Carbon Reduction Potential from Recycling in Primary Materials Manufacturing

R. Neal Elliott, PhD., P.E.

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© American Council for an Energy-Efficient Economy
1001 Connecticut Avenue NW, Suite 801, Washington, DC 20036
2140 Shattuck Ave, Suite 202, Berkeley, CA 94704

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Summary

One strategy for reducing the carbon emissions from U.S. industry is to increase the use of recycled feedstocks in primary materials manufacturing. The use of recycled feedstocks can reduce the energy required to produce the materials by as much as 95 percent in the case of aluminum. The American Council for an Energy-Efficient Economy (ACE^3) has estimated that if the average, overall recycled content of container glass, steel, aluminum and paper were each increased by about 10 percentage points, annual carbon emissions could be reduced about five million metric tons in the year 2000 through reduced process energy requirements. More aggressive targets for these products alone could produce reductions of roughly 13 million metric tons per year by 2010. The aluminum industry presents most of the potential for reducing carbon emissions trough greater materials recycling.

The energy savings are also significant. In 2000 the energy savings from increased use of recycled feed stocks could exceed 400 trillion Btus with annual savings increasing to 1.25 Quads in 2010.

The major barriers to achieving these goals are not technical, since some facilities are already operating at the suggested or higher levels of recycled content. Rather, it is the availability of quality, recycled materials that presents the greatest barrier to these energy savings and reduced emissions. Much of the effort on recycling has focused on attempting to reclaim the highest fraction of the waste stream. Unfortunately, less effort has focused on how to produce recycled feedstocks that meet the needs of the consuming manufacturers. This state can be viewed as the difference between a "market push" and a "market pull" perspective. The result of existing practice is the production of large volumes of recycled feed stock that do not meet market needs as is now being seen in Germany and in some U.S. cities (Porter, 1993 and Protzman, 1993) while some manufacturer have under-utilized capacity for the use of recycled feedstocks (Lewis, et al., 1993). It is necessary to strike a compromise between reducing the waste stream and producing the high-quality feedstocks required by manufacturers to achieve the greatest benefit to society.

Introduction

Manufacturing involves the transformation of feedstocks into intermediate materials from which we fabricate both the products we consume and the products that package these goods. Each step in the manufacturing process requires energy. Once this energy has been expended in the manufacturing process, the resulting product has its value enhanced by the transformation. When we transform a feedstock like ore into a material like a metal, we have permanently transformed the material. Once the final product has served its useful life, the original energy investment remains in the material. If the product is discarded the value of the energy is lost. Some of that energy investment may be recovered however, if that product is recycled. Use of recycled feedstocks the reduces demand for raw materials which may be imported or in limited supply. In the case of plastics, recycling lowers the use of oil, which on the margin is imported as a feedstock for production (EIA, 1994). Use of recycled feedstocks also directly benefits the environment by reducing the production of virgin feedstocks.

Table I
Energy Consumption in Primary Materials Manufacturing Industries

SIC	Industry	Total Net[1] Energy TBtu	Fraction of Manufacturing Energy
	U.S. Manufacturing Total	15,046	
3221	Container Glass	85	1%
26	Paper	2,472	16%
3312	Steel	1,569	10%
3334	Aluminum	252	2%
2821	Plastics	288	2%
	5 Primary Materials Industries	4,666	31%

[1] net energy represents the end-use consumption by the facility
Source: EIA, 1993

The five materials manufacturing industries investigated in this report account for about one-third of the energy consumed in all manufacturing (**Table I**) (EIA, 1993). All these materials can be reprocessed into feedstocks that can be used to produce more of these primary materials. Alternately, some materials may be put to other uses such as feedstocks for other products, or burned as fuels to produce energy. While any recycling of a product will produce some value (even if it is avoiding the costs of disposal), it is best to choose the use that produces the highest value (i.e., recovers the greatest value of resources). Unfortunately, landfills remain our most common disposal method (Goldman and Greenfield, 1990) and many of the products we consume are not recycled and therefore become a costly waste problem.

Reuse of a product in its final form is the most energy-efficient form of recycling. For example, the energy required to reuse a product like a bottle is near zero (Steinmeyer, 1992). This implies that the first step should be to develop manufactured products that are durable and can be reused. PepsiCo Inc. for example has introduced a soft-drink bottle in Hungary made from polyethylene terepthalate (PET) which is both reusable and recyclable. The returnable bottles can be cleaned and refilled up to 25 time before they are recycled into new bottles (Beck, 1993). If reuse is not feasible, the next best use of the material is to produce more of the same product from the recycled material. For example, 40 million Btus are required to produce a ton of paper from virgin materials while 27 million Btus are require to produce a ton from recycled feedstocks. Thus it is possible to recapture about one-third (13 million Btus) of the initial production energy (Energetics, 1990c). The paper has a fuel value of about 16 million Btus per ton, which if used to generate steam would yield about 13 million Btus of usable energy. While these uses may seem of equal energy value, the fuel value of the paper will be preserved when it is used to produce more paper, which can be done several times. Thus we can recapture the embedded energy cost several times before we use it as a fuel. Similar examples can be made between reusing plastics and burning them for fuel. Likewise glass can be used to produce more glass or as an aggregate in pavement production.

Potential for Recycling in Five Primary Materials Manufacturing

The glass, steel, aluminum, paper and plastics industries currently offer significant opportunities for replacing virgin feedstocks with recycled feedstocks. Recycled feedstocks are already in use to some degree in all these industries (**Table II**) (Lewis, 1993 and IRT, 1994). While the markets and industries that produce these materials are different, some common trends in the use of recycled feedstocks exist. Small-scale production facilities based wholly or largely on recycled feedstocks are emerging as an economical and highly competitive alternative to large-scale production based on virgin feedstocks. The emergence of minimills in the steel industry, the oldest of the secondary markets, may prove a predictor for market trends in other primary-materials industries. New minimill companies are already entering the aluminum and paper markets, locating close to the source of the recycled feedstocks to reduce transportation costs (Kansas, 1994 and Charlier, 1993).

Table II
Description of Primary Materials Manufacturing Industries

Industry	Recycled Content			1991 Production (million tons)	Average Energy Intensity (MBTU/ton)	Energy Savings/ Recycled Content[8]	Projected Production Growth Relative to 1991 Output	
	1991 National Average	SOTA	Max				2000	2010
Container Glass	31%	78%	90%	11.2	15.6	0.25	108%	120%
Steel	50%	100%	100%	97.9	22.7	0.17	132%	150%
Aluminum	31%	100%	100%	8.8	234.0	0.95	108%	120%
Paper	20%	100%	100%	100.0	40.3	0.33	125%	160%
Plastics	2%	50%	NA	23.3	31.0	0.30	170%	275%

Source: Commerce (1992), CMA (1992), DOE (1991), IRT (1994), Lewis and Morris (1993) and Steinmeyer (1993).

Glass

Of the 18 million tons of glass manufactured in 1991 in the U.S., the greatest potential for recycling is the 62 percent used for making containers (Commerce, 1991). The remainder, which is glass fiber and plate glass, has limited potential for recycling due to technical considerations such as contamination and variable composition. Of course, product reuse, which requires very little reprocessing energy, will yield the most energy savings. Glass can be recycled indefinitely and the reprocessing process can remove many of the contaminates like food residues and labels frequently found in the feedstocks. This makes glass recycling very relatively easy and cost effective (Anon., 1994).

In 1992, 31 percent of the container glass manufacturing feedstock was recycled cullet (glass scrap) (Lewis and Morris, 1993). At the best mills, 78 percent of the feedstock for green and brown glass is scrap. The recycled content of clear glass is lower because current recycling practices cannot produce high volumes of cullet with the purity required for quality product. The technical potential (or maximum practical recycled content) with improved recycling practices could approach 90 percent (Lewis, et al., 1993). At some of the best mills, the recycled content is being limited by the availability of high-quality cullet (Lewis and Morris, 1993).

Depending upon the glass plant, the energy required to produce container glass varies from 15 to 27 MBTU per ton. The source of energy used in the container glass industry is almost equally divided between natural gas and electricity, with the remaining 2 percent coming from oil (**Table III**) (Energetics, 1990a). Each percent increase in the recycled content will result in a 0.25 percent reduction in energy consumption in processing (Anon., 1992b).

Table III
Fuel Mix by Industry

SIC	Industry	Natural Gas	Petroleum		Coal	Wastes	Electric
			Residual	Distillate			
3221	Container Glass	52.4%	1.4%	0.3%	8.3%	19.8%	17.4%
3312	Steel	25.4%	2.0%	0.3%	35.7%	28.0%	8.3%
3334	Aluminum	8.3%	0.0%	0.4%	0.0%	0.4%	91.3%
26	Paper	22.2%	6.3%	0.4%	11.8%	50.4%	8.1%
2821	Plastics	52.4%	1.4%	0.3%	8.3%	19.8%	17.4%

Source: EIA, 1993.

Market changes to other forms of packaging have slowed the growth of container glass output to about one percent per year. For purposes of this analysis, this growth rate has been projected out through the year 2010.

Post-consumer recovery of recyclable materials in the ten states with bottle bills has run 75-90 percent, and these states account for the majority of the glass recycling nationwide. In other states, the recycling levels are closer to 10 percent (Lewis, 1993). Increased national recycling levels will set the stage for energy savings and emissions reductions in container glass manufacturing.

Steel

The steel industry can be divided into three categories: integrated steel production from iron ore; secondary production from scrap; and specialty steels. About two-thirds of domestic steel content is currently produced from recycled feedstocks (Anon., 1991). Recycled content varies by type of mill. Minimills like Nucor and Florida Steel operate on 100 percent scrap while integrated mills can use up to 50 percent scrap. The two type of mills use different processes, however. Minimills process scrap in electric-arc furnaces while the integrated mills employ basic-oxygen furnaces (Lewis and Morris, 1993). The minimill companies have taken share away from the older integrated steel companies in certain markets. For example, minimill operator Nucor is anticipated to take 15 percent of the flat rolled market by 2000 (Commerce, 1993). The presence of some contaminants such as copper and tin in recycled feedstocks reduces the strength of steel, thereby restricting steel produced from scrap to lower-valued products like rebar and light structural shapes (Ross, 1993). Recently some minimills have entered higher-value markets for products like wire rod, thin sheet and heavy structural shapes by careful feedstock selection and production operation (Wakesberg, 1991 and Nucor, 1991). In 1993, Nucor extended its penetration into the flat-rolled market by opening a thin slab caster mill. However, more than half of the steel market remains beyond the minimills capability due to product characteristics such as high strength and fine grain structure for some applications (Commerce, 1994).

Excluding energy losses in electrical generation and transmission, minimills use one-fourth of the net energy to produce a ton of steel from scrap that a conventional integrated mill requires to produce a ton from iron ore and coke. While the last 15 years have see an increase in the fraction of production coming from minimills because of their lower operating costs, integrated steelmaking is starting to recover with the construction of new, state-of-the-art integrated mills (Energetics, 1990b). Increased scrap prices and the relatively new, integrated mill base with its high utilization of conventional steel production capacity have decreased the price advantages that the minimills have benefitted from over the last fifteen years (Commerce, 1994).

Aluminum

7.3 million tons of aluminum was produced in the United States in 1991 of which 63 percent was produced by primary smelting and 37 percent from secondary recovery (Aluminum Association, 1993). 57 percent of the secondary production came from post-consumer scrap (Aluminum Extruders Association, 1992). Some mills are currently capable of using nearly 100 percent recycled stock though feedstock availability is a limiting factor (Anon., 1992a). Recycled stock requires only 5 percent of the energy required by primary processing, so each percent increase in recycled content results in a 0.95 percent reduction in energy consumption (Aluminum Extruders Association, 1992).

The largest share of U.S. aluminum production in 1991 went to containers and packaging (29 percent), with 16 percent going to transportation equipment and 14 percent to building and construction uses (Aluminum Association, 1993). While overall recycled content averages 31 percent, the recycled content varies by product with some products like foil having almost no recycled content. Beverage cans have the highest recycled content (56 percent) as well as the highest post-consumer recovery rate at a 62 percent level (Lewis and Morris, 1993). ACX's new Golden Aluminum Company minimill (a division of the Coors Company) is able to produce sheet for cans from 95 percent recycled feedstocks. Unfortunately Golden and other new minimill companies enter a glutted world market in which virgin ingots can be imported at less cost than any domestic production. This has introduced uncertainty into domestic production, with all manufacturers reducing capacity (Charlier, 1993 and Commerce, 1994).

Plastics

Plastics represent a group of materials of which 46 different types are in common use. In many cases a product may actually be made from several different plastic materials. Plastics are a rapidly growing product area. For example, the two liter plastic beverage bottle, introduced in 1977, had captured 22 percent of the soft drink volume by 1987 (Pollock, 1987). The U.S. Commerce Department projects a 6 percent annual growth rate for plastic materials. Currently much of these materials are used in packaging applications, although they are beginning to displace other materials such as glass, metals and paper in various other applications such as transportation equipment and construction materials (Commerce, 1994).

In 1991, industry-wide average recycled content level was about 2 percent. Though problems have been encountered with some high-profile plastics recycling efforts, the number of facilities and the quantity of plastics reprocessed has been increasing rapidly. In 1992, 103 facilities processed about 950 million pounds of six types of plastics. By 1993 the number of plants increased to 1,112 and quantity increased 25 percent to 1.2 billion pounds. Of the six types of plastics commonly recycled, rates for PET are highest at almost 24 percent (**Table IV**) (IRT, 1994).

The technical potential for using recycled feedstocks varies with the type of plastic and well as its application. Some applications like multi-layer, squeezable catsup bottles prevent easy recycling. However, the industry feels that it can increase the average recycled content if the infrastructure is created to make the recycled feedstocks available (Steinmeyer, 1993). Recycled feedstocks can be used to produce a wide range of products. Wellman Inc. of Shrewsbury, NJ recycles PET (largely from plastic soda bottles) into polyester and nylon fibers and plastic resins for other applications. A number of companies, including outdoor outfitter Patagonia, are now marketing apparel made from these fibers (Hamilton, 1994). Recycled plastic resins are also showing up in building materials including: framing lumber, sheathing, shingles, insulation, ceiling tiles and trim (Forest Service, 1994).

Table IV
U.S. Plastics Production and Recycling Levels, 1992

Plastic Types	Total Sales (Mill. lb)	Fraction Total Sales	Total Recycled (Mill. lb)	Fraction of Sales Recycled
#1: PET	1,937	4.5 %	460.5	23.8 %
#2: HDPE	8,840	20.5 %	443.9	5.0 %
#3: PVC	8,630	20.0 %	20.6	0.2 %
#4: LDPE/LLDPE	11,288	26.2 %	75.6	0.7 %
#5: PP	7,519	17.4 %	222.4	3.0 %
#6 PS/HIPS	4,896	11.4 %	37.3	0.8 %
Totals	43,110	100 %	1,260.3	2.9 %

Source: IRT, 1994

With an aggressive effort and changes in product design, we suggest a goal of 25 percent recycled content by 2000 and 50 percent by 2010. Each percent increase in recycled content would result in a 0.3 percent reduction in processing energy (Steinmeyer, 1993).

Paper

In 1991, the paper industry produced 100 million tons of paper. Approximately one-fifth of this was produced from recycled feedstocks (Lewis and Morris, 1993). Paper is the third largest manufacturing energy consumer, however 56 percent of its energy in 1992-93 was self-generated from its own waste products. Paper is considered a mature industry with competition from plastics having slowed paper's growth. However paper's ease of recyclability should keep growth steady into the next century. The Department of Commerce projects annual growth in excess of two percent (Commerce, 1994).

Based on an analysis of the energy in each step of the papermaking process (Energetics, 1990c), ACEEE estimates that producing paper from recycled feedstock requires about 33 percent less energy than production from virgin materials. Most of this saving comes from initial feedstock preparation and delignification steps that are avoided when using a recycled feedstock. However the elimination of these steps also eliminates the waste stream generated in these steps that is used a fuel source, requiring the use of other fuels.

Many paper mills can use some recycled feedstocks when the product specifications allow. In many of these mills, the recycled feedstocks come from waste paper produced within the mill (e.g., ends and trimmings) rather than from post consumer sources.

As with steel and aluminum, minimills operating entirely on recycled feedstocks are also a new trend in the paper industry. These facilities are now being located in urban areas, frequently sited adjacent to waste-to-energy facilities to provide a source of electrical and energy. The development of zero-discharge water systems for paper mills has helped make urban siting feasible. These minimills have been initially targeted at producing corrugated paper for boxes. The reduced transportation costs offered by urban siting improves the economic attractiveness of the facility. New firms such as Beloit Corp., Ogden Products and Sithe Energies are taking the lead in this sector of the paper industry, competing with the established industry leaders for market share (Kansas, 1994).

Limits and Barriers to Increased Recycled Content

It is unrealistic to assume that an industry could ever move its overall recycled content to the state-of-the-art levels, much less to the technical potential. The barriers are infrastructural, technical and market-related. The infrastructure is not currently in place to deliver the volume and quality of recycled feedstocks to aggressively expand recycled content. Many state-of-the-art facilities are not producing at their maximum recycled content because of the limited availability of quality feedstock (M. Lewis, et. al., 1993). Many current post-consumer, recycling programs do not produce feedstocks of a purity required for inclusion in a wide range of products. In the case of steel, for example, the presence of tin and copper in the scrap restricts its use to the production of lower quality steel, since these contaminants cannot be cost-effectively removed and their presence adversely affects the strength of the final product. The presence of one polyvinyl chloride (PVC) plastic bottle can ruin an entire batch of PET resin, because the PVC decomposes at the melting temperature of the PET (Anon., 1994). The market for products produced from lower-quality, recycled feedstocks is limited, so the potential for increasing the use of lower-quality, recycled feedstocks is likewise limited. A number of municipal recycling programs such as the Seattle, Washington program are encountering this type of problem (Richards, 1993). If recycling programs produced a higher level of purity in their recycled streams, the potential would then exist for their inclusion in the manufacture of a wider range of products (Ross, 1993).

Beyond the problems with contamination, there are other technical and economic barriers to the expanded use of recycled feedstocks. Some products, including clear glass and some types of paper, must contain a minimum level of virgin feedstock to meet performance specifications. While aluminum, steel and glass can be reprocessed indefinitely, plastic and paper can only be reprocessed a finite number of times until they degrade to the point that they are unusable (Anon., 1994). In other cases, like some chemical processes, paper making and some plastic resin manufacturing, some of the virgin feedstock goes to produce process energy, which can be more cost effective than purchasing other energy sources.

The marketplace also erects barriers to increased recycled content. The products that the marketplace demands often restrict their recycled content. Consumer preferences can be changed, as we have seen with paper, to actually demand higher recycled content. Another example is the latest volley in the "sneaker wars" in which Reebok and Nike are battling over who can produce a basketball shoe with the highest recycled content (Schrage, 1993). But some products that consumers desire restrict the ability of these products to be recycled. For example, certain paper products like gloss stock, have clays introduced into them to produce the finish. These additives become contaminants when the product enters the recycling stream. Likewise some new multi-layer plastic products have restricted potential for recyclability.

Though significant barriers do exist to increasing overall recycled content, changes to recycling practices and market demands can overcome these barriers. With the existing product mix and anticipated improvements in recycling programs, it is realistic to assume that market-wide recycled content could be increased 10 percentage points by the year 2000. The plastics industry feels that they could achieve an even more aggressive target of 50 percent by 2010 (Steinmeyer, 1993). Reasonable recycled content targets for 2000 and 2010 are presented in **Table V** based on state-of-the-art, market and technical considerations. The low targets are based on voluntary programs to encourage improvements in the recycling infrastructure, product design and manufacture. The high targets would involve the imposition of prescriptive measures such as "bottle bills" and source separation mandates which would produce larger volumes of higher-grade feedstocks. Such requirements have already been adopted by many states and communities, so wider adoption is not considered unduly onerous.

Table V
Recycled Content Targets for Selected Primary Manufactured Products

Industry	**Recycled Content**				
	1991 National Average	Target 2000		Target 2010	
		Low	High	Low	High
Container Glass	31%	37%	41%	45%	60%
Steel	60%	60%	65%	65%	70%
Aluminum	31%	37%	41%	45%	50%
Paper	20%	25%	30%	33%	50%
Plastics	2%	5%	20%	15%	35%

Source: IRT, 1994, Lewis, 1993 and Steinmeyer, 1993.

Energy Savings and Carbon Emissions Reduction Potential

Increased recycled feedstock use offers an opportunity for significant energy savings and carbon emissions reductions. If the proposed targets for recycled content were met, we estimate potential annual energy savings (using the methodology discussed in the appendix) of 430 TBtu by 2000 and 1265 TBTu by 2010. For these estimates, we include energy losses in electricity generation and transmission (i.e., we estimate the potential for primary energy savings). Based on the reported fuel mix for each industry (EIA, 1993), a prorated carbon coefficient was calculated for each of the five industries. The energy savings and carbon coefficients were then used to estimate the potential carbon emissions savings for each case. These calculations take into account the shift in fuel mix that results when production shifts to greater recycled material content. The results are presented in **Table V**. In the case of steel and paper, the increase in the recycled content would result in a change in the fuel mix for the industry (as described in the appendix) which will increase the carbon emissions. In steel manufacturing, the shift from coal to electricity raises the industry's carbon coefficient increasing net carbon emissions even though there is a slight improvement in energy efficiency. As explained in the appendix, we assume that the electricity used by the steel industry is based on the 1991 national average fuel mix for electricity production.

The impact of increased recycled content on fuel mix in paper is more complex. When paper is manufactured from recycled stock, the waste products used as fuel in virgin paper manufacturing are no longer produced and must be replaced with other fuels. What fuels are used will determine the resulting carbon coefficient for the industry. Some facilities like the Jackson Paper company in Silva, NC use wood waste from the wood products industry (Jahn, 1986), while some urban mini-mills are being sited next to waste-to-energy facilities to provide some of their energy (Kansas, 1994). If over a third of this additional energy comes from waste sources, the carbon emissions will decrease with increased recycled content as is discussed in the appendix.

The energy savings shown in **Table VI** represent the savings within the manufacturing process, but do not account for the energy required to collect, process and transport the recycled feedstock. The emissions from these steps would likely reduce the savings. Likewise the analysis does not include the energy savings that would be realized from reduced production and transportation of virgin feedstocks. While a quantification of the embedded energy in the feedstocks was not attempted, it is likely that the energy content in virgin feedstocks would be equal to or greater than that used to process and transport recycled feedstocks. Thus, we believe that a full accounting including all secondary effects would lead to even greater energy savings than based on manufacturing alone. However, this is an area that requires further research.

Table VI
Energy Savings and Carbon Emissions Reduction from Increasing Recycled Content of Manufactured Products

	Energy Savings (TBTU)				Carbon Reductions (MMT)			
	Target 2000		Target 2010		Target 2000		Target 2010	
Industry	Low	High	Low	High	Low	High	Low	High
Container Glass	2.8	4.7	7.3	15.1	0.1	0.1	0.1	0.3
Steel	0.0	20.6	22.9	45.8	0.0	-3.6	-4.0	-7.9
Aluminum	105.2	175.3	272.6	370.0	5.0	8.3	13.0	17.6
Paper	83.1	166.2	276.6	638.4	-0.2	-0.3	-0.5	-0.7
Plastics	11.1	66.3	71.5	196.7	0.2	1.3	1.5	3.7
All	202.2	433.1	656.9	1266.0	5.1	5.8	10.1	13.0

* see appendix for calculation

Source: ACE[3] and U.S. DOE, 1993.

Policy Recommendations

A wide variety of measures exists both for encouraging industry to increase recycled content in the manufacturing process as well as increasing the availability of quality recycled feedstocks. In order to achieve the recycled content targets indicated above, we recommend that the Federal Government adopt the following policies and programs:

Increasing the Availability of Recycled Feedstocks

- Greater support should be provided for R&D and demonstrations of new techniques for recovery of high quality recycled feedstocks from post-consumer waste streams, as well as innovative and non-traditional uses for waste materials.

- Federal programs should encourage and provide technical support to States and local governments on source separation , curbside pick-up, and other separation methods to increase the quality and volume of materials recycled materials thereby diverting them from landfills. Increasing recycled feedstock availability will require the cooperation of states, municipalities, the waste industry and consumers.

- Federal "bottle bill" legislation or minimum requirements for container reuse should be adopted. This measure would also facilitate the reclamation of a high quality feedstock stream by establishing an infrastructure to collect the products in a segregated form.

- Manufacturers of durable goods (eg., vehicles, buildings, and appliances) should be encouraged to:

    1) produce "recycling friendly" products that can be easily disassembled containing reusable components or ones made from readily recyclable materials;

    2) establish an infrastructure for collecting and disassembling used products; and

    3) reusing or recycling the components to the maximum extent possible.

- Tax incentives could be provided for investments in recycling infrastructure by the waste industry, building owners and retail establishments to increase the quality and volume of recycled feedstocks. Though these could prove costly to the Federal Government, they could be paid for through corresponding reductions in the subsidies provided for virgin materials production.

- Favorable tax treatment and other subsidies that encourage the use of virgin materials over recycled feedstocks should be reduced or eliminated.

- A general review of regulations should be undertaken to remove undesirable barriers to recycling and use of products with a high-recycled material content.

Encourage Market Acceptance of Products with High Recycled Content

- The public should be encouraged to accept, and specifications should be made more flexible for manufactured materials to allow for greater recycled content, as has occurred with the paper industry. With proper encouragement, the marketplace can create a demand for products with high recycled content.

- Federal procurement practices should give preference to goods and materials with a high recycled content.

Encouraging the Use of Recycled Feedstocks

- Voluntary targets should be set for the recycled content of key products (eg., steel, aluminum, paper, container glass and plastics) based on technical and economic potential, and availability of recycled feedstocks.

- Taxes on virgin feedstocks and credits for use of recycled feedstocks should be considered.

- Tax incentives for investment in process equipment that increases the capability for the use of recycled feedstocks in materials manufacturing industries.

If these initiatives are not effective in increasing the recycled content of relevant products, then stronger measures (e.g., mandated minimum recycled content targets and mandatory state post-consumer recycling levels) should be considered for adoption.

Appendix

Carbon Reduction Calculation Methodology

The carbon reduction potential from each material was estimated in four steps: 1) target, overall recycled content levels were set (**Table V**) based on recycled levels in state-of-the-art process and technical maximum levels as described in the text; 2) the energy savings from the increased recycling were estimated; 3) the prorated carbon coefficient was estimated using the targeted industry's fuel mix; and 4) the carbon reduction estimates in **Table VI** were obtained by multiplying the estimated energy savings by the prorated carbon coefficient.

Energy Savings

The average energy intensity for each industry was calculated based on 1991 energy consumption estimates from U.S. DOE (EIA, 1993) and production information collected by the Department of Commerce and various industry trade associations (International Trade Administration, 1989 and CMA, 1992). An estimate was made for sector growth based on market projections in the Commerce Department's *U.S. Industrial Outlook* (1994). An estimate of the reduction in energy intensity from increased recycled content was made for each material. The energy savings was estimated using the following equation:

$$\text{energy savings}_{\text{target year}} = [\text{recycled content}_{\text{target year}} - \text{recycle content}_{\text{Nat.avg.}}] \text{ x } [\text{energy/recycling ratio}] \text{ x } [\text{production}_{1991} \text{ x } \text{growth}_{\text{target year}}] \text{ x } [\text{avg. energy intensity}]$$

Prorated Carbon Coefficient

The prorated carbon coefficient was calculated for each material based on the energy fuel mix for its standard industrial classification (SIC) code as reported in the *Manufacturing Energy Consumption Survey* as shown in **Table III** (EIA, 1993). The wastes used as energy sources are in general process by-products. They are particularly important in the paper industry which uses the bark, waste wood and lignin byproducts as major fuel sources for both steam and electricity production (EIA, 1992).

In the paper and steel industries an increase in the recycled content will result in a change in the fuel mix. When paper is manufactured from recycled stock, the waste products used as fuel in virgin paper manufacturing are no longer produced and must be replaced with fossil fuels. Steel production from recycled stock uses electric-arc furnaces while direct steel making uses coal. Sine the carbon coefficient is higher for electricity than for coal, increased recycled steel production shifts the industry prorated carbon coefficient higher because of the increased electricity consumption.

The fuel mix information was then used to develop prorated derived carbon coefficients for each manufacturing industry. To do this, we relied upon the carbon coefficients reported in the *Climate Change Action Plan: Technical Supplement* (DOE, 1994)(**Table VII**). The carbon coefficient for wastes were assumed to be zero.[1] The electricity coefficient was calculated by weighting the fuel coefficients by the reported fuel mix for national electricity generation and then dividing by an assumed net system efficiency of 31.6 percent. The system efficiency was calculated by dividing the total fossil-electric generation by the total fossil-fuel consumption for electric generation (EIA, 1992). The fuel carbon coefficients and electric generation weightings are reported in **Table VIII**. To account for the change in the fuel mix for steel and paper the following equation was used:

Table VII
Carbon Coefficient by Energy Source

Energy Source	(MMT/Quad)
Natural Gas	14.2
Residual Petroleum	20.98
Distillate Petroleum	19.97
Coal	25.33
Waste	0.00
Electric National Average[1]	50.66

1. assumes national fuel mix for electricity generation and system efficiency to be 31.6%

Based on: DOE, 1994 and EIA, 1992

$$\text{carbon\_coeff.}_{\text{target}} = \text{carbon\_coeff.}_{\text{b ase\_year}} \text{ x } (1 - \Delta\text{\_recycled\_content}) + \text{carbon\_coeff.}_{\text{added\_fuel}} \text{ x } \Delta\text{\_recycled\_content}$$

where:

$$\Delta\text{\_recycled\_content} = \text{recycled\_content}_{\text{target}} - \text{recycled\_content}_{\text{base\_year}}$$

The prorated carbon coefficient values for each manufacturing industry are reported in **Table VIII**. In the case of steel, the energy fraction of the additional recycled portion is assumed to be met from electricity generated using the national fuel mix for electricity generation. The fuel mix for recycled paper production is based on the fuel mix for paper production (SIC-2621) with the fraction of energy derived from waste reduced to one-third of the total (**Table IX**).

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[1] In the case of wastes, the material would be burned or would decompose if not used as a feedstock; thus there is no net increase in carbon emissions when they are used as process fuels.

Table VIII
Prorated Carbon Coefficient for Energy Use in Materials Industries

Industry	Carbon Coefficient (MMT/Quad) 1991 Base	2000 Low	2000 High	2010 Low	2010 High
Container Glass	18.9	18.9		18.9	
Steel[1]	17.4	17.4	19.1	19.1	20.7
Aluminum	47.5	47.5		47.5	
Paper[2]	11.7	12.0	12.2	12.3	13.1
Plastics	18.9	18.9		18.9	

1. assumes for steel that the energy fraction of the additional recycled portion met from electricity generated using the national average fuel mix for electricity generation.
2. assumes for paper that the energy fraction of the additional recycled portion supplied from sources with a fuel mix of 16.4 MMT/Quad as described in the text and Table VIII.

Table IX
Fuel Mix for Pulp, Paper and Recycled Paper Production

SIC	Industry	Natural Gas	Petroleum Residual	Petroleum Distillate	Coal	Waste	Electric	Carbon Coeff. (MMT/ Quad)
2611	Pulp	11%	9%	0%	2%	74%	3%	5.74
2621	Paper	22%	7%	1%	16%	46%	9%	13.45
	Recycled[1] Paper	27%	9%	1%	19%	33%	11%	16.59

1. see text

Source: Derived from EIA, 1993

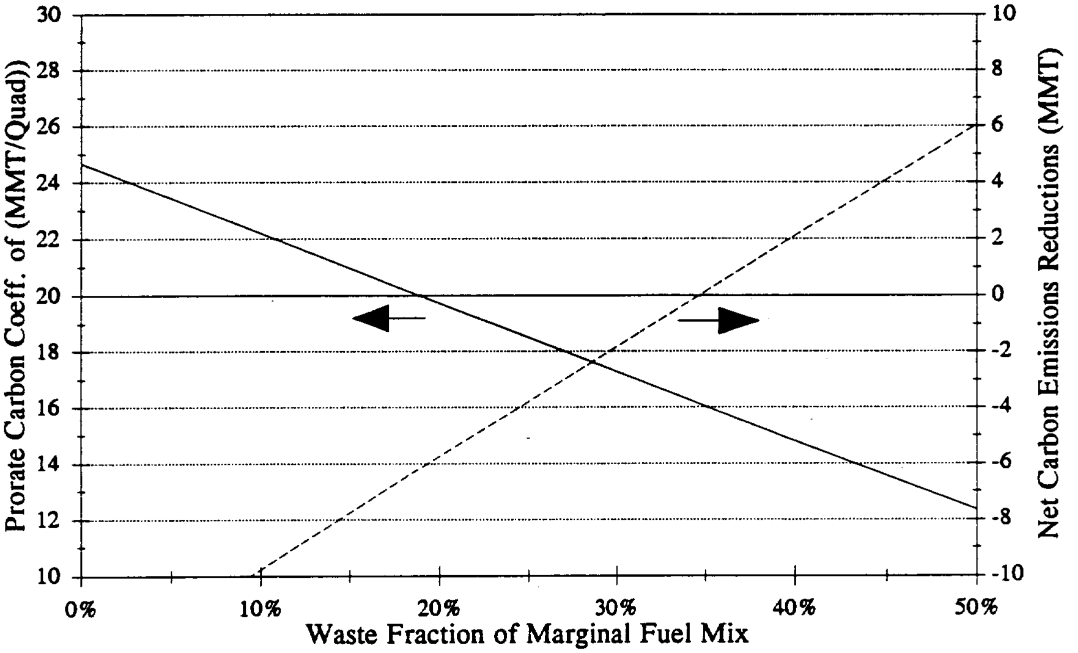

Figure 1 Effect of fuel mix waste-fraction for recycled paper production on net carbon emissions in 2010.

The impact of increased recycled content on fuel mix in paper production is complex. When paper is manufactured from recycled stock, the waste products used as fuel in virgin paper manufacturing are no longer produced and must be replaced with other fuels. The fuels that are used will determine the resulting carbon coefficient for the industry. Some facilities like the Jackson Paper company in Silva, North Carolina, use wood waste from wood products plants (Jahn, 1986), while some urban mini-mills are being sited next to waste-to-energy facilities to provide some of their energy (Kansas, 1994). The net carbon reduction figures are very sensitive to the fuel mix of the marginal energy figures (*Figure 1*). As the share of additional energy produced from waste sources increases, the carbon emissions will decrease with increased recycled content. The point at which additional carbon emissions are zero occurs when a third of the total energy for recycled paper production comes from waste.

References:

Aluminum Association (1993). *Statement of the Aluminum Association, Inc. Concerning the Impact of President Clinton's Energy Tax Proposal on the U.S. Aluminum Industry*, Washington, DC, March 6.

Aluminum Extruders Association (1992). *The Shapemakers: Extrusion Showcase*, Wauconda, Ill.

Anon. (1991). "Steel: the Recycled Material," American Iron and Steel Institute, Washington, DC.

Anon. (1992a). "Aluminum Mini-mills Change the Market for Scrap Aluminum," *Resource Recycling*, pp 23-26, October.

Anon. (1992b). *Glass Container Markets in the New York Region*, New York State Department of Economic Development, Albany, NY.

Anon. (1994). "Recycling: Is It Worth the Effort?", *Consumer Reports*, February.

Beck, Ernest (1993). "PepsiCo Test Hungary's Taste for Recyclables", *Wall Street Journal.*

Charlier, Marj (1993). "ACX Strives to Become Aluminum's Low-Cost Producer," *Wall Street Journal*, Nov. 29.

Chemical Manufacturers Association (CMA) (1992). *U.S. Chemical Industry Statistical Handbook*, Washington, DC.

Commerce, U.S. Department of (1991) *Current Industrial Reports*, Washington, DC.

Commerce, U.S. Department of (1993) *U.S. Industrial Outlook 1993*, Washington, DC.

Commerce, U.S. Department of (1994) *U.S. Industrial Outlook 1994*, Washington, DC.

Department of Energy (DOE) (1994) *The Climate Change Action Plan: Technical Supplement*, Washington, DC.

Energetics (1990a). *Industrial Profiles - Final Report: Glass*, Office of Industrial Technologies, U.S. Department of Energy, Washington, DC.

Energetics (1990b). *Industry Profiles - Final Report: Steel*, Office of Industrial Technology, U.S. Department of Energy, Washington, DC.

Energetics (1990c). *Industry Profiles - Final Report: Paper*, Office of Industrial Technology, U.S. Department of Energy, Washington, DC.

Energy Information Agency (EIA) (1988). *Manufacturing Energy Consumption Survey: Consumption of Energy, 1985*, U.S. Department of Energy, Washington, DC.

Energy Information Agency (1992). *Monthly Energy Review*, April, U.S. Department of Energy, Washington, DC.

Energy Information Administration (1993). "Manufacturing Energy Consumption Survey: Preliminary Estimates", *Monthly Energy Review*, September, U.S. Department of Energy, Washington, DC.

Energy Information Administration (1994). *Annual Energy Outlook 1984*, U.S. Department of Energy, Washington, DC.

Forest Service (1994). *Housing: A Home for Recycled Materials*, U.D. Department of Agriculture, Washington, DC.

Goldman, L. J. and L. I. Greenfield (1990). *Clay Liners for Waste Management Facilities-Design, Construction, and Evaluation,* Noyes Data Corp., Park Ridge, NJ.

Hamilton, Martha M. (1994). "Soda-Bottle Chic", *Washington Post*, Tuesday, April 12, page A1.

International Trade Administration (1989). *1989 U.S. Industrial Outlook*, U.S. Department of Commerce, Washington, DC.

IRT Environment (1994). *The Energy Newsbrief*, Vol. 8, No. 25, May 25.

Jahn, Larry (1986). *Directory of Wood Burning Facilities in North Carolina*, Extension Wood Products, North Carolina State University, Raleigh, NC.

Kansas, Dave (1994). "Environment", *The Wall Street Journal*, January 21.

Lewis, Michael, et al. (1993). *Economic Development through Scrap-Based Manufacturing*, Draft, U.S. EPA, Washington, DC.

Lewis, Michael and David Morris (1993). *Saving BTUs Through Recycling*, Institute for Local-Self-Reliance, Washington, DC.

Lewis, Michael (1993). Personal communication, Institute for Local Self-Reliance, Washington, DC.

Nucor Corporation (1991). *Nucor Corporation 1991 Annual Report*, Charlotte, NC.

Pollock, Cynthia (1987). *Mining Urban Waste: The Potential for Recycling*, Paper 76, World Watch Institute, Washington, DC.

Porter, J. Winston (1993). "Trash That Recycling Plan", *Wall Street Journal,* June 28.

Protzman, Ferdinand (1993). "Germany's Push to Expand the Scope of Recycling", *The New York Times*, July 4.

Richards, Bill (1993). "Trash Dance:Recycling in Seattle Set National Standard But Is Hitting Snags", *Wall Street Journal*, Page A1, August 3.

Ross, Marc (1993). Personal communication, Physics Department, University of Michigan, Ann Arbor, Michigan.

Schrage, Michael (1993). "Arch Rivals in Sneaker Business are Hot on Innovation's Heel," *The Washington Post*, pg. D2, Friday, June 18.

Steinmeyer, Dan (1992). "Energy Use in Manufacturing," *The Energy-Environment Connection*, Jack Hollander, editor, Island Press.

Steinmeyer, Dan (1993). Personal communication, Monsanto, St. Louis, MO.

Wakesberg, Si (1991). "Minimills Ponder Tomorrow," *Scrap Processing and Recycling*, pp. 81-87, September/October.