure to insure worker safety and health and for improper or poor waste management. There are many civil penalties for noncompliance or negligence. In some cases negligent actions or inactions can lead to criminal charges and possible imprisonment. Total facility shutdown is not unheard of. Regulations and penalties, as disincentives, include policies which prohibit the EPA from approving or recommending to private parties any facilities that have Category 1 violations. Many states also follows this procedure. Regulatory policies also require that penalties for noncompliance be large enough to offset any economic gain from noncompliance. Owners or stockholders are directly affected since penalty expenses for violations are not tax deductible.

- Clean Water Act
- Clean Air Act
- Resource Conservation and Recovery Act
- Toxic Substances Control Act
- Occupational Safety and Health Administration-Act
- The Occupational Safety Communication Act
- Comprehensive Environmental Response Compensation and Liability Act
Table 3 describes high risk or overly expensive approaches to dealing with environmental and safety problems.

<table>
<thead>
<tr>
<th>Undesirable Pollution and Safety Solutions</th>
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<tr>
<td>• Illegal or Improper Dumping, Storage, or Emissions</td>
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<tr>
<td>• Ignoring Inventory and Materials Control Systems and Records</td>
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<tr>
<td>• Absolute Reliance on Contracted Hazardous Waste Disposal</td>
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<tr>
<td>• Expensive Emission Control or Treatment Equipment</td>
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<tr>
<td>• Total Reliance on Personal Protective Gear and Clothing</td>
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TABLE 3: UNDESIRABLE POLLUTION AND SAFETY SOLUTIONS

Profits from investments and operations, along with maintenance of equity, are major concerns for all businesses and investors. Managers and investors frequently view compliance with pollution regulations and workplace safety requirements as being costly and counterproductive. There is little doubt that strict environmental regulations have resulted in costly changes involving everything from basic production techniques to management and control strategies. However, in many cases, environmentally sound approaches to managing the processing of hazardous materials can lead to overall cost savings and productivity improvements. Waste and pollution reduction strategies do not always have a detrimental effect on profits and productivity. Regardless of perceived expenses or profits, ignoring sound waste reduction and pollution prevention strategies will prove to be more costly in the end. In many cases pollution reduction strategies have provided a quick return of investment and have actually improved productivity. A number of successful approaches are noted below.

MANAGING CONTAMINATED SOLVENTS

Use of acetone and other similar solvents for general cleaning is standard practice for many fabricators of composites. Solvents are used to clean spray equipment, rollers, brushes, tools, finished surfaces, and even the hands of employees involved in lay-up operations. Since these solvents become contaminated with residue from resins and catalysts, their storage and disposal usually fall under strict governmental regulations. Precise records must be maintained on the delivery, storage, and disposal of these solvents. Use of solvents for cleaning and maintenance operations frequently represents a major expense in terms of purchasing the virgin solvents and payments for hazardous waste removal and disposal. Prices for transportation and storage can exceed $300 per barrel for moderately contaminated waste. Given the RCRA "cradle-to-grave" philosophy regarding waste generation, the expenses may not end with payment of invoices for shipping and disposal. Long-term liabilities and responsibilities for problems that might evolve from storage or disposal of contaminated solvents must also be considered.

In the past some operators have allowed evaporation or spills to take care of much of the disposal of contaminated acetone. Recent developments in regulations and record keeping requirements are making sloppy disposal techniques very risky, even for the smallest producers. In extreme cases, users can be held accountable for disposition of solvents based on records of quantities purchased. On-site storage of contaminated waste is strictly regulated, and severe penalties may be imposed upon violators.

Under existing state and federal laws the generator of a hazardous waste is never relieved of the responsibility for that material. Obviously, the best approach to limiting long-term liability is to avoid using hazardous materials and generating hazardous waste. Operations which do not use hazardous materials or generate hazardous waste have no liability. Where production of hazardous waste or the use of hazardous materials cannot be avoided, strategies should focus on
reducing the volume of those materials. Decreasing the volume will also reduce the magnitude of the long-term liability because environmental effects are frequently related to waste volume.

Given the status of current regulations and rising solvent costs, alternatives to traditional solvent use and management systems should be considered. At least four basic approaches appear to have considerable merit for fabricators who must deal with contaminated solvents. Biodegradable solvents, in-plant recycling, out-of-plant recycling, and incineration have proven to be viable options to conventional secured landfill disposal techniques.

**Substitutes for Organic Solvents**
A number of suppliers have developed biodegradable solvent substitutes for cleaning tools, fixtures, and application equipment. These substitutes are water soluble and are usually disposed of through typical municipal sewer systems (consult local officials). These cleaning agents are sold in concentrated form and are not flammable. MSDS sheets for these chemicals make them appear much safer than compatible solvents and there appear to be no chemicals which pose major threats to workers or to the environment.

In terms of drawbacks, these materials must be mixed with a proper quantity of water and require heating for efficient use as a cleaning agent. A holding tank system must also be developed to allow resin and catalyst contaminants to solidify and settle out of the mixture. After the contaminated mixture is poured in a settling tank, contaminants settle to the bottom and must be removed and allowed to dry. In most operations, this dry residue is handled like other solid waste generated from cutting and finishing operations. Effort must be made to insure that tools, gloves, and other equipment are thoroughly dry before being placed back in use. In order to minimize possible water contamination, some producers continue to use small quantities of organic solvents as a rinse.

**In-Plant Solvent Recycling**
Many fabricators are finding in-plant distillation systems to be a cost efficient approach to dealing with contaminated solvents. Batch type units have proven to be successful in meeting the needs of firms producing small to moderate quantities of contaminated solvents such as acetone. Unit sizes commonly available range from 5 to 55 gallon units.

A basic batch type system should consist of four major components including: a contaminated solvent collection tank, a heated boiling chamber, a condenser, and a clean solvent collection container. A typical low cost system is diagramed in Figure 1. The operating systems for these units are typically contained within a single compact cabinet. Space required to house a unit is generally less than the space required for storage of virgin solvents and contaminated waste.

Contaminated solvents are poured into the solvent collection tank during normal employee cleanup operations. The contaminated solvent collection tank should have an inlet that can be properly sealed to prevent evaporation. In collecting any solvent for recycling, considerable care must be exercised to avoid cross contamination with other solvents or water. A filtering screen should also be placed in the inlet collection system to prevent solids and sludge from clogging pumps and/or feed pipes which deliver contaminated resins to the heat chamber. If the collection tank is situated higher than the top of the heat chamber, piping and valves can be permanently installed so that solvent can be gravity fed into the heat chamber. If the collection tank is not located above the heat chamber, a pumping system may be required to transfer solvents for processing.

The heat chamber is designed so that a vapor tight seal can be maintained during heating and cooling cycles. In the chamber contaminated solvents are heated to a predetermined vaporization temperature, and these vapors are channeled out of the container to an external condenser. Heat
can be supplied by means of electric elements or by steam bands. Steam units offer some advantages in terms of speed and safety and can be attached to existing plant steam lines or a boiler supplied by the manufacturer of the still. The heat chamber will also be equipped with either a bag or pan to facilitate collection of the unusable residue which has been separated from the reclaimed solvent. This residue is referred to as "distilled bottoms" or "still bottoms".

![Diagram of solvent distillation system]

**FIGURE 1: BASIC BATCH SOLVENT DISTILLATION SYSTEM**

Depending on design requirements, condenser units may be water cooled or air cooled. Water cooled units are generally more compact and more efficient but require connection of external water inlets and drains. In the condenser, vapors are cooled rapidly in order to promote condensation. This condensate is clean solvent and is drained off and collected in appropriate containers. These collection containers may vary from a single bulk storage unit to conventional barrels. The solvents collected in this manner are generally ready for use without further treatment or additives. The distillation recovery option seems particularly appealing since Federal EPA regulations (Regulation 40 Part 261.6) do not require a permit for this type of solvent treatment. State regulations vary; most require notification that a solvent distillation unit is being installed.

There are a number of cost factors affected by the use of batch distillation units. In comparison to conventional disposal techniques, the quantities of solvents which must be disposed of by hazardous waste handlers may be reduced by as much as 90%. Since usable solvents are produced, the outside purchase of virgin solvents can be dramatically reduced. Long-term liabilities for waste disposal are also significantly reduced. The units do require a considerable initial investment. Prices may vary from approximately $3,700 for a basic 5 gallon per batch unit to more than $36,000 for a relatively sophisticated 55 gallon unit with labor saving automatic control systems and pumps. Stills also require energy for heat, labor for operation, and water for the condenser. These operating costs will generally be less than 50c per gallon, with some manufacturers claiming costs under 20c per gallon. Other expenses include disposal of distilled bottoms, bags, and maintenance.
Batch type distillation systems do not normally require full-time operators or extensive operator training. With the most basic design, an attendant is assigned the duty of filling the heat chamber with contaminated solvents, sealing the unit, activating appropriate controls, deactivating the controls after the cycle is completed, and removing the residue distilled bottoms from the heat chamber. The complete cycle time normally ranges from three to eight hours, but the operator need only be present during start-up, shutdown, and cleanup. Supplies consumed in the processing of solvents are usually limited to disposal bags.

![Diagram of a high efficiency batch distillation system](image)

**FIGURE 2: HIGH EFFICIENCY BATCH DISTILLATION SYSTEM**

The addition of automatic controls and pumping systems to load waste solvents can greatly reduce labor demands and prove greater assurance that the unit will be shut down if an operational problem occurs. A diagram of a larger unit with automated controls is shown in Figure 2. The units can be equipped with a number of standard and optional automatic control systems for materials handling, cycle control, and safety. Liner bags may be used to collect still bottoms and keep the boiling chamber clean. Total operator time required for each cycle is normally less than 15 minutes.

Selection and installation of a batch type distillation system requires careful study and planning. Demonstrations of equipment should be carried out using representative samples of contaminated solvents from your facility. Insurance requirements, safety, and fire codes should be taken into consideration before a system is selected and installed. Vapors produced during distillation can be highly flammable, so units and surrounding equipment should be of an explosion proof design. Results may be disappointing on solvents which have been heavily contaminated with water or other elements with high vaporization temperatures.

**Supplier Based Solvent Recovery**

Some facilities have successfully used supplier based solvent recovery as a cost efficient means of dealing with contaminated solvents. In firms where in-plant-recycling has not proved feasible or gained favor with management, successful arrangements have been made for outside recovery of solvents. Often these arrangements are made with solvent suppliers who can reclaim the contaminated solvents at a cost considerably lower than the cost of producing virgin materials. Contracts and arrangements for these services take a variety of forms.
In most cases "toll" arrangements are made to insure that the waste generator's solvents are handled separately. The reclaimed solvents are then returned to the generator along with virgin stock. This arrangement helps reduce the likelihood of solvents becoming contaminated by undesirable substances produced by other waste generators. Some firms have developed service agreements which do not place restrictions on the source of the reclaimed solvents which they purchase. Other companies may elect to specify the purchase of virgin materials only. Separate arrangements, whereby new solvents are purchased from one source and contaminated solvents shipped to another firm, are also common.

Solvent Incineration
Incineration is also an option for disposing of contaminated solvents. Acetone and similar solvents can serve as a fuel source for heat recovery because of its high BTU value and low halogen content. In some industries, a number of large companies have installed in-plant incinerators to burn waste solvents. Although in-plant incineration does not appear to be particularly suited to the requirements of most fabricators, out-of-plant incineration may be attractive to some.

Waste solvents may be sent to cement or light aggregate plants for use as a fuel. This option may be particularly attractive to small producers. Companies, specializing in such operations, can send their trucks to the customers facility to pick up waste solvents. These waste solvents must normally be pumpable. Collection can be made from large tanks or drums. Cost per gallon for the service is somewhat dependent on the nature of the waste collected. When high BTU value is maintained, costs are reduced. Contaminants that add halogen adversely affect cost. Heavily contaminated solvents and still bottoms may also be disposed of by incineration. Burning contaminated solvents and/or still bottoms in an aggregate or cement kiln produces no ash. This effectively relieves the generator from further liability, since no solid or liquid waste remains.

Just as with out-of-plant recycling, out-of-plant incineration requires an efficient management and control system. Contaminated solvents must be collected in tanks or drums as a part of normal employee cleanup operations. The contaminated solvent collection system must be carefully monitored. A filtering screen should be placed in the inlet collection system to separate solids and sludge. The collection tank, or drums should be sealed to prevent loss of BTU value through evaporation and contamination. Water and trash will also drive up the cost of the service. Transportation of the contaminated waste must also be viewed as a potential liability.

Production-Based Waste and Pollution Reduction Strategies

Air Assisted Airless Spray Guns
Use of resin spray applicators has become standard practice for most fabricators. Conventional gun-type resin application systems use either compressed air or high fluid pressures to atomize resin materials. In air spray systems atomization requires the flow of a large volume of air at high pressure. These systems offer good control over spray patterns but are not well suited for efficient delivery of thick resins such as those used for gel coats and lamination. Airless spray gun systems are designed so that resins are atomized by being pumped at extremely high pressure through an atomizing nozzle.

Airless spray guns are considered to be more efficient in delivering resins to the work surface. Large quantities of gel coat and other resins can be rapidly transferred with these systems. For efficient atomization and delivery, pressures in excess of 3,500 psi may be required. These high pressures, while necessary for atomization and spray pattern development, contribute to excessive fogging, overspray, and bounceback during the spray-up process. Recent developments in spray-gun design have resulted in new systems which blend positive characteristics of both air and airless spray guns into one unit.
Air assisted airless guns, like conventional airless guns, utilize high fluid pressures to atomize resins through a spray nozzle. This high pressure nozzle atomization is further augmented by introducing pressurized air into the resin as it exits the pressure nozzle. An example of the nozzle function is pictured in Figure 3.

Pressures normally used with either air spray guns or airless spray guns may be reduced when using air assisted airless systems. Unlike conventional air spray guns, air assisted airless systems require a very low compressed air pressure at the nozzle. This low air pressure produces an envelope which picks up material dispensed from the pressure nozzle tip. The envelope can be regulated to assist in developing a controllable spray pattern. With low pressure air assist, the fluid pressures required for atomization and delivery pattern development can be reduced by, as much as, 30%.

Air assisted airless spray guns can insure that the high volumes of material transfer attainable with airless systems can be maintained while reducing material losses due to excessive fogging, overspray, turbulence, and bounceback. Reduced delivery pressures can help insure that a cleaner, safer, and more comfortable work area is maintained. External emissions and the need for high levels of make-up air may also be reduced.

Lower pressures may help reduce material waste and other expenses. Less energy is required to operate the unit. Lower operating pressures reduce the cost and maintenance of pressure lines and fittings. Lower pressures also reduce wear on pumps, fittings, and controls. Reduction in overspray residue in the work area simplify routine cleanup of surfaces in the working environment.

A number of companies have experimented with the use of these guns for gel coat and heavy resin applications. The units purchased were generally installed on existing pump units. Operation of the units did require some operator familiarization. Characteristics of the spray guns were learned quickly by the operators, and no loss in production or quality was noted. Coverage of deep draft, narrow mold openings created some problems. These problems were eliminated through operator training. Overall production performance was judged to be better than conventional airless units with a notable reduction in fogging, overspray, airborne emissions, and spray booth build-up.
Prepreg Fiber Reinforcing

For a number of years fabricators of composite aircraft structures have relied on the use of fiber reinforcements that are presaturated with resins. These materials, referred to as "prepregs," offer a number of advantages over conventional spray techniques. Resin to fiber ratios can be closely controlled; atomization of pollutants is practically eliminated; and cleanup and disposal problems are greatly reduced. These advantages are, however, not enough to make prepregs widely accepted by fabricators with less stringent quality assurance and performance demands.

Prepregs are generally formulated with more expensive epoxy based resins which require placing the lay-up in an oven or autoclave to complete the cure cycle. These more expensive resins are normally combined with exotic, high strength reinforcing materials, such as graphite fibers. Storage is also a problem since the materials must remain refrigerated until the lay-up process is begun. Use of prepregs, would appear to be a viable approach for eliminating many of the airborne emission problems associated with spray and roller applications. High prices, difficult storage requirements, and autoclave processing will relegate prepregs to applications where extremely high strength-to-weight-ratios take precedence over cost factors.

In-Plant Resin Impregnation

Equipment is now available to provide the fabricator with some of the advantages offered by prepregs while using lower cost polyester resins and fiberglass materials. Impregnators can be placed within the lamination area of a plant and be mounted in such a manner as to feed resin saturated reinforcing materials directly to the molding operation. Conventional resin pumps and catalyst metering devices supply resins to a roller-reservoir system. Woven fiberglass is impregnated as it passes through this reservoir system. A schematic of the system is pictured in Figure 4.

Impregnators can be designed to fit a variety of potential applications. The units can be mounted to overhead track and lift systems, over stationary conveyor fed lines, on bridge cranes, or on portable carts. Conventional resins and roll fiber materials can be used. Machine size and capacity can be engineered to provide a variety of output feed rates and to accommodate a number of roll widths. Units currently available can produce as much as 20 linear feet per minute with resin-to-glass ratios controllable to within ±2%. Larger units have an output capacity which can exceed 1,000 pounds of laminate per hour with a 50% glass content.

Impregnators would appear to have some potential for reducing pollution associated with open molding operations. Delivery of the resin to the reinforcing laminate by means of an impregnator would help insure that a cleaner, safer, and more comfortable work area would be maintained. Since there would be no spray atomization of resins, the levels of in-plant and external emissions would be minimized. At the same time, requirements for high levels of make-up air and elaborate air handling systems would be minimized. There may also be potential for improving quality through greater control of fiber to resin ratios.
Resin Roller Dispensers
Resin roller dispenser units utilize a fluid pumping system to draw resins from drums or bulk distribution lines. This pumping system also includes a separate, fully adjustable catalyst pump. Resin and catalyst are precisely metered and pumped to a gun-type head for mixing. The gun head is essentially an internal mix airless spray gun without an atomization nozzle. The atomization nozzle is replaced by an attachment which directs the catalyzed resin to an attached roller.

Units which attach to existing spray gun heads or other feed systems are available. A flexible material hose is attached to the mixing chamber of the spray gun. This hose will feed resin directly to the roller dispenser. Resin is dispensed directly onto the roller surface through a perforated T-bar. An example of a roller dispenser system is pictured in Figure 5.

The high pressures normally associated with the use of either airless spray guns or air assisted airless guns are not required. Since atomization is not required, resin delivery pressures may be well below 100 psi. Pressures are normally regulated for the purpose of controlling the rate of resin delivery. Catalyst flow rates are precisely tied to resin flow to insure a high level of control over catalyst-to-resin ratios and cure rates. Delivery rates for catalyzed resins may be as high as 20 pounds per minute.
ComDress Molding
Fabricators who rely on spray application of resins for lay-up, should carefully consider alternate methods. Open molding spray-up and hand lay-up production techniques are frequently employed by smaller firms or those who produce limited numbers of units from each mold. Open molding carries a high per piece cost due to labor intensity, limited daily output from each mold, and considerable atomization of resins. Closed mold technologies may offer a practical alternative for some companies. Closed molding operations practically eliminate requirements for atomization of resins and may offer a number of production advantages over conventional approaches to molding. The closed molding technologies most frequently applied to production of fiberglass components are compression molding and resin transfer molding.

Compression molding can reduce high per unit cost, but only if production volume is high enough to sufficiently spread out the high cost of the required matched metal dies. Special molding compounds of resin and reinforcing materials are normally required. The molding
compounds are compressed between heated matched molds. Output is high, because the molding compounds cure rapidly in the heated mold. Some materials yield a good finish without application of a gel coat. Both surfaces of the molded product will be as smooth as the mold surfaces. Compression molding processes have been used successfully in the automotive industry for more than 25 years. Production output requirements for most molders do not approach the 150 parts-per-mold-per-shift figure required to reasonably spread out the costs of molds and tooling.

**Resin Transfer Molding**

Another closed mold process known as resin transfer molding (RTM) has recently seen a surge of interest. Like compression molding, RTM utilizes matched molds. However, the matched molds do not have to be made of metal, and high pressure mold closing systems are not required. RTM appears to offer many advantages to firms that seek production of 100 to 10,000 parts per year.

RTM production systems can be set up to replace many conventional open molding processes. Molds can be produced from the same materials and with the same techniques required for production of conventional molds. The molding resins and filler materials differ little from materials used to produce similar components in open molds. Even the gel coat finishes are the same as those produced in open molding.

Since molding pressures typically are low, the molds can be made of plastic based composites rather than metal. The matched molds are laid-up over a pattern in the same manner and with the same types of materials used to produce molds for open molding. Some specialized tooling is required to insure that alignment and clamping pressure are maintained when the molds are closed. The molds must also be properly reinforced to avoid flexing during the injection and curing cycles. Inlet ports and vents must be properly located so that resin is pumped into all parts of the mold. Mold and tooling quality determine the quality of the part. RTM is pictured in Figure 6.

Some aspects of quality and productivity may be improved through the use of RTM. The molding system produces parts that can have an excellent finish on both sides. Open molding requires at least two molding operations and secondary assembly work to produce parts with two finished surfaces. Since conventional mold making practices can be employed, start-up and tooling can be accomplished quickly and economically. With complex parts, the lay-up of reinforcing materials, core stock, inserts, and resin can be accomplished in one step. Curing cycle time requirements may be greatly reduced.

RTM applications seem best suited for intermediate volume production of small to mid-size components. Large items, such as boat hulls, are produced using RTM techniques, but tooling costs per unit are quite high. Items such as seats, hatches, doors, automotive parts, tubs, and bath units are much better suited to this type of processing. Molds for these products can be kept to a reasonable size and can produce parts that require a minimum of trimming, assembly, and secondary finishing.
There are many reasons for the popularity of open molding fabrication processes. Materials such as epoxy resins and fiberglass may be combined to manufacture products with outstanding properties. The open molding process can yield a variety of reasonably priced structures with high strength, outstanding corrosion resistance, excellent chemical resistance, light weight, and outstanding appearance. Molds and tooling are simple, and investments in specialty equipment may be considerably below investments associated with other manufacturing processes. Product lead time can be very short, and the process is well suited to the production of prototypes and limited quantity product runs. Production related drawbacks of the process include high labor commitment for each product, long production and curing cycles, limited daily output for each mold, and high pollution potential.

Overall, the plastics industry uses far more thermoplastics than thermosetting plastics. Thermoplastics processing offers faster curing cycles, lower emissions during processing, lower costs per pound of raw material, ease of recycling, and lower labor intensity. Open molding of thermosetting plastics is likely to continue as a viable process because of the design constraints associated with many products, limited unit production requirements, performance requirements, and market demands. Recent advances in processing technologies and thermoplastic resin systems are causing many in the industry to examine alternative approaches to the molding process. New engineering grades of thermoplastics can be reinforced with fiberglass or other fibers. These materials can rival the strength of many of the strongest thermosets. Production machinery and tooling costs are still high for thermoplastics forming processes such as injection molding, extrusion, and blow molding. Often thousands of products must be produced in order to provide a reasonable amortization for mold costs alone (large molds machined from stainless steel may cost more than $100,000). Molds for processes such as rotational molding or thermoforming can be produced at costs low enough to warrant the interest of some open molders.
Resin Storage

A number of approaches are utilized for purchasing resins for open molding operations. Many processors elect to purchase all materials in 55 gallon drums while others prefer to purchase resins in bulk quantities. Large firms, such as bath fixture manufacturers, purchase practically all general purpose resins in bulk and store these materials in large storage tanks. Smaller companies usually purchase general purpose resins in drums. Specialty resins such as gel coat colors, tooling resins, and fire retardent resins are almost always purchased in drums.

Bulk Storage

Both the bulk and drum purchase strategies have positive and negative attributes. Where large quantities of resins are consumed, bulk systems enable companies to purchase resins at lower prices. Lower prices are possible because of quantities purchased, elimination of packaging in the form of barrels, and ease of handling in terms of loading and unloading. Bulk systems are well suited for delivering large quantities of resins to vats for mixing with fillers or other additives. Drum purchases fit the requirements of users who need flexibility in terms of quantities purchased. When compared to the use of drums, bulk storage requires installation of expensive storage tanks and resin delivery pumps and piping. Occasional users find that drums eliminate storage tank cleanup and reduce the likelihood of overextending the storage life of large quantities of resin.

Bulk storage of resin eliminates many problems associated with drums. With drums, a systematic approach to inventory, control, and disposal must be established in order to assure that resins are used before their storage life expires. Drums can collect at a rapid rate, and it may be difficult to dispose of them. Many landfills refuse to accept drums. Disposal of drums containing liquid residue may call for handling the drum as hazardous materials. Landfills will not accept drums containing liquids. Storage of both full and empty drums is also a problem. Considerable floor space is required for storing large quantities. A management system must be employed to insure that the contents of the oldest drums are used first. Use of drums normally implies a commitment of labor to materials handling. Drums must be transported from the delivery truck to the storage area, from the storage area to the point of use, and then from the point of use to the storage area.

Mini-Bulk Resin Storage

Fabricators can consider an approach to resin storage that offers some advantages over both the bulk and barrel strategies. Special containers which are large enough to supply several hundred gallons of resin, but small enough to be handled by a small forklift, form the heart of what are referred to as mini-bulk resin systems. These stainless steel containers are shipped to the user by truck and may be stored in one central location. Since the units can be stacked, floor space dedicated to resin storage is reduced by 37% or more. When new shipments of resin arrive, the empty containers are returned to the supplier. The tanks are steam cleaned and refilled for delivery.

The mini-bulk system offers a number of other positive features. Inventory, product control, and record keeping are easier to manage. Products can be tied directly to the resin batch used in their lay-up without resorting to extensive record keeping and drum labeling. There is no mixing of different batches from different barrels or mixing batches within a large bulk tank. There are no partially used barrels to dispose of or store. As with bulk storage, there is a need to use a materials distribution system to deliver resins to the work area. This resin distribution system typically consists of a closed loop plumbing system which is used to circulate resin to all areas of the facility. A circulation loop is required to prevent resin from solidifying in pipes. Resin is continually circulated and returned to the storage tank. This action helps keep the resin mixed and prevents settling and the build-up of gel. A low pressure
A pneumatic pump is ideal for resin delivery. A diagram of a typical approach to mini-bulk storage and delivery is included in Figure 7.

**FIGURE 7: MINI-BULK RESIN STORAGE AND DELIVERY**

A typical mini-bulk system consists of stainless steel tanks that measure 42 inches X 42 inches X 55 inches and have a capacity of 300 gallons. The resin tanks are supplied and shipped by a number of resin suppliers. Tanks are unloaded with a small forklift and stored in or near the main production area. One central resin supply loop and pump can be used to distribute resin to a number of outlets in the adjacent lay-up area. On a per pound basis resin prices are usually the same as for drum shipments. Other cost saving factors have emerged. Since less floor space is required, inside storage of resin is possible. This approach helps keep resins warm in winter and promotes faster and better curing. Time lost to handling resin drums has been greatly reduced, and production interruptions due to empty resin drums are eliminated. There are also fewer drums to dispose of and store. For small to medium sized operations, installation costs for the resin distribution system may be recovered in less than a year.

**Facility-Based Waste and Pollution Reduction Strategies**

Use of spray applicators or other wet delivery systems is common practice for composites fabricators. While these application devices yield high resin output, they also tend to produce excessive fogging, overspray, and bounceback of atomized solids and vapors. Factors other than spraying also contribute to pollutants entering the workplace. Even if resins are applied by processes not requiring spraying, the very nature of their chemical curing process will still produce considerable vapor and odor. There are always other environmental and physical dangers such as chemical spills involving resins, catalysts, or solvents. Because of the nature of these chemicals, there is always considerable risk of fire and explosion. Emissions in the form of airborne dust particles is also a potential problem since most products require post-molding grinding and finishing operations.

Many firms are producing open molded products in physical facilities that are poorly designed for the production techniques used. Fabricators often perform spray-up in large open structures. This approach normally results in contamination of air throughout the entire facility and necessitates rapid turnover of large volumes of plant air in order to reduce
airborne vapors and solids. Because of this turnover, expenses involved in heating make-up air are increased significantly. When incompatible activities are carried out in these open facilities, there is also considerable potential for cross contamination, such as dust in finishes or trash in the lay-up.

**Confining Applications**

Confining incompatible applications is not an uncommon practice in the industry. Localizing operations such as gel coat application or lamination spray delivery makes the placement of appropriate filtering systems less complicated. Where regulations, company policy, nuisance odor, or excessive exposure to chemical create problems for the fabricators, confining spray applications should merit considerable attention. Confining the high pollution outputs associated with these operations increases the efficiency of filtration or other treatment processes. Plant maintenance operations and housekeeping can also benefit from confining spray application to isolated booths or bays. Where application is carried out in the open plant environment, some undesirable output of resins in the form of heavy vapors and solids results. This contamination can affect air throughout the facility. In addition to creating potential respiratory problems and nuisance odors, the contamination causes a number of housekeeping problems. Potential fire problems result because heating, air conditioning, and air handling systems throughout the plant become coated with a build-up of solids. Walls and floors throughout the area also become coated with this build-up. Efforts, required to keep equipment and fixtures clean, increase where coating applications are not confined. A well designed application area can keep these contaminants out of the other plant areas. Such facilities can be easily equipped with disposable wall and floor coverings, filters to protect ventilation systems, treatment systems, and other features which help insure safety, reduce emissions, and simplify housekeeping chores.

**Air Filtration and Recirculation Systems**

Selective filtration of plant air should be given serious consideration by any fabricator who is pressured to reduce pollution output. Heavy vapors and solids can be removed from the plant exhaust flow. Even simple paper or fiberglass filters have some effect on the levels of nuisance odors entering the outside environment. Overspray and particulate build-up on plant air handling equipment is reduced along with the build-up of solids on nearby structures, equipment, cars, vegetation, and the ground. Where such external deposits are visible the production facilities will appear to be excessively dirty and high in pollution output. Even when a facility is equipped with simple, through the wall exhaust fan systems, filter units can be fabricated and installed to reduce emissions and prolong the life of air handling equipment.

Some firms are left with little choice about filtering plant exhaust. For a few high output facilities, emission cleanup is mandated by regulatory agencies. Where regulations are severe, elaborate filtration and purifications systems are required. For many operations dry filtration can be used to maintain local appearance as well as remove vapors, dust, and overspray. Water wash spray booths have also been successfully used to control emissions associated with spray application of industrial finishes. Manufacturers of spray application equipment frequently market conventional and “water wash spray booths.” The typical unit features a powerful exhaust system which pulls contaminated air through a mist or spray of water. Most filtration units are designed to provide a water wash by using pumps to spray water in the air passageway. Pumpless designs are also available. Special chemicals can be added to the water reservoir for the purpose of trapping contaminants. Chemicals added to the water can make contaminants settle to the bottom of a collection tank or float on the surface for collection.

Waterfall units appear to offer some advantages over conventional dry filtration units. Dry filters clog quickly during heavy spray-up application. This clogging lowers the surface velocity of air sweeping the work area and replacement of filters drives up maintenance costs. The air passages on waterfall units do not clog, and filtration capacity remains high unless
Water in the reservoir becomes overloaded with solids. Potential fire hazards are also reduced by the water wash system. Most local codes accept water wash spray booths as the best type of spray booth available. Units can be designed to fit the requirements of almost any production facility. Although use of these units for paint spray operations is widespread, there are a limited number of applications in composites production facilities.

**Fume Incineration**

High heat can be used to eliminate fumes and odors associated with styrene and other polymers. In situations where emissions associated with open molding processes are particularly high or severely restricted by regulation, incineration may prove to be a viable option. Incineration of styrene requires temperatures approaching 1,400°F. These high temperatures mean that any system developed for incineration must be carefully engineered to insure safety, a reasonable working life, and efficient use of energy.

Designs which provide only a gas fired heat chamber are relatively inexpensive to design and construct. Such designs however will require excessive use of fuel to heat all exhaust air in a relatively short period of time. Common afterburner units are designed to rapidly ignite and oxidize the volatile organic compounds (VOC) found in fumes. Efficiency of these units can be improved by adding a tube type "catalytic" converter to hold the VOC's at a high temperature for a longer period of time.

Another design concept features a number of ceramic filled recovery chambers connected to a central burn chamber, the plant exhaust duct, and a discharge stack. These connections are made through a complex manifold system which is connected to a modern computerized monitoring and control system. A simple diagram of a unit depicting the interaction of two recovery chambers with the burn chamber is shown in Figure 8. Each recovery chamber can alternate between being in the "inlet" or "outlet" mode.

When a chamber is in "inlet" mode, plant exhaust is fed over the heated ceramic material in the chamber and out into the burn chamber. As the VOC's leave the chamber, their temperatures are very close to the incineration temperature. Oxidation is completed in the central chamber. The burn chamber is equipped with a burner system in order to maintain a predetermined temperature. Some ignition of the volatiles will occur while they are passing through the ceramic materials in the recovery chamber. When the content of volatiles is high, this auto ignition may provide all of the heat required for recovery, and the burner system will go to the pilot mode.

Purified air is passed from the burn chamber through the ceramic bed in a chamber which is in the "outlet" mode. Heat from this air is absorbed by the ceramic material. As heat is withdrawn, the cooled air exits to an exhaust fan and discharge stack. Most units consist of a central burn chamber and up to seven recovery chambers. Once sufficient exhaust is passed through an "outlet" chamber, the ceramic bed becomes hot enough to allow the chamber to switch roles and become an "inlet" chamber. The units have to be brought up to temperature before the plant exhaust system can be placed in use.

Performance of the unit is electronically monitored and controlled through a system of sensors connected to a computer unit. In order to meet stringent environmental regulations, a permanent record of the unit's operation can be automatically entered on a paper time chart. All plant equipment can be tied to uninterrupted operation of the unit. If the unit is not operational, all resin application systems would automatically shut down. Units tend to have outstanding maintenance records and relatively low fuel consumption.
Conclusions

Cost efficient waste and pollution reduction programs can be established for fabricators of composites if a long term view toward managing resources is adopted. In many cases firms have implemented sound approaches, to waste reduction and management, which have provided profitable returns on the required investments. Efficient management of pollution and waste related problems requires careful examination of all available alternatives. Management must look beyond simple one step solutions that often simply sidestep or delay dealing with the problems at hand. Consideration must be given to selecting approaches which interact with all areas including basic production approaches, facility design, and management strategies. Profitable reduction approaches are best developed when careful attention is paid to refining material flow patterns, conserving materials, conserving utilities, separating incompatible operations, elimination of liabilities, and inventory control. A number of the most desirable approaches to pollution and waste reduction strategies are listed in Table 4.

- Use of Alternative Materials With Fewer Environmental and Safety Concerns
- Establishment of Responsible Management and Control Systems
- Reduce the Quantity of Potentially Hazardous Material Used
- Refine Production Process and Facilities
  - Minimize Worker Exposure
  - Reduce Inside and Outside Emissions
  - Reduce Waste Generation
  - Improve Production and Quality

TABLE 4: DESIRABLE APPROACHES TO POLLUTION AND WASTE REDUCTION