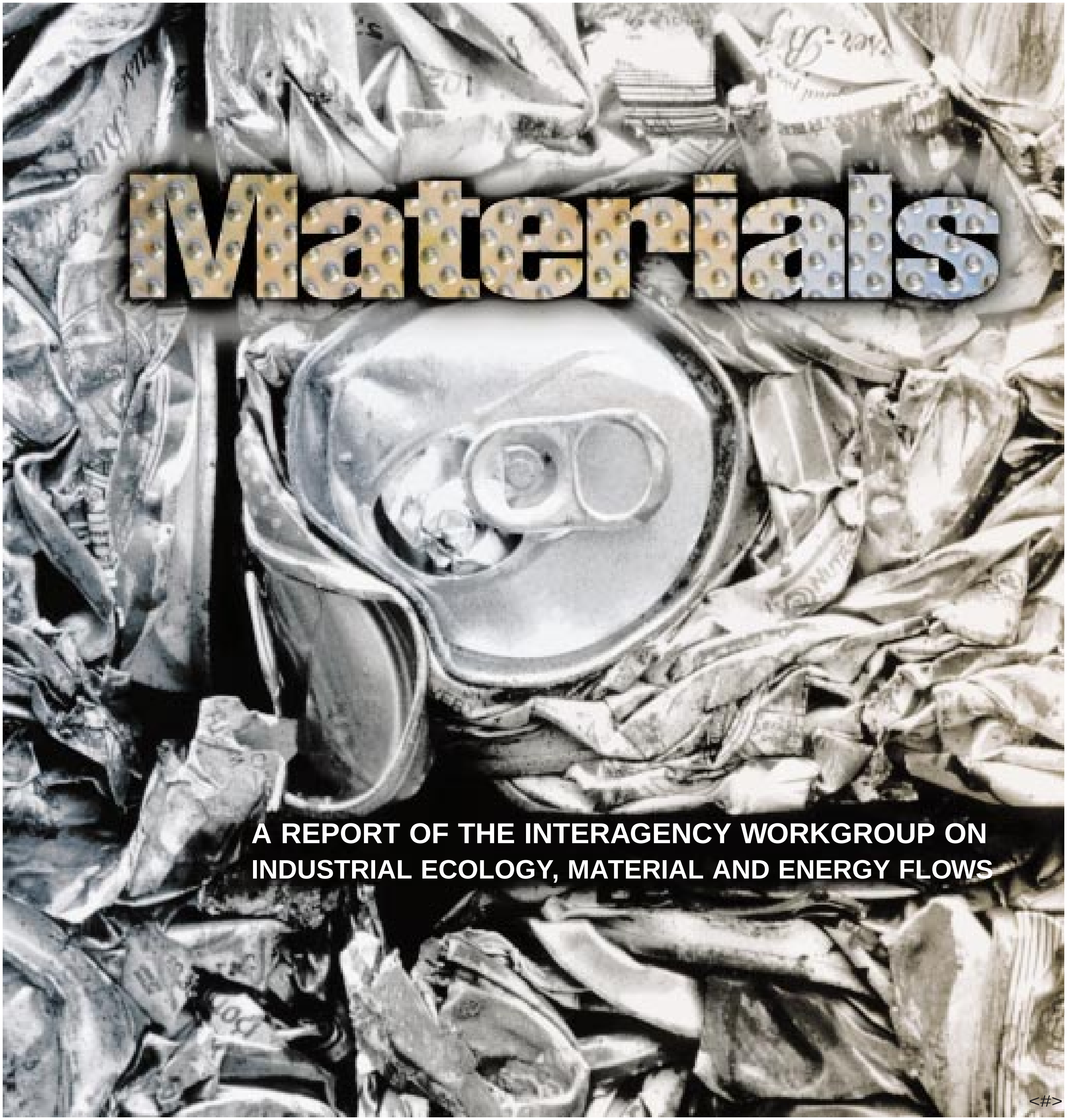

Materials

A REPORT OF THE INTERAGENCY WORKGROUP ON INDUSTRIAL ECOLOGY, MATERIAL AND ENERGY FLOWS

Participating Agencies

U.S. Environmental Protection Agency

U.S. Department of Agriculture

- U.S. Forest Service

U.S. Department of Energy

U.S. Department of Commerce

U.S. Department of the Interior

- U.S. Geological Survey

U.S. Department of Housing and Urban Development

U.S. Department of Transportation

U.S. International Trade Commission

Office of the Federal Environmental Executive

> "The Council on Environmental Quality and the Office of Science and Technology Policy will initiate a Federal interagency working group on analysis and research on industrial ecology and materials and energy flows in production and consumption."
>
> Administration Implementation of the Policy Recommendations of the Report of the President's Council on Sustainable Development, March 7, 1996.

Members of the Workgroup are (back row, left to right): David Bassett, Marilyn Biviano, John Hood, David Berry; (front row, left to right): David Rejeski, Grecia Matos, Remy Esquenet, Alan Schroeder. Not shown: Suzanne Giannini-Spohn, Thomas Gunther, Eugene Lee, Clare Lindsay, Bob Lipnick, Toni Marechaux, Howard Rosen, Bob Knisely, Karl Tsuji, Mary Roy, Fran McPoland, Robert Shaw, Mark Decot, Ken Hansen, Karen Laney-Cumming, and David Mednick.

Preface

This document is built on a simple premise: understanding how and why we use materials and energy can help us use them more efficiently. As global population increases, we can to do more with less, producing the goods and services we need as a society with less energy, fewer materials, and reduced environmental impact, while leaving more natural resources available for future generations.

In some cases, the data, analytical tools, and technologies to achieve this goal already exist. However, it will require the combined efforts of the government, industry, universities, and non-governmental organizations to ensure their application. In other cases, research will be needed to increase our understanding of material and energy flows and design a new generation of efficient products and processes utilizing environmentally-benign materials. The emerging science of industrial ecology can provide the basis for closing the loops of materials and energy flows and improving production and resource use efficiencies.

In the pages that follow, we provide a brief history of materials, summarize their use today, and illustrate a number of ways to use materials more effectively. The report is illustrative, not exhaustive. It ends with a summary of activities the federal government can undertake, alone or in partnership with others, to facilitate a greater understanding of materials and more efficient approaches to their use.

Washington, DC
August, 1998

ABOUT THIS DOCUMENT

This document was produced by the Interagency Workgroup on Industrial Ecology, Materials and Energy Flows. The Workgroup was launched in the spring of 1996 in response to the recommendations of the President's Council on Sustainable Development. With representatives from almost a dozen Federal agencies, the group works to coordinate government activities on material flows.

Beside participants from the Federal government, many other individuals from industry, universities, and municipal government contributed to this document. It was a collaborative effort, but does not represent a consensus view of the contributors or official policy of the Federal government. The report is meant as a "thought piece" to stimulate greater discussion about the crucial role of materials in our economy.

Information on the Workgroup (including a longer report entitled Material and Energy Flows and an inventory of Federal databases on materials) can be found on our website at:

http://www.oit.doe.gov/mattec/img.htm

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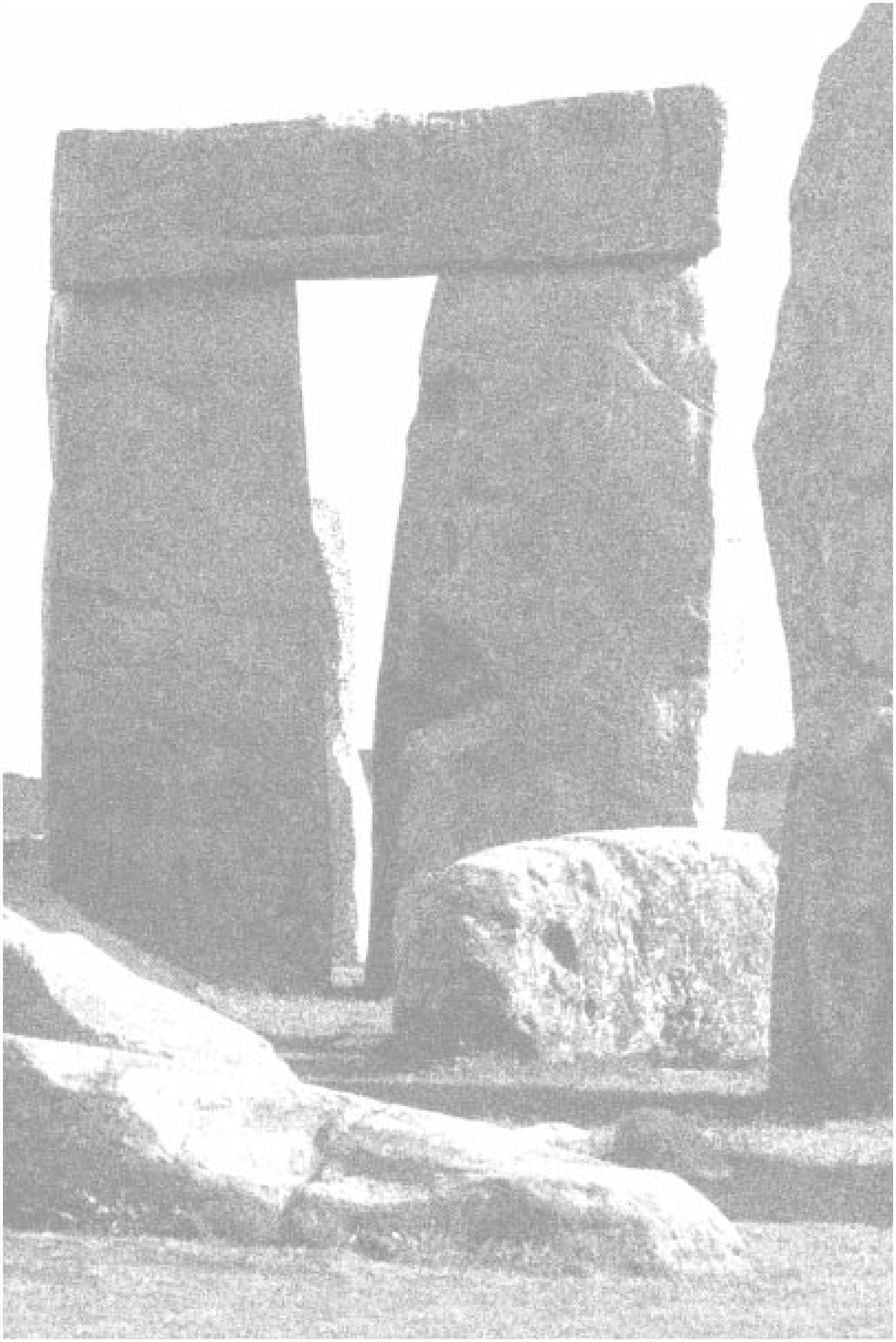


STONE

They wrote in stone, lived in stone,

STONEAGE

told time with stone, moved water with stone,

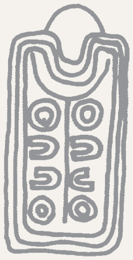
STONEHENGE

and shaped stone with stone.

STONEMASON

BEGINNINGS

Flint, granite, limestone, sandstone; the Inca stonemasons; the pyramid builders; the Anasazi cliff dwellers; the ancients who raised the monoliths and dolmens at Stonehenge and Carnac — for millennia, stone shaped the world and together with hides, wood, and natural fibers, sustained humanity. Then bronze and iron changed civilization, slowly at first and then at a dizzying pace.



First bronze artifacts

In 1816, a Danish museum curator by the name of Christian Thomsen coined the terms Stone, Iron, Bronze and Steel Ages to emphasize the link between human development and the control and production of materials.

10,000 B.C.

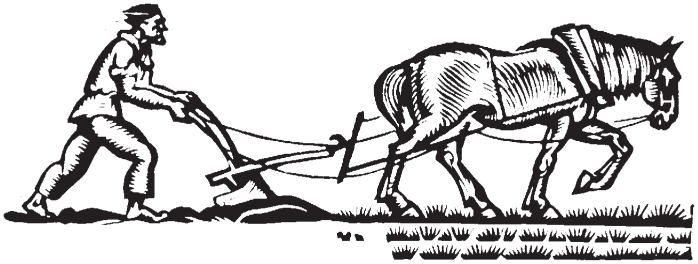
MESOLITHIC STONE AGE

And when the Emperor passed, he did not address the swordmaker. Despondent, Amakuni noticed that half the returning soldiers were carrying broken swords. Amakuni and his son shut themselves in the forge and worked for thirty days and thirty nights, selecting the best ores and refining their forging process. They emerged with a curved blade with a single edge, and the other swordmakers thought them insane. The following spring there was another war and as the Emperor returned and passed by he said to Amakuni: "You are an expert swordmaker. None of the swords you made failed in battle."

Story on the origins of the samurai sword
Yamoto Province,
Japan 700 A.D.

"Oh the Iron! Alas the Iron!" King Desiderius exclaimed as he looked out at the armor and weapons of Charlemagne's approaching army. It was 773 A.D. By then iron had changed the face of civilization and the Stone Age world forever, transforming both warfare and work.

One simple change, the introduction of the iron plow in Northern Europe, would radically alter human labor and nutrition. By cutting deep furrows, it would reshape the landscape; by requiring draft animals which few peasants could afford, it would restructure society; and because of the increased feed needed by the animals, it would change the methods of agricultural production.



They will beat their swords into plow-shares . . .

Isaiah 11:4

But this was just the beginning. Humanity would create new and more efficient tools. Iron tools of war: swords, stirrups, guns, and cannons. Iron tools of peace: bells, clocks, and the printing press. Water power turned the mill wheels faster and dropped the hammers harder, doubling and tripling output in Europe (in 1540, 100,000 tons of iron; by 1840, 2,400,000 tons). The Industrial Revolution came — coal and steel, steam,electricity, aluminum, and oil.

July 14, 1907: “Be it known that Leo H. Baekeland, a citizen of the U.S. residing at Snug Rock, Harmony Park, Yonkers, has invented certain new and useful Improvements in Methods of Making Insoluble Condensation Products of Phenols and Formaldehyde....” Bakelite: “The Material of a Thousand Uses.” Combs, billiard balls, toothbrush handles, washing machine impellers, telephones, radios, pens and propellers.

Celluloid. Cellophane (seals moisture out, and freshness in!). Viscose, rayon (is like the times we live in! Bright, colorful, luminous). Nylon, polyester, vinyl, fiberglass, saran, silicon, Teflon, PVC, PET, Kevlar (it can stop bullets). Brownie cameras, the Corvette, the Zip-lock bag, wash-and-wear, CD’s, credit cards, and bottles turned into clothes. Almost everything we see and touch. The material world.

– I just want to say one word to you.

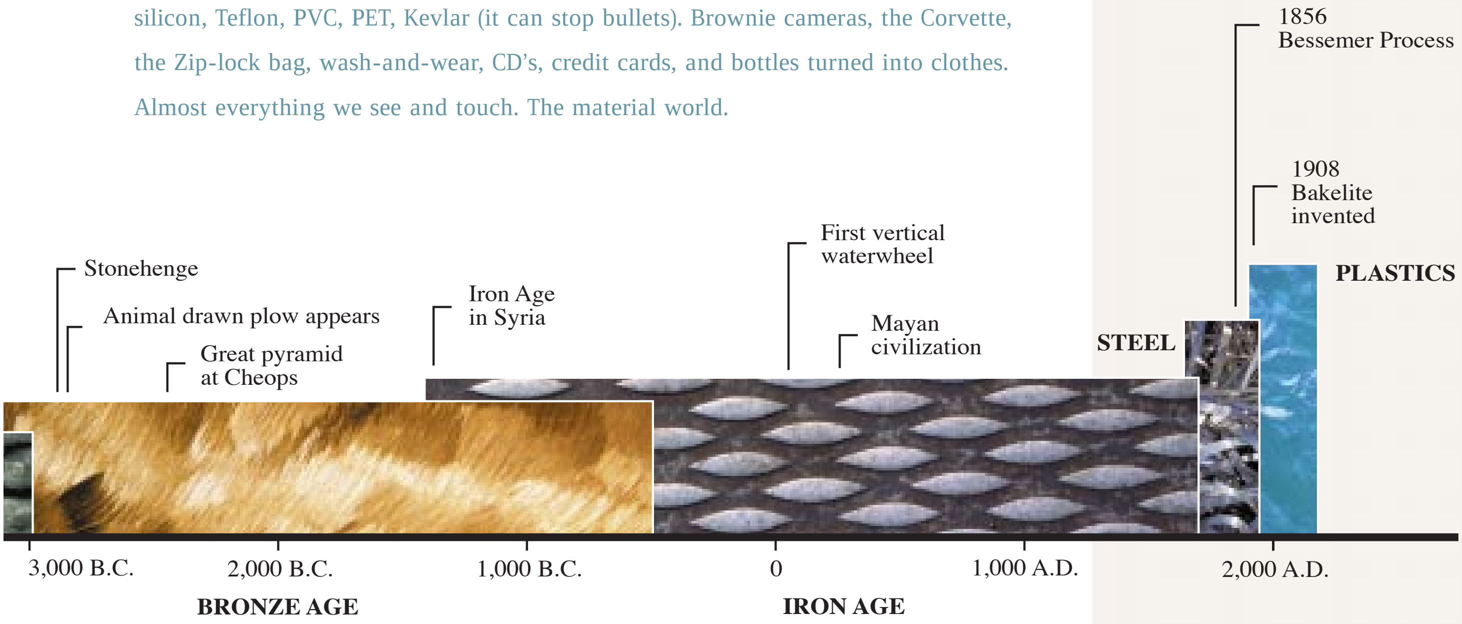
– Yes Sir.

– Are you listening?

– Yes, sir, I am.

– PLASTICS.

The Graduate 1968



Material Flows in the

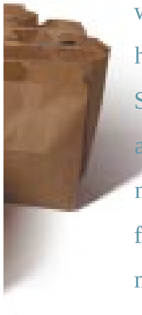
The earth can't withstand a systematic increase of material things. If we grow by using more stuff, I'm afraid we'd better start looking for a new planet.

Robert Shapiro
CEO, Monsanto

Our consumption of energy, food, transportation, consumer products, and infrastructure mobilize materials – an average of 300 shopping bags per person per week.

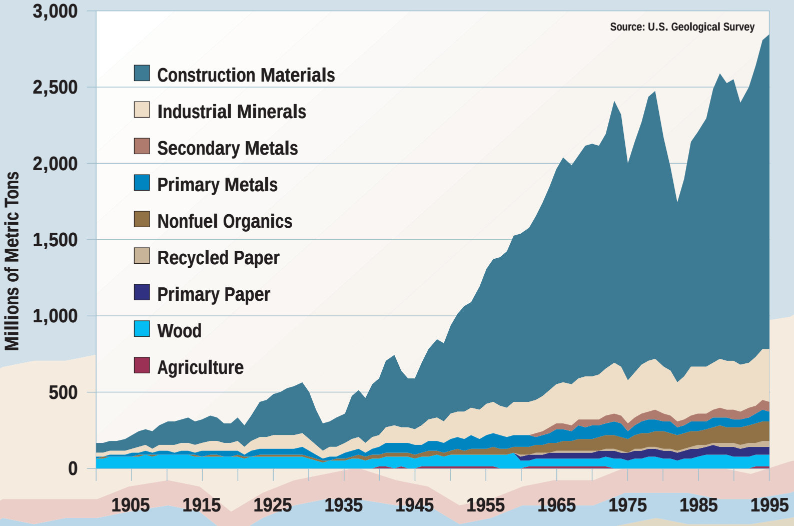
20th Century

Modern, industrial economies use 100,000 pounds to 187,000 pounds of natural resources per person per year —the weekly per capita equivalent of 300 grocery bags filled with materials. This conclusion was reached in a comprehensive resource flow study of Germany, Japan, the Netherlands, and the United States titled Resource Flows: The Material Basis of Industrial Economies.



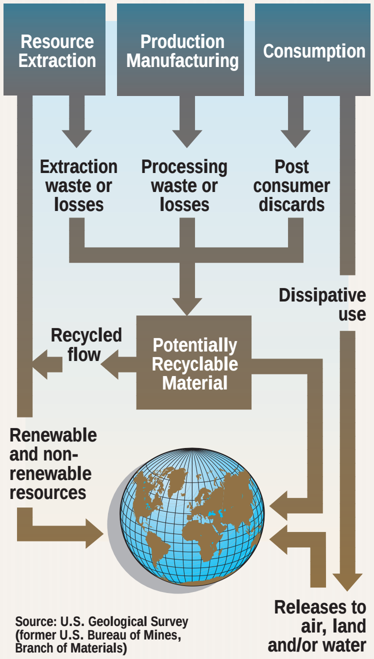
This report considered the role of “hidden flows” which includes the removal of overburden and waste from ore, soil erosion, and earth moved during construction when calculating total natural resources “mobilized” by human consumption. These hidden flows account for almost 77 percent (by weight) of material use in the United States. The chart on the right shows total annual net use (without hidden flows) of non-fuel materials in the United States from 1900 to 1995. While there has been a marked increase in recycling, the use of most raw materials, particularly for construction, has climbed dramatically over this century. It will be difficult to maintain this trend in materials use. If, as expected,

U.S. CONSUMPTION OF RAW MATERIALS



Material use in The United States is part of a global system of material flows. Resources are extracted via mining or harvesting, used in production, and then consumed as goods or services. Each stage generates flows of wastes that are recycled or returned as waste to the Earth. Some man-made materials, however, cannot be reused or easily assimilated by nature due to toxicity, non-degradability, or prohibitive costs.

MATERIAL CYCLE



Source: U.S. Geological Survey (former U.S. Bureau of Mines, Branch of Materials)

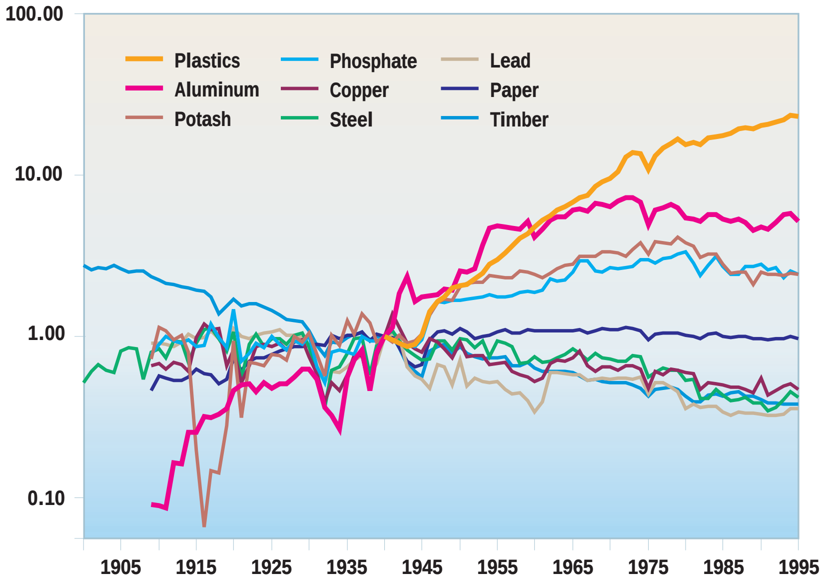
economic activity is to grow four-or-five-fold over the next half century with significant increases in population, great improvements in efficiency are needed. While many raw materials are abundant, the environmental impact of much higher use rates may be unacceptable to society. Planning for technical and economic solutions is needed now.

Recognizing this, the Organization for Economic Cooperation and Development. (OECD) recently adopted a long range goal that industrial countries should decrease their intensity of material use by a factor of ten over the next four decades. That would be equivalent to using only 66 pounds of materials per $100 of GDP, compared to the present value of approximately 660 pounds per $100 of GDP. Proponents of this goal say the efficiency improvements can be attained using currently available technologies. Already, Japan, for example, maintains a standard of living similar to the United States using only about half of the materials and energy per person.

Improvements in our standard of living may be achieved through efforts at greater efficiency rather than greater levels of material and energy consumption. The figure on the opposite page illustrates the intensity of U.S. materials use from 1900-1990. Annual consumption data are divided by Gross Domestic Product (GDP) in constant 1987 dollars and normalized to unity in the year 1940. Notice how heavy materials such as steel, copper, lead, and lumber – all materials used for infrastructure – become less critical to economic growth over the course of this century. Paper, by converting its role from manufacturing to information services, followed the economy closely. Use of light-weight materials such as aluminum and plastics has out paced economic activity since World War II.

Substances such as plastics represent an entirely new class of synthetic materials. Cheap and abundant fossil fuels combined with advances in physics, organic chemistry, and material science enabled us to create innovative materials previously unknown in the natural world. It is these materials, and their combinations, that allowed the development of the transistor, magnetic tape, fiber optics, and countless other objects we use in our daily lives. Developing these materials has given us a new economy, spread much prosperity and knowledge, and enabled us to live longer. Moreover, these new materials are sometimes used as smart, efficient replacements for “natural” materials. For example, fiber optics are continually replacing old copper wire communication lines. This material substitution increases carrying capacity by 30-50 times, provides invulnerability to electromagnetic interference, and reduces environmental impacts associated with the extraction and processing of copper. However, new materials are not necessarily panaceas. Some products made with such materials are made inefficiently, some are toxic, and some are not recyclable or reusable at the end of their lifetimes. The rethinking and redesign of materials and material flows provides a pathway to solve these issues, enabling us to meet our material needs in a more sustainable way.

MATERIALS: INTENSITY OF USE



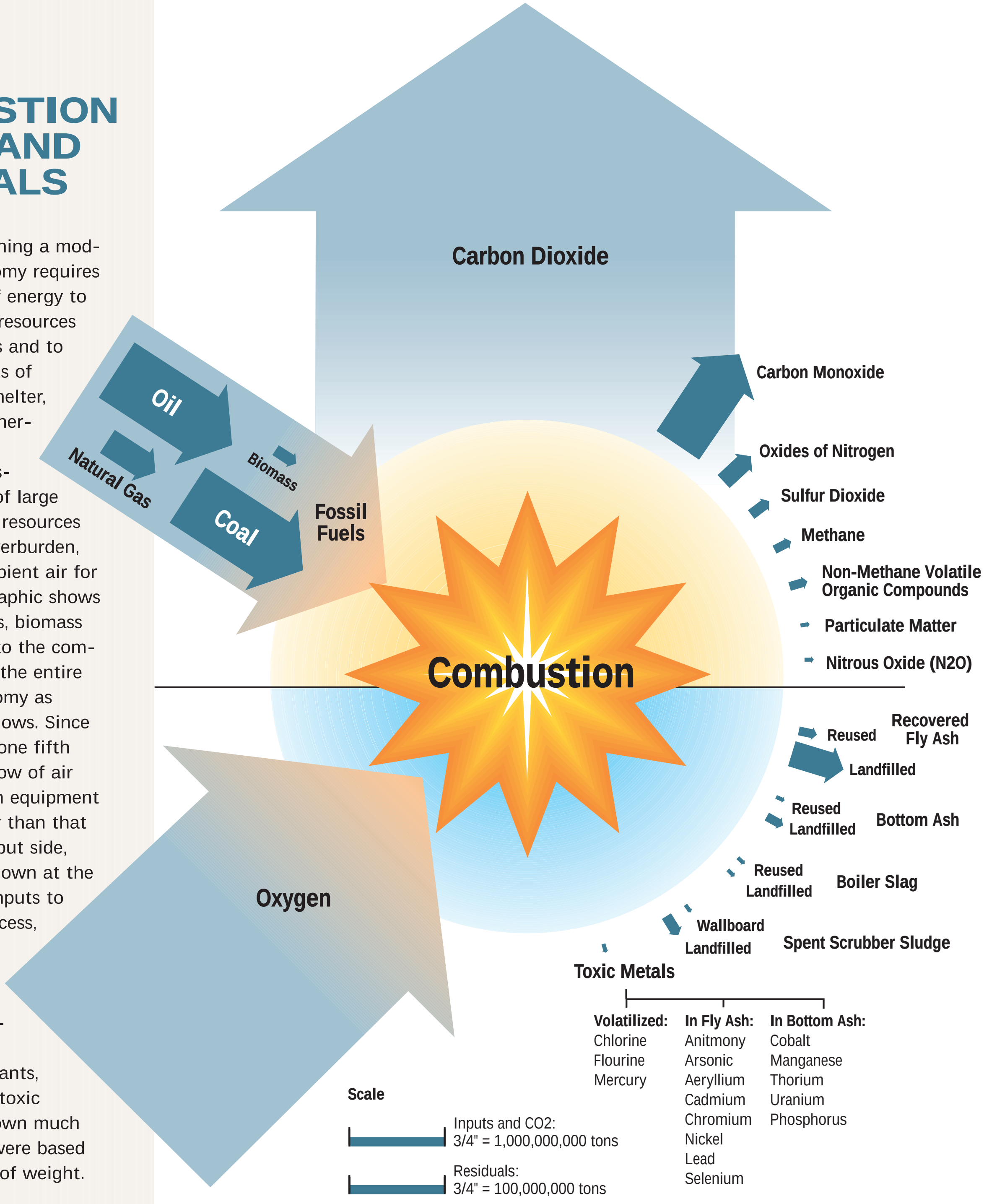
First transistor

Without these advances in materials, you wouldn’t have stood a ghost of a chance of making a transistor.

John Pierce
Bell Laboratories

COMBUSTION FLOWS AND RESIDUALS

The business of running a modern industrial economy requires massive amounts of energy to transform material resources into useful products and to provide the comforts of lighting, mobility, shelter, warmth, etc. But energy flows are also material flows, causing the movement of large amounts of natural resources including mining overburden, fossil fuels, and ambient air for combustion. This graphic shows coal, oil, natural gas, biomass and oxygen inputs to the combustion process for the entire United States economy as graphically scaled flows. Since ambient air is only one fifth oxygen, the mass flow of air through combustion equipment is five times greater than that shown. On the output side, carbon dioxide is shown at the same scale as the inputs to the combustion process, but the remaining residuals are scaled up by a factor of 10 for better visualization. Conventional pollutants, residuals and trace toxic metals could be shown much larger, if the scale were based on toxicity, instead of weight.



Examples of Material Flows in the U.S. Economy

The following section contains examples which illustrate how an understanding of material flows can lead to new insights, policy options and challenges. A number of general cautions and lessons emerge. (1) Given the massive amount of materials flowing through the economy, even small "leakages" can result in thousands of pounds or tons of toxics flowing into the environment. This is especially troubling if the toxic materials persist for long periods of time or are particularly mobile (in the air, ground water, etc.). (2) We need to be aware that the consumption of materials in our country can cause damages elsewhere, potentially in countries where the population does not enjoy the same level of protection from strong environmental, public health, and worker protection laws. We need better systems to track transboundary material flows and their associated impacts. (3) Our current assumptions about the sources and drivers of material flows may be out of date, inaccurate, or simply wrong. Data on the flow of key materials needs to be continually examined and our understanding updated.

Silver

Where did the silver come from? This is the question the Regional Water Quality Control Board was asking when significant levels of silver were detected in water, sediments, and tissues of fish and marine mammals in San Francisco Bay. A material flow analysis done by the California EPA and University of California Los Angeles lead to an unlikely candidate- the dentist office. Of the over 3,800 metric tons of silver consumed in the United States every year (1991 data), approximately 50 percent is used in photographic and radiographic materials and one half of that amount in the over 90,000 dentists'

TURNING SILVER INTO GOLD

The northern region of Kaiser Permanente's California Division has constructed a centralized silver recovery and fixer reprocessing plant that both saves the company money and assures compliance with environmental laws. Each year, over 100,000 gallons of fixer (and, at some facilities the wash water) are collected from 50+ medical centers and clinics and transported to a Kaiser Permanente recycling facility in Berkeley.

The system cost $210,000 to construct and roughly $70,000 in legal and consultant time to permit. Operation costs consist primarily of sludge disposal (approximately $50,000 per year) and 50 hours of labor per month. Income from the silver flake is about $240,000 per year. In addition, $330,000 (the cost of paying for the fixer to be recycled commercially) is saved annually. The facility is a profit making system that reduces silver loadings to waste treatment plants and waterways that paid for itself in less than one year.

THE SUCCESS OF BATTERY RECYCLING REGULATIONS

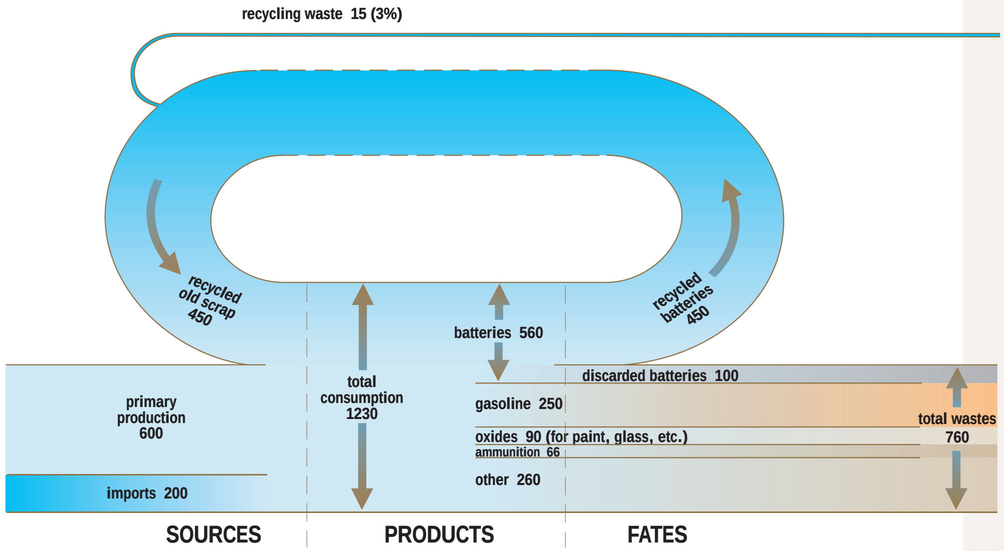
The success of automotive battery recycling highlights the positive effects of appropriate government policy and regulation. Over 95 percent of all automotive batteries are recycled through a system of government sponsored programs. Although there are no federal regulations, all 50 states have similar policies requiring battery sellers to collect used batteries when a new one is purchased. The incentive for the consumer often takes the form of a $5 - $10 rebate when the old battery is turned in.

offices around the country. It was not heavy industry, but parts of the service sector such as small dental offices and photographics shops which were mobilizing a bulk of the silver flow. Much of this silver becomes part of the waste stream, typically dissolved in fixer solutions, and ends up going down thousands of drains. The material flow analysis provided important insights and highlighted some significant challenges, both technological and regulatory. Because the volume of the fixer used per site is low (80 percent of the sites use less than 5 gallons/month) and the sites are scattered, recovery or recycling is often difficult. The existing regulatory system also discourages both on-site and off-site recovery of silver in developer waste streams. The result is ecological impacts from increased silver mining, detrimental effects on the operation of sewage treatment plants, and increased risks for marine animals. However, cost-effective solutions are possible (see box on previous page) and need to be further explored and supported.

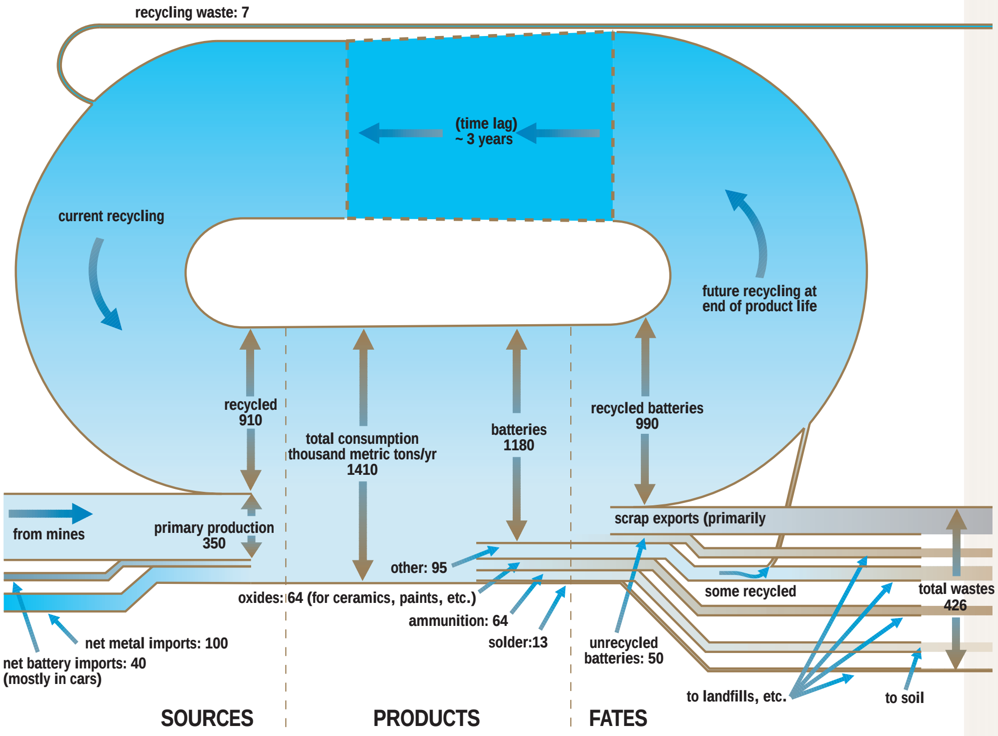
Lead

The negative impacts of lead on human health have been known for centuries. However, it was not until the 1970's that lead became the target of regulatory activity which eliminated much of its dissapitive use in gasoline and paints. A dramatic decrease in blood lead levels in the general population followed. The dominant use remains in lead acid batteries (1,180 metric tons per year) and a significant amount of that demand is now met through recycling (estimates are between 93 and 98 percent). The infrastructure for recycling lead batteries in the U.S. is becoming more and more fully developed and effective pollution control technologies have reduced the threats to populations living near secondary processors of lead. The accompanying graphics compare the flow of lead through the U.S. economy in 1970 (before regulatory intervention) and in 1993-4. Though lead use remained constant, the systems analysis enables us to see that a large portion of lead use shifted from a dangerous use in gasoline to a potentially safer use in enclosed, recyclable batteries. Today, we face two challenges: to close the domestic lead cycle and to better understand the fate of lead being exported to other countries for reprocessing.

1970
LEAD FLOWS



1993-94
LEAD FLOWS



These figures show the sources, use, recycling, and disposal of lead in the United States for 1970 and 1993-94. Over that time period, total lead consumption increased from 1230 to 1410 metric tons per year and the use of lead in batteries doubled. However, battery recycling (shown by the large loop) also increased proportionately. In addition, the use of lead in gasoline was almost totally eliminated and other dispersive uses reduced.

From: Socolow, R. & Thomas, V. 1997. "The Industrial Ecology of Lead and Electric Vehicles," Journal of Industrial Ecology, Volume 1, Number 1.

Arsenic

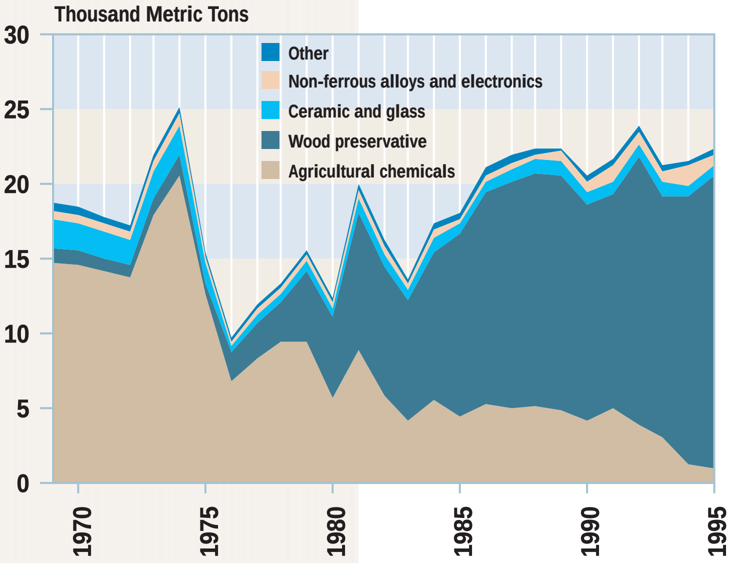
Arsenic, a by-product of copper mining, was historically used in the United States as a pesticide or desiccant for crops such as cotton. However, the dissipative uses of arsenic in agriculture were curtailed by the development of substitutes, and EPA decisions in 1987 and 1993 to prohibit use of inorganic arsenicals as non-wood pesticides and desiccants. Today, arsenic is mainly used as a wood preservative, primarily in the form of chromated copper arsenate (CCA).

Fueled by the building and real estate boom in the 1980's, arsenic use in pressure-treated wood skyrocketed, with approximately 48 billion board feet or 113,000,000 cubic meters of wood products being treated with CCA since 1985 (this is equivalent to a cube that is 15 miles on each side being produced each year). U.S. consumption of pressure treated wood now accounts for 90 percent of the worldwide arsenic demand and makes this country the world's largest consumer of arsenic.

Interestingly, the domestic production of arsenic ended completely in 1985 when ASARCO, the sole remaining producer, closed its smelter in Tacoma, WA. Today, U.S. demand is met entirely through imports —mostly from China, the world's largest producer, and Chile, a growing provider. Shifting arsenic production to foreign countries exemplifies the need for global material flow analyses which take into account all flows including those crossing international borders.

U.S. ARSENIC USE

1969-1995



Solutions

Recycle

materials from discarded products, reprocess and use to manufacture "new" products.

Remanufacture

discarded goods, disassemble, clean, and reassemble into "rebuilt" products.

Redesign

products or processes to dramatically improve efficiency of material and energy use and make recycling easier.

Rethink

how goods and services meet human wants more efficiently.

Recycle

Recycling refers to virtually any reuse of a material that would otherwise be considered waste. The most well-known, and commonly practiced, recycling examples include aluminum cans, newspapers, and glass containers. However, wastes like these represent only a small portion of the total solid waste generated in the U.S. Industrial wastes from manufacturing, oil and gas production, and mining represent enormous opportunities for increased recycling with significant energy, environmental and economic savings. Recycling not only saves materials, it saves energy. If we recycle aluminum it cuts energy use by 96 percent versus using virgin ore. For steel and copper, the savings are 74 and 87 percent respectively. The 120 million tons of materials currently recycled in the United States every year through municipal programs, auto recycling, and construction and demolition recycling saves over 3 million BTU,s of energy -- an amount equal to the total electricity demand of the United States for almost 4 months.

To make the system work, however, we need to do more than just bring papers to the curb. Across all of America, businesses, institutions, and households need to "close the loop " by demanding and buying more products with recycled content. By buying recycled, we can help stimulate demand and reduce our levels of natural resource use, decrease need for additional landfill space, lessen the waste associated with primary processing, and lower the amount of energy to extract and process materials -- all of which generally save money and lead to far less environmental degradation.

Recycling concrete is one example that illustrates the financial and environmental advantages of re-using materials once considered to be waste. Much of our Nation's transportation infrastructure was constructed after World War II, and now requires significant renovation or replacement. Many contractors are recycling concrete as a supplement to natural aggregates such as crushed stone, sand and gravel. Recycled concrete is now used as road base in 44 states. It is also becoming popular in other road construction applications for erosion control and ancillary landscaping.

The financial savings are considerable. Recycling concrete saves the costs of transporting used concrete to the landfill, currently about $0.15-$0.20 per ton/mile, and eliminates the cost of disposal which can be as high as $100 per ton. The energy savings over mining, processing, and transporting new aggregates are also significant. Additionally, using recycled concrete is environmentally beneficial. Although concrete waste is not considered environmentally hazardous, the large volume of material generated makes it difficult for landfills to accommodate. Also, foregoing the mining of tens of millions of tons of natural aggregate saves resources and prevents considerable environmental impact.

Remanufacture

Remanufacturing is the process of disassembling a worn-out product, cleaning, repairing, or replacing its parts, then reassembling them to make a rebuilt product. Virtually anything can be remanufactured, from furniture to auto parts or soda machines. The remanufacturing industry encompasses over 73,000 U.S. firms directly employing 480,000 people. Total annual industry sales in 1996 were $53 billion, a value greater than the entire consumer durables industry (appliances, furniture, audio and video, farm and garden equipment). Remanufacturing is an ideal

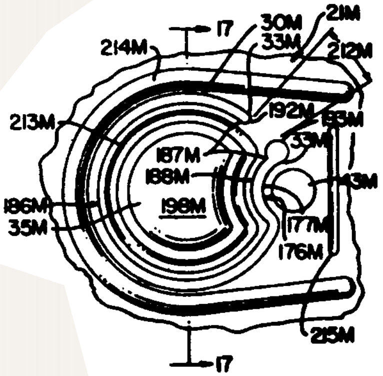
ASSET MANAGEMENT

Whether it is recycling, remanufacturing, reuse, or resale, the key to success is viewing a product as a long-term asset to be managed rather than a waste destined for disposal. In 1994, IBM opened their Asset Recovery Center in Endicott, New York. Within three years, the 300,000 square foot center was recovering 35 million pounds of computers and computer parts annually. Used IBM equipment returns to Endicott from all over the United States, ten 18-wheeler trucks rolling in every day. Precious metals such as gold, silver, and platinum are recovered; Pentium modules are tested and resold to other vendors; some machines are repaired and sold as used equipment; and usable spare parts such as disk drives and CD ROMS are refurbished.

Asset management and design for environment are interdependent. At IBM the Asset Recovery Center works closely with the Engineering Center for Environmentally Conscious Products in Raleigh, North Carolina, to ensure the entire life cycle of the product is considered and a former waste stream can be turned into an income stream.

form of recycling because it recaptures some of the costs of labor, energy, and manufacturing in addition to the cost of materials. A Massachusetts Institute of Technology study indicated that approximately 85% of the energy expended in the manufacture of automobile components was preserved in the remanufactured product. Another study by the Frauenhofer Institute in Stuttgart, Germany, found that the annual energy saved by remanufacturing world-wide is equal to the electricity generated by 5 nuclear power plants, and saves enough raw materials to fill 155,000 railroad cars forming a train 1,100 miles long.

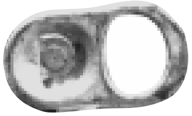
Remanufacturing works best, however, if we design with disassembly in mind. Products which are designed to be thrown away cannot be remanufactured. In addition, remanufacturers face many barriers to the market including competition with new products and perceptions by many that remanufactured goods are inferior to new products. Like recycling, a commitment of organizations to "buy remanufactured" can help create important markets for rebuilt and refurbished products.



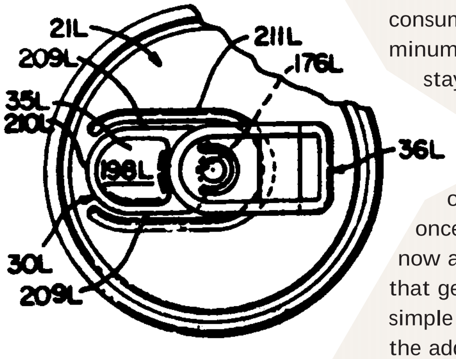
Redesign

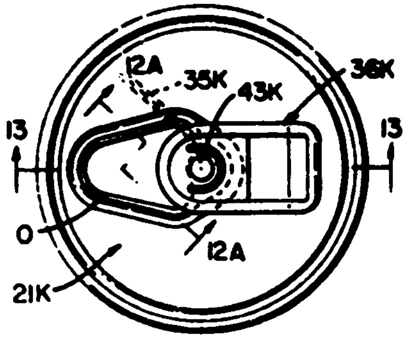
Achieving a reduction in resource use while maintaining our current standard of living requires a "cradle to rebirth" philosophy. Manufacturers can continue to redesign their products to use materials more efficiently, require less energy to operate, and make the products easier to remanufacture and recycle. These design changes have several important benefits. The products have less environmental burden since items that were once landfilled or incinerated—perhaps releasing harmful chemicals—can be recycled, preventing these toxic substances from reaching the

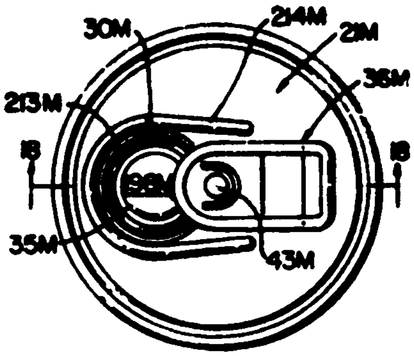
environment. Redesigning products can also have economic advantages as well. Producers have found that redesigned products often cost less to produce and give them a competitive advantage. Finally, broader social benefits may also be achieved. By redesigning products we may reduce many hidden costs associated with production and consumption. We can live in a cleaner environment, and consumer costs may decrease.



Aluminum cans and the redesigned pop-top is an excellent example (see box). Although the recycling benefit was inadvertent, the pop-top design makes a significant impact given that every minute the U.S. recycles over 100,000 aluminum cans. Furthermore, since recycling aluminum saves 95 percent of the energy needed to mine, ship, and convert raw material into aluminum, the financial and environmental savings are considerable.







A BETTER IDEA

In the early 1970's the aluminum can was being blamed for an environmental crisis. Billions of removable tab-tops – those small, sharp-ringed pieces of aluminum – were being discarded along roadsides, parks, and beaches, becoming dreaded hazards to the barefoot vacationer or curious toddler. In 1976, Daniel F. Cudzik, an employee of the Reynolds Metals Company, saved the aluminum can. His invention of the pop-top gave consumers a easy-to-open aluminum can with a tab that stayed attached. Cudzik's invention had other unanticipated benefits. That extra little piece of aluminum, that was once usually thrown away, now accompanies every can that gets recycled. Cudzik's simple design change enabled the additional recycling of about 200,000 metric tons of aluminum since 1980 which equates to about 3 billion kilowatt-hours of saved electricity. A reduction in electrical demand of this size at a typical coal-fired power plant prevents the release of 900,000 pounds of Carbon Monoxide, 900,000 pounds of fine particulate matter, 20 million pounds of Nitrogen Oxides, 42 million pounds of Sulfur Dioxide and over 6 billion pounds of Carbon Dioxide.

Rethink

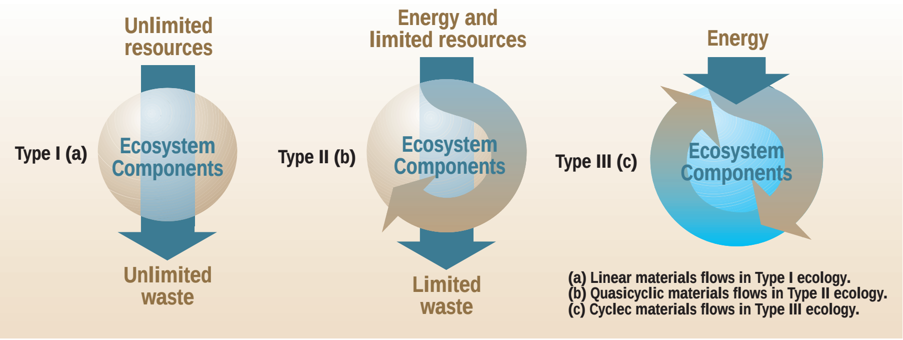
> *Pollution is nothing but the resources we are not harvesting. We allow them to disperse because we've been ignorant of their value.*
>
> Buckminster Fuller

Industrial Ecology (IE) offers a blueprint for rethinking how we can use materials and energy more efficiently. Emerging as a distinct discipline in the mid to late 1980's, industrial ecology integrated a number of streams of thought from diverse areas such as design for environment, input-output modeling, industrial metabolism, and studies of the interface between human and natural systems. Industrial ecology is, above all, a whole-systems paradigm which challenges practitioners to view industrial activity within a larger ecological and social context.

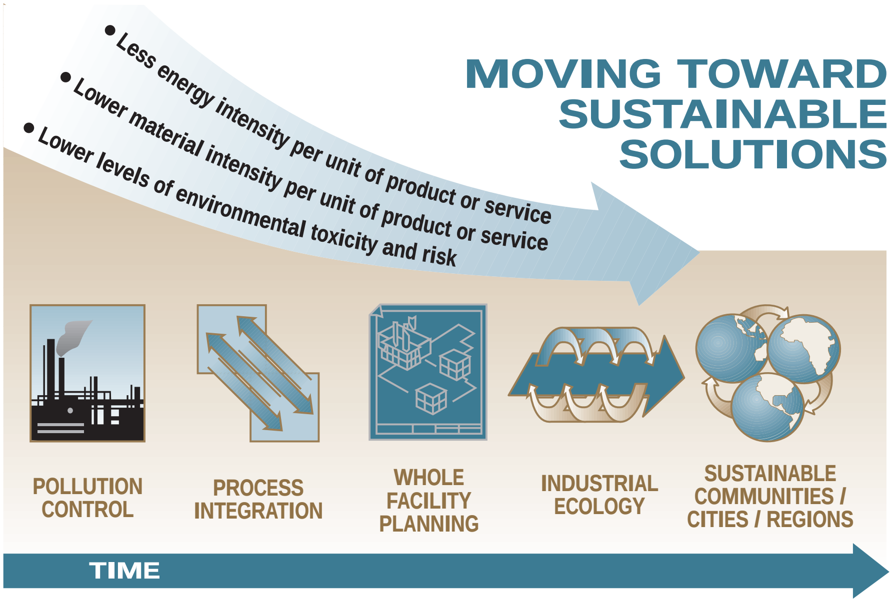
Industrial ecology takes its lead from our natural world, where we find a range of living systems which are in various stages of development in terms of their efficiencies. Ecologists call these Type I, II, and III systems (see below). Some of these systems are very efficient at using materials and energy and reusing any remaining wastes. A Type III ecosystem can become almost self-sustaining, requiring little input to maintain basic functions and provide a habitat to thousands of different species.

In an analogous way, industrial ecology aims to create a world where the production of needed goods and services is achieved with minimum impact to our natural

INDUSTRIAL ECOLOGY



(a) Linear materials flows in Type I ecology.
(b) Quasicyclic materials flows in Type II ecology.
(c) Cyclec materials flows in Type III ecology.

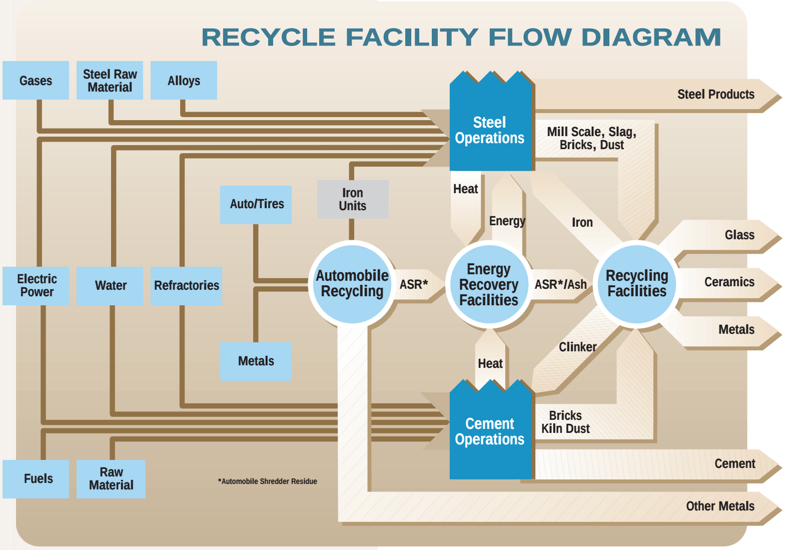


environment. The chart above illustrates our transition from a Type I flow-through system with rudimentary end-of-pipe controls to one built on integrated process design and holistic approaches that reduce material and energy use as well as environmental impacts. Practical implementation of this transition begins in several ways: efficiencies are increased in resource extraction and manufacturing and products are designed with less material and energy inputs. All of these steps must be accompanied by commitments to recycling, remanufacturing, and redesigning.

Integrating industrial ecology within our economy will bring significant benefits. Beyond reduced resource use, lessened environmental degradation, and gains in productivity, industrial ecology opens new opportunities for business and government. Companies can offer innovative new products and services with a clear competitive advantage and lower liability risks. They can also partner with other companies or municipalities to turn waste streams into valuable production inputs. IE can assist government agencies (federal, state and local) by defining new policy opportunities, highlighting areas for partnerships with the private sector, guiding research and development, and, overall, facilitating sustainable economic development.

The idea of industrial ecology is that former waste materials, rather than being automatically sent for disposal, should be regarded as raw materials--useful sources of materials and energy for other processes and products...The overall idea is to consider how the industrial system might evolve in the direction of an interconnected food web, analogous to the natural system, so that waste minimization becomes a property of the industrial system even when it is not completely a property of an individual process, plant, or industry.

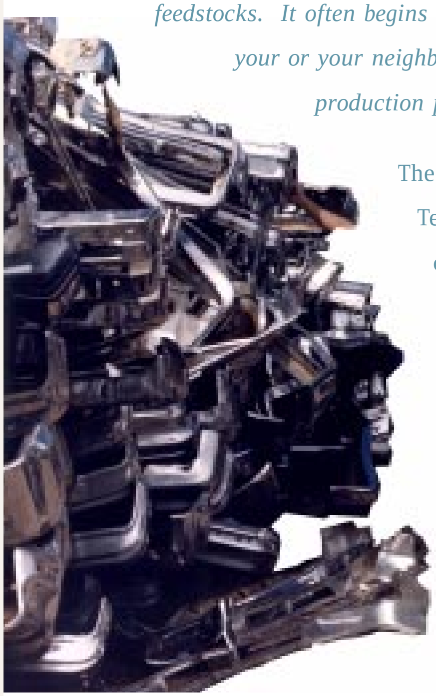
Robert Frosch
"Toward the End of Waste:
Reflections on a New Ecology
of Industry"
Daedalus, Summer 1996


RECYCLE FACILITY FLOW DIAGRAM

CASE STUDY 1

Industrial Symbiosis

Industrial symbiosis is the creation of synergies between various industries, agriculture, and communities to profitably convert waste into valuable products or feedstocks. It often begins with a "look over the fence" and discovery that your or your neighbor's waste can become a valuable input into a production process.



The Chaparral Steel Company, located in Midlothian, Texas, owns and operates a technologically and conceptually advanced steel mill that produces bar and structural steel products by recycling scrap steel. The company has embraced the philosophy of industrial ecology, giving Chaparral a competitive advantage that increases profits, saves natural resources, and lowers environmental pollution. The

> ***We at Chaparral believe that in the future, it will not be enough to be a producer of quality products. Manufacturers will have to accept the responsibility for the environmental worthiness of the entire process including the generation of the co-products and wastes. We believe in this fundamental principle and have set for ourselves a new challenge of zero wastes, 100 percent product steel making.***
>
> Libor Rostik
> Vice President
> Technology and Development
> Chaparral Steel

company has formed several unique relationships with neighboring companies to convert their industrial by-products and wastes into valuable resources. In 1993, a consumer for the "waste" slag produced in the company's ultra high powered electric arc furnaces was discovered in a neighboring cement plant. A new company, CemStar was created that adds slag to the cement raw material mix, yielding larger batches of high-quality Type I Portland cement without compromising its characteristics. Using slag in this way increases its value significantly relative to its former use as road construction material. This by-product-to-resource conversion conserves natural resources while reducing energy requirements 10-15%, about 1,500 kilowatt-hours per ton. In addition, it is estimated that the percentage of slag used in the CemStar process reduces the amount of CO2 emissions by the same percentage.

Chaparral has also made themselves into a world-class recycling facility. Using their adjacent automobile shredder facility, one of the largest in the world, Chaparral transformed over 700,000 tons of old cars and other light scrap into raw material.

This example affirms the practical and desirable results of adopting industrial ecology practices. Chaparral has pushed the limits of steel-making to the point where virtually every thing they produce is a useful product to nearby enterprises.

Chaparral is a member of the Business Council for Sustainable Development for the Gulf of Mexico. They are working with a group of U.S. and Mexican chemical, petrochemical and engineering companies in Tampico, Mexico, to map the materials flowing through these companies and then identify synergies based on the results. The goal is to identify at least five profitable new by-product synergies by the end of the year-long project.

The 10 million automobiles sold annually in the United States require over 14 million tons of materials. Fortunately, it has become cost-effective to recycle vehicles and today about 75 percent of automobile materials are recycled. However, the relatively small percentage of remaining waste still translates into approximately 3.5 million tons of materials that must be placed in shrinking landfills.

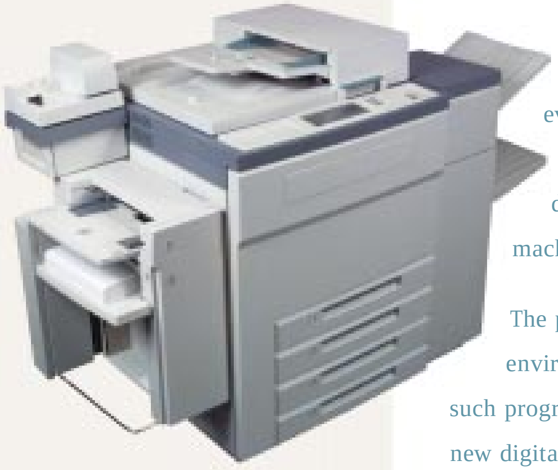
Recently, the Chaparral Steel Company has taken automobile recycling technology one step further with the purchase of the exclusive rights to an innovative flotation separation technology that is able to economically separate automobiles into essentially pure components. This capability means that the non-chlorinated plastics, rather than being landfilled, may instead be used as a highly efficient and clean fuel source. In fact, this technology will allow profitable mining of plastics from municipal landfills in the future. In addition, the separation process will yield aluminum, magnesium, and other materials so clean that Chaparral hopes to attract other processing facilities to its Midlothian site.

CASE STUDY 2

Design for Environment

Over the past few years, more and more businesses have embraced Design for Environment — an approach where environmental concerns are integrated into the entire life cycle of a product, from design through manufacturing, distribution, use, and beyond. As this case study from Xerox illustrates, getting people to work together as a team can be critical to the success of Design for Environment.

(March, 1992, Northern New Mexico): Eleven people from Xerox spent several days in the desert learning and appreciating how their lives and their work connected to the natural world around them. Over the next four years, more than 300 people, from secretaries to corporate vice presidents, participated in similar treks through nature, in New Mexico, the Adirondacks, and the Catskills.



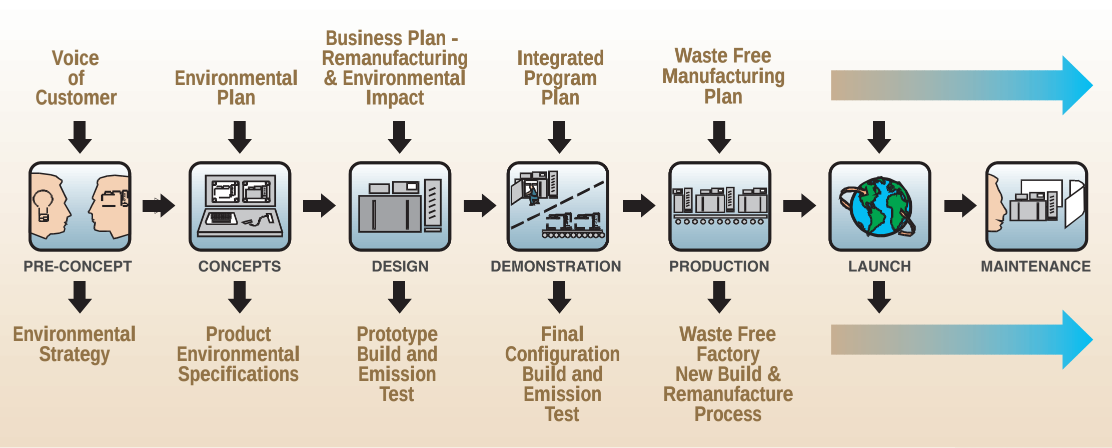
They were part of a unique project to design and launch the Xerox Document Center DC265 copier, developed under the code name Lakes. They conducted Earth Days, handed out t-shirts and mugs, designed their own logo, and even visited a landfill, where, in an almost unbelievable coincidence, they saw a Xerox box sitting on top of the junk pile. As a result, the team developed a goal that no landfill would ever see a Document Center machine; every part would be reusable or recyclable.

The project began in 1991 with a proactive effort to anticipate future environmental requirements out to the year 2005; requirements being shaped by such programs as the German Blue Angel, Nordic Swan, and U.S. Energy Star. The new digital copier needed to be upgradeable and extensible in order to manage obsolescence. Customer focus groups were established worldwide and inputs from the focus groups drove the program's requirements to create a waste-free customer office. The final vision integrated future environmental requirements, customer needs, and a commitment by Xerox to do-the-right-thing environmentally. In the implementation of the program, no one was exempt, from those who selected materials, designed the machine, and built it in the factory, to those who serviced it in the field and dealt with the return of parts from customers.

This program arose from the increasing recognition on the part of many organizations, both public and private sector, that the institutional structure and cultures which provided end-of-pipe controls will not necessarily create integrated solutions. Without a serious commitment to change, it is difficult to go beyond buzz words and achieve the deeper organizational and value changes needed to make approaches like Design for Environment a reality. Ultimately, these new ways of tackling environmental problems require a rare combination of vision and culture change that permeates the entire organization and embodies a commitment to continual improvement as new information, tools, and opportunities arise.

> ***At Xerox, environmental protection is our collective responsibility. It is built into our corporate culture and value system and, quite simply, is part of the way we do business.***
>
> Paul Allaire
> CEO, Xerox Corporation

PRODUCT DELIVERY PROCESS



The Government's Role

I honestly believe we are in the midst of a philosophical shift in our civilization, away from single-cause, single-effect analyses and toward a systems analysis approach that looks at the complete life-cycle of a product, that looks at a process from the origin of the natural resources to the ultimate disposal of the waste products and opportunities for recycling inbetween.

Vice President Al Gore
White House Conference on
Environmental Technology
December 1994

The federal government, along with our state and local partners, plays a critical role in supporting industrial ecology and a more efficient use of material and energy resources throughout the U.S. economy. Achieving greater resource efficiencies may require changes in the whole system including transportation, energy generation or other public infrastructure. This is beyond the capacity of an individual firm or sector and increases the importance of state, regional, national, and sometimes international participation and cooperation.

Data and Information

Virtually all the existing data on the flow of materials through the U.S. economy is a result of federal programs dating back to the late 1800's. Because the substitution of one material for another can take decades, long-term collection of a set of core statistics is critical to our understanding of material cycles and shifts in both materials production and demand. With the dissolution of the U.S. Bureau of Mines in 1995, the data collection for many materials has been transferred to the U.S. Geological Survey. It is crucial that this function continues and that researchers, policy makers, businesses, and non-governmental organizations have ready access to a consistent set of statistics on material extraction, use, disposal, and reuse. Several European governments already gather such data. The federal government also needs to examine how information based strategies such as the Toxic Release Inventory (Emergency Planning and Community Right to Know Act of 1986) can be broadened and applied to support more efficient material use of benefit both to producers and the community-at-large.

Research

The federal research agenda to support industrial ecology is both broad and diverse. This includes, but is not limited to, the following activities:

- Supporting mass balance studies to locate opportunities to close material loops, especially in cases where leakages present significant environmental impacts.
- Sector-based studies (forest products, chemicals, medical services, etc.) to support more efficient materials use by industry.
- Research to better understand how changes in materials use can mitigate environmental impacts.
- Research to develop suitable national indicators of material and resource efficiency.
- Research to support alternative methods of materials processing to reduce toxicity and emissions.
- Research to develop more environmentally-benign and recyclable materials.

Given the small amount of funding likely to be available for such research, care needs to be taken to develop priorities in consultation with industry, non-governmental organizations, and other key stakeholders.

Regulation

Definitions of waste as described in federal, state, and local regulations can have a major impact on our ability to reuse, recycle, remanufacture, and recover valuable materials from waste streams as well as reducing or eliminating these wastes. In this regard, regulations such as the Resource Conservation and Recovery Act (RCRA) need to be examined for incentives and disincentives to the more cost effective use of materials. At a global level, the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal will impact the movement and handling of wastes between countries. Antitrust statutes that might bar the collaboration of firms necessary to close material loops need to be examined. If there are no immediate substitutes for toxic materials in existing and emerging products, it is crucial that public policy support the development and implementation of recycling infrastructures and other strategies to close loops.

INDUSTRIAL ECOLOGY AT A REGIONAL LEVEL

The Environmental Protection Agency, Office of Solid Waste, is funding a unique project in North Carolina to reduce waste and increase the efficiency of resource use at a regional level. The project is being implemented by the Triangle J Council of Governments (TJCOG), a local government planning agency that has served the Research Triangle Park area for over 35 years. TJCOG will convene individual and group meetings of businesses in a six county (3,300 square mile) area to assist firms in identifying materials, energy, and water inputs and outputs. This information will be displayed and analyzed using a Geographic Information System to explore potential partnerships between businesses regarding the cascaded use of resource inputs, energy sharing, or joint treatment of outputs. This project fills an important gap. Though no individual firm would be motivated to conduct such a study, there may be significant and multiple benefits to both businesses and the local economy if resource flows are better understood at a regional level and resources can be utilized more efficiently.

This Administration is determined to strengthen the role of the Federal Government as an enlightened, environmentally conscious and concerned consumer.

Executive Order 12873
October 20, 1993

Procurement

The Federal government is the largest organization in the nation. It purchases about 7-8 percent of all goods and services in the economy with state and local government accounting for an additional 12-13 percent. The purchasing practices of the public sector can have a major impact on the markets for goods. Executive Order 12873 signed in 1993 helped increase the demand for recycled content paper, not only through direct government purchases but through the acceptance of the Federal standards on recycled content by state and local governments and by the private sector. Federal purchases of recycled paper are now at 64 percent. Recent revisions to the Executive Order expand and strengthen the federal government's role in procuring a variety of products containing recycled content and support new efforts to develop guidance on what constitues environmentally-preferable products. In addition, the revised E.O. contains provisions for government purchases of bio-based products manufactured from agricultural wastes and feedstocks.

Education

The Federal government can help to raise awareness of the importance of materials and the role that our consumption choices play in mobilizing their flow. Through extension services, publications and web sites, the government can provide ready access to federal databases, relevant regulations, technologies, and best practices to encourage a more efficient use of materials in our businesses, schools, and communities.

Market Mechanisms

Federal and State governments can examine the impact of taxes, subsidies, and various market-based incentives on material use and efficiency. Such mechanisms can influence behavior and purchasing decisions, and provide another set of tools with the potential to reduce waste and encourage a more efficient use of energy and materials.

References

Adriaanse, A. et. al. (1997): Resource Flows: The Material Basis of Industrial Economies, World Resources Institute, Wuppertal Institute, Netherlands Ministry of Housing, Spatial Planning and Environment, National Institute for Environmental Studies (Japan).

Allenby, B.R. & Graedel, T.E. (1995): Industrial Ecology, NJ: Prentice Hall

BCSD-GM (1997): By-product Synergy: A Strategy for Sustainable Development, Austin, TX: Business Council for Sustainable Development - Gulf of Mexico.

Braudel, Fernand (1979): Der Alltag: Sozialgeschichte des 15.-18.Jahrhunderts, Munich: Kindler.

Burke, James (1978): Connections, NY: Little Brown & Co.

Fenichell, Stephen (1996): Plastic: The Making of a Synthetic Century, NY: Harper Business.

Kimbrough, D.E., Wong, P.W., Biscoe, J. and Kim, J. (1996): "A Critical Review of Photographic and Radiographic Silver Recycling," The Journal of Solid Waste Technology and Management, November, 23(4).

Lebow, Stan (1993): The Leaching of Wood Preservative Components and Their Mobility in the Environment: Summary of Pertinent Literature, Washington, DC: U.S. Forest Service, General Technical Report FPL-GTR-93.

Loebenstein, Roger, J. (1994): The Materials Flow of Arsenic in the United States, Bureau of Mines Information Circular 9382, United States Department of the Interior.

Lund, Robert, T. (1996): The Remanufacturing Industry: Hidden Giant, Boston, MA, Boston University.

Mokyr, J. (1990): Twenty-Five Centuries of Technological Change: An Historical Survey, NY: Harwood Academic Publishers.

National Research Council (1997): Environmentally Significant Consumption, Research Directions: Washington, D.C., National Academy Press.

Office of Science and Technology Policy (1995): Bridge to a Sustainable Future: The National Environmental Technology Strategy, Washington, D.C., U.S. Government Printing Office.

Organization for Economic Co-Operation and Development (1996): "Meeting of OECD Environmental Policy Committee at Ministerial Level (Point 19 on Factor Ten Eco-Efficiency)," Paris, Feb. 19-20.

Petroski, Henry (1996): Invention by Design: Cambridge, MA: Harvard University Press.

Socolow, Robert & Thomas, Valerie (1997): "The Industrial Ecology of Lead and Electric Vehicles," The Journal of Industrial Ecology, 1(1).

Wernick, I.K., Herman, R., Govind, S., and Ausubel, J.H. (1996): "Materialization and Dematerialization: Measures and Trends," Daedalus, 125(3).

Wernick, I.K. & Ausubel, J.H. (1997): Industrial Ecology: Some Directions for Research, Berkeley, CA: Office of Energy and Environmental Systems, Lawrence Livermore National Laboratory.

White House Conference on Environmental Technology (1995): Working Papers From the Conference Held In Washington, D.C., December 11-13, 1994, U.S. Government Printing Office.

White, Lynn (1962): Medieval Technology and Social Change, Oxford, Clarendon Press.

Yumoto, J. (1958): The Samurai Sword: A Handbook, Rutland, Vermont: Charles E. Tuttle.

ACKNOWLEDGMENTS

The Interagency Working Group on Industrial Ecology, Material and Energy Flows would like to thank the following for their comments, ideas, and inspiration: John Elter, Ed deJong, and Willie Marsh, Xerox Corporation; Diana Bendz, Dan McDonnell, IBM Corporation; Gordon Forward, Chaparral Steel; Mark Zemelman, Kaiser Permanente; Andy Mangan, The Business Council for Sustainable Development-Gulf of Mexico; Michael McKenna, Bell Laboratories; Judy Kincaid, Triangle J Council of Governments; Robert Socolow, Valerie Thomas, Amit Ronen, Princeton University; Iddo Wernick, Columbia University; Jesse Ausubel, Rockefeller University; Thomas Graedel, Yale University; Eric Rodenburg, World Resources Institute, David Kimbrough, Castaic Lake Water Agency and Jacqui Cragg, Executive Office of the President Library.

The Workgroup is grateful to the Environmental Protection Agency, Office of Solid Waste, for their support of the production of this document and to the U.S. Geological Survey and Department of Energy (Office of Energy Efficiency and Renewable Energy) for help with data collection and analysis. Special thanks go to: Don Bleiwas, Donald Clarke, Thomas Goonan, Thomas Kelly, Daniel Sullivan, John Sznopek, Lorie Wagner, and David Wilburn.of the Denver office of the U.S. Geological Survey for the diligent editing and helpful comments.

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