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Project Summary

Status, Trends and Implications of Carbon Fiber Material Use

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This study estimates the future usage of carbon fiber composite materials in both consumer and industrial products, and the resultant economic impact of the disposal of these products and industrial scrap in both the municipal and industrial waste streams. The technical and economic substitutability of carbon fiber composite materials for materials now in use is analyzed, and the major uses of this material forecasted. Potential problems relating to the disposal of products containing carbon fiber materials are analyzed, and estimates are made of the economic impacts of the disposal of these products for alternative scenarios that cover a wide range of disposal technologies. The economic impact of the disposal of products and industrial scrap containing carbon fiber composite materials is found to be small for all of the scenarios investigated.

This Project Summary was developed by EPA's Industrial Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Carbon fiber is produced by subjecting polyacrylonitrile or petroleum pitch fibers to high temperature and pressure. The resultant fibers have a graphitic molecular structure which makes them high in tensile strength, light in weight, and resistant to corrosion. Fibers are also good electrical conductors and do not readily oxidize except at high temperatures. Carbon fiber composite materials are made by binding the fibers in a thermosetting or thermoplastic resin matrix. Currently, composites are predominately used in the transportation sector (e.g. for aircraft parts). They are also used for the construction of prostheses and other consumer goods such as golf clubs and tennis racquets. Because of some of the carbon fibers, properties of their release into the atmosphere could result in unfavorable environmental impacts. The objective of this study was to determine whether the disposal of consumer goods or industrial products containing carbon fiber reinforced plastics ("carbon fiber composite materials") would result in environmental impacts of economic consequence.

This study investigated the economic and technical incentives for the use of carbon fiber materials, projecting demand to 1990. It identified the life cycle of different categories of carbon fiber products and determined the disposal paths for each. Since the useful lives of these products range from five to 10 years for sports equipment to 20 or more years for aerospace items, most of the carbon fiber produced in 1990 will not enter the waste stream until the early 2000s. It can therefore be assumed that the carbon fiber disposal rate will be equal to or less than the 1990 production rate for 10 to 15 years after 1990. This period is referred to in the report as "post-1990." The study projected the annual economic impact of carbon fibers released from waste disposal during this time.

For the purpose of this study, carbon fiber refuse was aggregated into two groups: that which entered municipal waste streams and that which was disposed of in industrial waste streams. Points of release to the environment were identified and estimates were made of annual fiber release rates for each of the waste streams. With the use of previously published risk assessments which determined the impacts of carbon fibers in the environment as a function of fiber release, estimates were made of the cost (in dollars) arising during the disposal of carbon fiber composites.

Because carbon fibers are good electrical conductors and are very light weight, they may be dispersed over a large area and could damage electrical equipment. The study therefore focused the cost analysis on electrical failures arising from carbon fibers released during disposal.

Only the impacts of incinerating carbon fiber composite material were addressed. Those associated with incinerating raw carbon fiber or preimpregnated carbon fiber materials were not analyzed, because manufacturers were found to be aware of potential hazards associated with incinerating these materials and to use other disposal techniques. Also, because of the high cost of carbon fiber, steps have been taken to minimize the amount of scrap from these materials.

Health hazards from carbon fiber release were not considered in this study because the extant health effects data when the study was performed were insufficient for the derivation of risk functions.

The results of this report are based on calculations which use a number of engineering estimates. Besides projections of future demand for carbon fiber composite materials, estimates were made of scrap disposal pathways, incinerator release rates, pollution control equipment efficiencies, and electrical damage functions. Conservatively high estimates of carbon fiber use, and fiber release rates were used to indicate an upper limit to potential impacts. Ten disposal scenarios were considered to account for varying percentages of composite scrap recycled, landfilled, or incinerated.

Findings and Conclusions

Future Composite Use

There are many current and potential applications for carbon fiber composites in both consumer and industrial sectors. The extent to which composites will be substituted for conventional structural materials will be determined by their cost effectiveness, which varies from application to application. Composites will be used in consumer goods when the buyer is willing to pay the extra cost (often twice the current price of alternative materials) for durability and light weight. In the transportation sector, composites will be used because they are corrosion resistant and because their high strength-to-weight and stiffness-to-weight ratios can result in fuel savings.

Table 1 shows projected carbon fiber demand for various industrial sectors to 1990. It can be seen that in the near-term, the aerospace industry will be the principal user of composites, while towards the end of the 1980s, demand in the automobile industry is expected to increase substantially. Demand for fibers in sporting goods and for miscellaneous applications is not expected to grow as rapidly.

Three principal benefits result from using carbon fiber in the transportation sector. First, production costs are reduced because of design simplification. Secondly, carbon fiber composites have a longer life in many applications and therefore reduce maintenance costs. Thirdly and most importantly, carbon fiber use saves fuel. If graphite springs are used for double-axle trucks, it is estimated that body weight would be reduced by 272 pounds, resulting in pre-tax profits in the range of $100 to $800 per truck. If graphite sidewalls, partitions, ceiling and stowage bins are used in a fleet of 1,383 three-engine Boeing 767s, it is estimated that $60 million would be saved from reduced fuel consumption during the lifetime of the fleet. (Note that the carbon fiber used in this fleet is 2 percent of the total estimated industrial fiber use in 1990; the use of carbon fiber in other transportation vehicles should further increase fuel savings.)

Disposal of Composite Materials

Carbon fiber entering the municipa waste stream is expected to be compose primarily of discarded consumer products (In this study, automobile disposal i considered under industrial waste streams. Most sports equipment manufacturer produce little composite scrap (in the 1 t 5 percent range), because composit costs are high and manufacturers attemp to minimize waste by designing efficient and by turning scrap into marketabl items. The same appears to be true fo manufacturers of other consumer goods Therefore, the contribution from consumer goods manufacturers to municipa waste is essentially negligible. Approximately 500 kg of carbon fiber composit enter the municipal waste stream annually from the disposal of consumer goods

Industrial scrappage, used industria products, and oversized consumer products enter the industrial waste stream The quantity of fiber consumed (and thu disposed of) throughout the industria sector is much larger than that used i consumer goods. Nine percent of th carbon fiber produced in 1980 was fabrication scrap and thus entered the industrial waste stream immediately, while 6 percent was used in industrial products The remainder went to consumer goods Thus about 73 percent of the fiber produced will eventually enter the industria solid waste stream. It is estimated tha approximately 82 percent of the carbo fiber produced in 1990 (about 720 tonnes) will eventually enter the industrial refuse stream.

Waste Disposal Paths

The method of disposal of municipal and industrial waste is an importan determinant of the likelihood that fibe will be released and thus that the environment will be affected. As of 1980 th

Table 1. *U.S. Carbon Fiber Demand Projections Through 1990, 1000 Kilograms (1000 Pounds)*[a]

Demand Sector	*Year 1980*	*1983*	*1985*	*1990*
Aerospace	*182 (400)*	*591 (1300)*	*1000 (2200)*	*2273 (5000)*
Sporting Goods	*141 (310)*	*227 (500)*	*318 (700)*	*591 (1300)*
Automobile	*6 (14)*	*45 (100)*	*91 (200)*	*4545 (10000*
Other Industries	*87 (192)*	*159 (350)*	*227 (500)*	*409 (900)*
Totals	*416 (916)*	*1022 (2250)*	*1636 (3600)*	*7818 (17200*

[a]*Source: Composite Market Reports, Inc., "Annual Market Estimate for Graphite, Prepreg an Fiber, 1979 through 1985," (1980), and personal communications.*

disposition of municipal waste was as follows:

- 89 percent landfill
- 4 percent incinerated without recovery
- 1 percent incinerated for energy recovery
- 6 percent source separation

Many pressures, including increases in energy costs, shortages in land available for landfill, and environmental concerns favor changing this mix in the future. These pressures were accounted for when environmental impacts were projected in terms of several different scenarios for future municipal waste disposal.

The manufacturers of fiber tend to recycle, reuse or otherwise limit the amount of scrap produced. Many recycle the carbon fiber scrap by chopping it up. When disposal is necessary, some type of container is used to segregate the fiber from other industrial wastes. Subsequently, the containers are usually placed in landfills, although they are occasionally stored. It was estimated that only 0.5 percent of the carbon fiber used by industry now enters the industrial waste stream. Future incineration trends are reflected in five industrial waste disposal scenarios in the full report.

Most carbon manufacturers and pre-impregnators are conscientious in advising their customers about handling carbon fiber material. Some attach labels stating acceptable disposal procedures, whereas others recommend recycling.

In general, the aerospace industry takes appropriate precautions when disposing of carbon fiber scrap. The firms are knowledgeable about the properties of carbon fiber and composites. Many aerospace firms generate a substantial amount of scrap but have not instituted recycling programs. Most scrap is segregated and landfilled. Some companies cure their scrap into blocks, whereas others put the scrap into 55 gallon drums.

The amount of scrap produced by the remaining users of carbon fiber is small. Many of these companies are in the research and development stage and use very little carbon fiber. Companies already producing carbon fiber generally landfill the scrap.

Industrially used products containing carbon fiber range from loom shuttles to both structural and non-structural parts of commercial aircraft. Disposal of these products varies, depending on the application. Because of the tight manifest control system maintained for all military and commercial airplane parts in this country, disposal is generally through landfilling, not incineration. Automobiles are scrapped and non-recyclable parts such as those made of carbon fiber are landfilled. In the future, approximately 10 percent of the carbon fiber used in automobiles may reach the municipal waste stream after being discarded by repair shops, specialty body shops, and the like. Carbon fiber products used in non-transportation industries will be discarded with other industrial waste.

Release Mechanisms and Cost Impacts

Carbon fibers are released during disposal principally from incinerators. Because carbon fibers are oxidized only at high temperatures (above 1000°C), the composite matrix (e.g., a thermoset resin) is rapidly destroyed during combustion and fibers may be entrained in combustion gases and emitted from the stack of the incinerator

Two other potential fiber release mechanisms were shown to be insignificant. One was from fires in landfills and the other was due to explosions in waste shredding operations. A third release mechanism, particulate emissions from waste shredding operations, is being investigated further by the U.S. EPA.

Estimated fiber release rates from municipal mass-fired incinerators with various pollution control and waste heat recovery equipment are shown in Table 2. The fiber release rate from incinerators is affected by the type of incinerator, pollution control equipment, and waste heat recovery equipment employed. The release rates were calculated assuming a conservatively high upper bound to the *uncontrolled* fiber release of 4 percent (i.e. 4 kg of fibers released per 100 kg of composite incinerated).

The estimated annual average economic impact arising from the disposal of carbon fiber in municipal waste streams is very small, as shown in Table 3. The upper bound case—Scenario 5—assumes that all municipal waste would be incinerated, requiring over 900 new, large incinerators. This incineration rate is unlikely in the 1990s.

Table 2. *Fiber Release Rates for Municipal Incinerators with Various Forms of Particulate Control*

Particle Control System	Stack Release of Free Fibers (%)
No Active System (Cyclone)	3.6
Bag House	0.04
Wet Scrubber	1.2
Electrostatic Precipitator (ESP)	0.8
Heat Recovery and ESP	0.24

Industrial incineration will take place predominately in multi-chamber and starved-air units, with lesser use of fluidized bed, multi-hearth, rotary kiln and single chamber incinerators. Release rates for both multi-chamber and starved-air units were estimated to be 0.12 percent and 0.36 percent, with and without waste heat recovery units.

A much larger volume of composite material may enter the waste stream at a manufacturing plant or may be discarded as part of the transportation equipment waste stream. Table 4 shows the economic impacts obtained from the five scenarios for type and volume of industrial waste disposal. The most likely upper bound to fiber release is represented by Scenario D, in which 10 percent of the composite material in automobiles is incinerated along with all industrial waste from non-aerospace industries. This scenario also reflects the incinerator mix likely to be used by industry in the 1990s and shows a very small economic impact from carbon fiber disposal.

Table 3. *Comparison of Scenarios Considered for Composite Disposal in Municipal Sector*

Scenario	Total Number of Incinerators	Percent of Refuse Burned	Carbon Fiber Burned (Kg/Day)	Annual Cost
1. Baseline Case	41	4	80	$ 1,693
2. Near Future Case	51	5	100	$ 1,828
3. Far Future Case	39	8	160	$ 1,197
4. Intensive Energy Recovery Case	487	60	1,200	$ 6,795
5. Upper Bound Case	989	100	2,000	$27,306

To determine an *extreme* upper bound to economic impacts of carbon fiber disposal in the industrial waste stream, it was assumed in Scenario E that all carbon fiber used in industry was incinerated and that incineration occurred using the least efficient incinerators considered in this study (i.e. municipal incinerators with no active controls). The resultant annual cost of approximately two million dollars is still low compared to benefits of carbon fiber (e.g. fuel savings). In any case, it is highly unlikely that all carbon fiber composite used in industry will be disposed of through incineration or that incinerators with such high emission rates will be used.

Table 4. *Comparison of Scenarios in Industrial Sector*

	Scenarios	*Disposal Practices*	*Incinerator Population*	*Particulate Control*	*Cost Pe[r] Year ($)*
A	*Baseline Case*	*Current*[a]	*Current*	*None*	*5,250*
B	*Future Trend Case*	*Current*	*No Single Chamber*	*With Heat Recovery (+Wet Scrubbers)*	*466*
C	*Current Upper Bound*	*Aerospace Scrap Landfilled 10% Automobile +100% All Other Industrial Waste Incinerated*	*Current*	*None*	*131,351*
D	*Future Upper Bound*	*Aerospace Scrap Landfilled 10% Automobile +100% All Other Industrial Waste Incinerated*	*No Single Chamber*	*With Heat Recovery (+Wet Scrubbers)*	*11,660*
E	*Worst Possible Case*	*All Industrial Waste Incinerated*	*Least Efficient Type (Municipal)*	*None*	*1,907,999*

[a]*As of 1980.*

This Project Summary was prepared by staff of Econ, Inc., Princeton, NJ 08540; the EPA author ***Benjamin L. Blaney*** *(also the EPA Project Officer, see below) is with the Industrial Environmental Research Laboratory, Cincinnati, OH 45268.*

The complete report, entitled "Status, Trends and Implications of Carbon Fiber Material Use," (Order No. PB 83-147 751; Cost: $16.00, subject to change) will be available only from:

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