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Here is the fax of
list of participants.

I called Marc Chupka
re: the list of subsidies
for virgin materials. He

said he had very
general figures, but would
look around for specifics.

A book will be published
in the spring w/outcome
of conference. For more info
call Robert Skolon

(609) 258-5446

LEVEL 1 - 1 OF 1 STORY

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HEADLINE: Strategies for manufacturing: wastes from one industrial process can serve as the raw materials for another, thereby reducing the impact of the industry on the environment

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BODY:

Strategies for Manufacturing

People create new technologies and industries to meet human needs more effectively and at lower cost. Innovation is a major agent of progress, and yet innovators' incomplete knowledge sometimes leads to undesirable side effects. Such unforeseen consequences of new inventions are not unique to the feverish industrialization of the 19th and 20th centuries. The ancient Greek myths tell of Pandora and the box full of plagues, of Prometheus punished for stealing fire from the gods and of Icarus, who plummeted from the sky when the sun's heat melted the wax of his wings. In historical times the shift from rawhide to tanned leather, although it made for garments and tools that lasted much longer and were more comfortable to wear and use, brought stench and disease, so that tanneries had to be segregated from the communities they served.

Today such inadvertent effects can have a global impact. Consider, for example, the invention of chlorinated fluorocarbons. Before CFC's were developed in the 1930's, refrigerator compressors contained ammonia or sulfur dioxide; either chemical was toxic, and leaks killed or injured many people. CFC's saved lives, saved money and provided such elements of modern life as air-conditioned buildings and untainted food. Only later did atmospheric scientists determine that CFC's contribute to global warming and affect the chemistry of the upper atmosphere, where they destroy ozone.

Such failures should not diminish the fact that technology has improved the lot of people everywhere. Standards of living in many parts of the world are better today than they were 20 or 30 years ago. Many of the adverse effects of industrialization have been brought under control by further applications of technology. Yet as the world's population and standard of living increase, some of the old solutions to industrial pollution and everyday wastes no longer work. There is often no "other side of town" where the modern equivalents of tanneries can be put, no open space beyond the village gates where garbage can be dumped and do no harm.

By the year 2030, 10 billion people are likely to live on this planet; ideally, all would enjoy standards of living equivalent to those of industrial democracies such as the U.S. or Japan. If they consume critical natural resources such as copper, cobalt, molybdenum, nickel and petroleum at current U.S. rates, and if new resources are not discovered or substitutes developed, such an ideal would last a decade or less. On the waste side of the ledger,

at current U.S. rates 10 billion people would generate 400 billion tons of solid waste every year--enough to bury greater Los Angeles 100 meters deep.

These calculations are not meant to be forecasts of a grim future. Instead they emphasize the incentives for recycling, conservation and a switch to alternative materials. They lead to the recognition that the traditional model of industrial activity--in which individual manufacturing processes take in raw materials and generate products to be sold plus waste to be disposed of--should be transformed into a more integrated model: an industrial ecosystem. In such a system the consumption of energy and materials is optimized, waste generation is minimized and the effluents of one process--whether they are spent catalysts from petroleum refining, fly and bottom ash from electric-power generation or discarded plastic containers from consumer products--serve as the raw material for another process.

The industrial ecosystem would function as an analogue of biological ecosystems. (Plants synthesize nutrients that feed herbivores, which in turn feed a chain of carnivores whose wasted and bodies eventually feed further generations of plants.) An ideal industrial ecosystem may never be attained in practice, but both manufacturers and consumers must change their habits to approach it more closely if the industrialized world is to maintain its standard of living--and the developing nations are to raise theirs to a similar level--without adversely affecting the environment.

If both industrialized and developing nations embrace changes, it will be possible to develop a more closed industrial ecosystem, one that is more sustainable in the face of decreasing supplies of raw materials and increasing problems of waste and pollution. Industrialized nations will have to make major and minor changes in their current practices. Developing nations will have to leapfrog older, less ecologically sound technologies and adopt new methods more compatible with the ecosystem approach.

Materials in an ideal industrial ecosystem are not depleted any more than those in a biological one are; a chunk of steel could potentially show up one year in a tin can, the next year in an automobile and 10 years later in the skeleton of a building. Manufacturing processes in an industrial ecosystem simply transform circulating stocks of materials from one shape to another; the circulating stock decreases when some material is unavoidably lost, and it increases to meet the needs of a growing population. Such recycling still requires the expenditure of energy and the unavoidable generation of wastes and harmful by-products, but at much lower levels than are typical today.

Today's industrial operations do not form an ideal industrial ecosystem, and many subsystems and processes are less than perfect. Yet there are developments that could be cause for optimism. Some manufacturers are already making use of "designed offal," or "engineered scrap," in the manufacture of metals and some plastics: tailoring the production of waste from a manufacturing process so that the waste can be fed directly back into that process or into a related one. Other manufacturers are designing packaging to incorporate recycled materials wherever possible or are finding innovative uses for materials that were formerly considered wastes.

Three examples delineate some of the issues involved in developing self-sustaining industrial process systems: the conversion of petroleum derivatives to plastics, the conversion of iron ore to steel, and the refining

and use of platinum-group metals as catalysts. We have picked these examples because each represents a different stage in the evolution of a closed cycle. Examining their workings and shortcomings should provide insight into how subsystems can be improved so as to develop an industrial ecosystem.

The iron cycle, in which recycling is well established, is a very mature process with a history dating back thousands of years, even though extensive production of steel did not begin until the 19th century. The plastics cycle, in which reuse is just beginning to make its mark, is less than 100 years old; the first completely synthetic plastic, Bakelite, was introduced shortly after the turn of the century. The platinum-group-metals cycle--in which reuse is common because of the high cost of the materials involved--is even younger: industrial noble-metal catalysts became widely used only in the early 1950's, and the widespread use of noble metals to reduce pollution from automotive exhaust dates back less than 15 years.

The plastics system is potentially highly efficient, but realizing that potential poses challenges that have yet to be met. Plastics are a diverse group of chemically complex compounds whose use has grown explosively, so that they now present a growing disposal problem. Plastics are formed into any number of products, and different plastic resins are difficult to distinguish. This difficulty leads to problems in collection, separation and recycling. Moreover, breaking plastics down to their original chemical constituents is often technologically infeasible or economically unattractive.

The drawbacks of plastics must nonetheless be weighed against their benefits. Plastic containers, for example, are safer than the glass containers they replace. Countless injuries, from minor cuts to severe lacerations, have been prevented by the substitution of plastic for glass in milk bottles and containers for bathroom products such as shampoo. Plastic containers are generally lighter than glass or metal ones, so that less energy is required to transport them; they also require less energy to make than glass or metal containers, especially if they are recycled. The Midwest Research Institute in Kansas City, Mo., determined that compared with glass containers, half-gallon polyvinyl chloride (PVC) containers require less than half the energy to produce and transport and consume one twentieth the mass of raw materials and less than one third as much water in their manufacture. They also generate less than half of the waste of glass manufacturing.

Each kind of plastic poses different problems depending on its particular composition and use. PVC, of which almost four million tons are produced every year in the U.S., is a particularly dramatic example of the complex threats plastics pose to the environment. PVC, which accounts for about one sixth of total plastic production, is made into products ranging from pipes to automobile parts to shampoo bottles. Its production requires both hydrocarbons and chlorine. (The chlorine makes the plastic's impact on the environment greater than it would be if only hydrocarbons were required--as is the case for polyethylene, for example.) Natural gas is the most commonly used feedstock for PVC in the U.S.; elsewhere it is naphtha, a petroleum fraction. In either case the feedstock is converted to ethylene, which is chlorinated to form vinyl chloride monomer; the monomer molecules are then linked to form PVC.

The efficiency of the production process has already been improved. For example, manufacturers have developed more efficient membrane cells for the electrolysis of sodium chloride to produce the required chlorine. (The sodium

chloride, common table salt, is dissolved in cells through which a current flows; sodium ions migrate to one electrode, and chlorine ions migrate to the other. A membrane separates the two electrodes.) The membrane cells also eliminate the asbestos and mercury required in older electrolysis cells, thus reducing hazardous wastes.

Even so, the PVC production process exemplifies classic "end of pipe" control measures for reducing pollutants. Emissions of vinyl chloride monomer during manufacturing are tightly controlled, a practice instituted when it became known that the monomer is both toxic and carcinogenic. Unreacted vinyl chloride is generally stripped from the finished PVC by low-pressure steam. Most of the monomer is recovered and recycled, but some of it is present at concentrations too low for easy recovery and recycling; instead it is sent to an incinerator to be broken down. Scrubbers remove hydrochloric acid from the exhaust.

Recycling of PVC during manufacturing is fairly straightforward. Plants that make PVC products typically recycle almost all of their in-house scrap. At General Motors, for example, scrap generated in the manufacture of PVC parts such as decorative trim, seat covers and dashboards is segregated by color, reground, melted and used along with virgin PVC.

Once plastic enters the consumer market, however, recycling becomes considerably more complicated. Only about 1 percent of the PVC discarded by consumers is recycled. The wide range of products in which PVC is found makes collection and recovery more difficult, but it also creates interesting opportunities. For example, potential health hazards and liability concerns prevent recycled plastics from being incorporated into containers where the plastic touches food; recycled bottles may find their way into drainage pipes instead.

Other vinyl products that cannot easily be recycled can be burned to produce heat or electricity. PVC contains roughly as much energy as wood or paper, but its chlorine content poses problems: incinerators that burn PVC must have scrubbers to prevent emissions of hydrochloric acid, which contribute to acid rain. During combustion the chlorine can also form small amounts of dioxins, which are believed to be potent carcinogens. As a result, the incineration of discarded PVC is discouraged. Although recent tests by the New York State Energy Research and Development Authority have shown that properly designed and operated incinerators do not emit significant quantities of hydrochloric acid or dioxins, environmentalists and regulators are not convinced that incinerators would achieve such low emission levels in practice.

Because of its chlorine content, PVC is a worst-case example of the problems plastics pose. Other polymers such as polypropylene and polyethylene present fewer environmental hazards. They have physical properties similar to those of PVC, but they contain no chlorine. Polyethylene terephthalate (PET), the material used in carbonated beverage bottles, is recycled in nine states that have mandatory deposit laws: California, Connecticut, Delaware, Maine, Massachusetts, Michigan, New York, Oregon and Vermont. Bottles collected in these states account for 150 million of the 750 million pounds of PET resin produced every year. Recyclers pay from \$ 100 to \$ 140 per ton of PET, making it the second most valuable component of municipal solid waste after aluminum. The PET is reconstituted into resins for injection molding to produce products ranging from automobile parts to electronic devices or is spun into polyester fibers that go into pillows, stuffed furniture, insulated clothing and

carpeting.

As the infrastructure for collecting and sorting PET and other consumer plastics grows, recycling rates should increase significantly. According to recyclers such as Wellman Inc., of Shrewsbury, N.J., which currently processes about 100 million pounds of PET a year, the market for recycled plastics is limited by collection efficiency rather than by demand.

The industrial system for iron presents a different picture. Techniques for recycling are well established, and there is a strong infrastructure for collecting scrap. Yet discarded metal continues to pile up in scrapyards and across the U.S. because there is not enough demand for it. Elemental iron, the predominant component of both steel and cast iron, is the backbone of modern life: it is used in roads, in the automobiles that pass over the roads and in buildings. In the U.S. iron production begins when ore is mined in huge open pits as deep as 100 meters or more. The ore is concentrated and formed into pellets at the mine and then converted into pig iron in a blast furnace, where it is heated with coke, limestone and air. The coke adds carbon to the mix, and the limestone and the oxygen in the air react with impurities in the ore to form slag, which is then removed. Small admixtures of other elements yield steel to be cast, rolled or forged into billets, slabs, beams or sheets.

Once iron has been formed into products, which are eventually discarded, its properties (especially its ferromagnetism) facilitate identification and separation. The enormous amount of iron in circulation makes recycling relatively easy and economically attractive. It is not surprising, therefore, that every year millions of tons of scrap join iron ore to produce steel products. The scrap generated by stamping steel parts for automobiles, for example, is recycled into engine blocks and other castings. All four foundries that GM operates rely entirely on scrap steel obtained from other GM operations and on scrap iron generated during the casting process.

Although iron recycling is a relatively simple process, the system is not a closed loop. Much of the scrap from discarded consumer products is not recovered but is scattered around the countryside, where it corrodes away a little every year and is considered a blight rather than an asset. In 1982 recoverable iron scrap amounted to 610 million tons; at the end of 1987 the figure had risen to more than 750 million. A major reason for the increase is that U.S. production of iron and steel during this period was the lowest it had been since the end of World War II. The demand for scrap to make steel decreased while iron and steel products continued to be scrapped at the previous rate.

Shifting patterns of steel manufacturing, both in the U.S. and around the globe, are responsible for the increase in scrap. One subtle culprit is a technology shift from open-hearth furnaces to basic oxygen furnaces for producing steel. Basic oxygen furnaces (so called because they make steel in a large closed vessel supplied with pressurized oxygen) require only 25 tons of scrap steel to be mixed with every 100 tons of pig iron from the blast furnace, as opposed to a nearly equal mix for the open hearth.

The shift to basic oxygen furnaces began in the U.S. about 1958, and today open-hearth furnaces account for less than 3 percent of total production. Open-hearth furnaces were replaced to improve manufacturing efficiency and reduce air pollution, but their disappearance led to a decline in iron

recycling. In making these changes, steelmakers had no economic mechanism for taking account of the adverse environmental impacts of scrap accumulation or the possible long-term effects of consuming more iron ore for each unit of steel.

More recently minimills have been built that rely on electric-arc furnaces and consume scrap steel almost exclusively. These low-volume mills have increased their share of U.S. steel production, but not enough to compensate for the lost demand for scrap to feed open-hearth furnaces. Furthermore, minimills produce only a limited range of steel products, and many of those products must be made from scrap containing very low levels of impurities. Scrap that contains excess copper, for example, is not suitable for making sheet steel, because the resulting sheet is too brittle to form into products. If electric-arc furnaces are to make significant inroads into the U.S. stock of scrap iron, they must be coupled to production facilities that produce a wider range of products, and better techniques must be developed for dealing with impure scrap.

Platinum-group metals (platinum, palladium, rhodium, ruthenium, iridium and osmium) were, until the mid-1970's, part of a very efficient industrial system. These metals were once recycled with efficiencies of 85 percent or better, but the advent of catalytic converters for automobiles dealt this system a shock from which recycling rates are only now beginning to recover.

Recycling of platinum-group metals is dictated not so much by the environmental effects of their disposal as by their limited supply and the difficulties of mining and refining them. Ores contain only about seven parts per million of mixed platinum-group metals, so that about 20 million metric tons a year must be refined to produce 143 tons of purified metals--an amount that could fit into a cube roughly two meters on a side.

About 60 percent of the platinum-group metals mined is formed into metal products such as jewelry, ingots for investors and chemical-reaction vessels; these products are eventually recycled with almost complete efficiency. The remainder is used to make chemicals and catalysts for chemical plants, petroleum refineries and automobiles. Catalysts adsorb molecules on their surfaces and promote chemical reactions that either join the molecules together or break them into smaller ones. Catalytic converters for automobiles, which reduce exhaust emissions of hydrocarbons, carbon monoxide and oxides of nitrogen, are the most rapidly growing use of platinum-group metals; consumption rose from about 11.5 metric tons in 1975 to about 40 in 1988. Automobiles currently account for most of the yearly permanent consumption of platinum-group metals.

Platinum-group metals in industrial applications are recycled quite efficiently. Each plant uses large amounts of catalyst, so that the payoffs from recycling are clear. Used catalysts are generally recycled every few months, providing a large, continuing stream of materials for reclaimers to process. In chemical and pharmaceutical plants, for example, catalysts are typically recycled in less than a year, and about 85 percent of the platinum-group metals in them are recovered. Some petroleum refineries are even more successful, recovering up to 97 percent of their noble metals.

The automotive pattern of noble-metal use stands in sharp contrast to that of the process industries: there are tens of millions of catalytic converters, each of which contains only a few grams of platinum-group metals (less than two grams of platinum, for example), and the lifespan of about 10 years for an average

car makes for a much slower turnover of recyclable materials. As a result, only about 12 percent of the platinum-group metals in catalytic converters is currently recycled.

Poor recycling rates for automotive catalysts can be blamed almost entirely on the lack of an effective means for collecting discarded converters. The technology for recovering platinum-group metals from the converters is quite well understood; a plant opened by Texasgulf Minerals & Metals, Inc., in Ala. in 1984 recovers 90 percent of the platinum, 90 percent of the palladium and 80 percent of the rhodium from used converters. Millions of individual converters, however, are dispersed among thousands of scrapyards and almost 2,000 automotive scrap recyclers. The cost of locating, collecting and emptying the converters and then transporting the catalyst to a reprocessing plant is sufficiently high so that recycling is not profitable for most refining operations unless the price of platinum exceeds \$ 500 an ounce.

The outlook for catalytic-converter recycling is improving. Now that most of the first-generation of cars built with catalytic converters have found their way to U.S. scrapyards, there is a large, continuing flow of raw materials for recyclers. More important, an infrastructure for collecting spent converters is being established. Even Japanese companies such as Nippon Engelhard have set up collecting organizations in the U.S. to acquire automotive catalysts for reprocessing in Japan. In addition the introduction of more stringent emissions controls in Europe, where catalytic converters have not been required, will increase the demand for platinum-group metals, making recycling more profitable.

The life cycles of plastics, iron and the platinum-group metals illustrate some of the issues involved in creating sustainable industrial systems. Equally important is the way in which the inputs and outputs of individual processes are linked within the overall industrial ecosystem. This linkage is crucial for building a closed or nearly closed system.

Like their biological counterparts, individual manufacturing processes in an effective industrial ecosystem contribute to the optimal function of the entire system. Processes are required that minimize the generation of unrecyclable wastes (including waste heat) as well as minimize the permanent consumption of scarce material and energy resources. Individual manufacturing processes cannot be considered in isolation. A process that produces relatively large quantities of waste that can be used in another process may be preferable to one that produces smaller amounts of waste for which there is no use.

A good example of the subtleties involved is the dematerialization of manufactured goods--the use of plastics, composites and high-strength alloys to reduce the mass of products. The trend toward dematerialization has drawn increasing attention in recent years. The mass of a typical automobile, for example, has decreased by more than 400 kilograms since 1975; about 100 kilograms of the decrease are due to the substitution of aluminum and plastics for steel. Lighter cars burn less gasoline. Steel, however, is easy to recycle, whereas the composite plastics that have replaced it resist reuse. The net result may be an immediate drop in fuel consumption but an overall increase in the amount of permanent waste created and in the resources consumed.

Waste-minimization activities in U.S. industries have been aided by regulations developed in the late 1970's to control hazardous-waste disposal. The regulations, reflecting long-term environmental costs, have increased the

cost of landfill disposal from less than \$ 20 a ton to \$ 200 a ton or more, making alternatives to disposal profitable. Many companies find it profitable to sell their wastes as raw materials. For example, Meridian National in Ohio, a midwestern steel-processing company, reprocesses the sulfuric acid with which it removes scale from steel sheets and slabs, reuses the acid and sells ferrous sulfate compounds to magnetic-tape manufacturers.

If the production of unrecyclable wastes is to be eliminated, similar steps must be taken for each of the low-level by-products in large stream of process effluents. Although emissions at each stage of such manufacturing processes may be relatively small, taken together they can cause serious pollution problems. Minimizing each of these myriad smaller emissions one at a time is a complex and potentially costly challenge.

The challenge can be met in part by implementing a multitude of relatively small changes. Some chemical plants and oil refineries, for example, have significantly reduced their hazardous-waste output by simply changing their procedures for buying and storing cleaning solutions and other low-volume chemicals. By doing so, they have been able to eliminate the need to dispose of leftover amounts.

At ARCO's Los Angeles refinery complex, a series of relatively low-cost changes have reduced waste volumes from about 12,000 tons a year during the early 1980's to about 3,400 today, generating revenue and saving roughly \$ 2 million a year in disposal costs. The company sells its spent alumina catalysts to Allied Chemical and its spent silica catalysts to cement makers. Previously these materials were classified as hazardous wastes and had to be disposed of in landfills at a cost of perhaps \$ 300 a ton.

Alkaline carbonate sludge from a water-softening operation at the refinery goes to a sulfuric acid manufacturer a few miles away, where it neutralizes acidic wastewater. (The acid manufacturer previously purchased pure sodium hydroxide for the same purpose.) A few outflow pipes have been rerouted to improve access for loading, and plant personnel must track the [rho]H of their sludge, but the total investment has been minimal.

The ARCO refinery has also started to recover oil from internal spills and other wastes in a new \$ 1-million recycling facility. When the recycler is fully operational next year, it is expected to reduce wastes by another 2,000 tons. Off-site treatment or landfiling will still be needed for miscellaneous wastes such as solvents, spray cans and the several hundred tons of asbestos insulation being removed from the plant each year.

ARCO's situation is not unique; other major refiners and chemical manufacturers are engaged in similar efforts. For example, investments of \$ 300,000 in process changes and recovery equipment at Ciba-Geigy's Toms River plant in New Jersey reduced disposal costs by more than \$ 1.8 million between 1985 and 1988. Dow Chemical established a separate unit to recover excess hydrochloric acid, which it then either recycles to acid-using processes or sells on the open market. The operation recovers a million tons of acid a year at a profit of \$ 20 million.

By-products and effluents created during manufacturing represent only the supply side of the industrial ecosystem. The demand side is the consumer, who takes in manufactured goods and produces scrap that could be the raw materials

for the next cycle of production. If the industrial-ecosystem approach is to become widespread, changes in manufacturing must be matched by changes in consumers' demand patterns and in the treatment of materials once they have been purchased and used.

The behavior of consumers in the U.S. today constitutes an aberration in both time and space. Whereas a typical New Yorker, for example, discards nearly two kilograms of solid waste every day, a resident of Hamburg or Rome throws out only about half that--as New Yorkers did at the turn of the century. Moreover, U.S. consumer habits and waste-management practices form a complex pattern that hinders efforts to reduce waste generation and the growing pressure on municipal landfills. The vast bulk of consumer wastes consists of organic materials and plastics that could relatively easily be composted, recycled or burned to produce energy but instead are stored in landfills, for which land was readily available in the past and where costs were low.

Today, as landfills across the U.S. near capacity, many communities have initiated garbage-sorting programs to reduce the amount of unrecycled waste; more initiatives are likely to follow. Some other countries have already instituted fairly sophisticated collection and treatment practices that go well beyond standard sorting and recycling. Japan, Sweden and Switzerland, for example, have set up collection centers for batteries from portable radios and other consumer products. The batteries contain heavy metals that render composted wastes unsuitable for fertilizing crops; the metals also contaminate fly and bottom ash from incinerators, so that the ash must be disposed of as hazardous waste.

An effective infrastructure for collecting and segregating various consumer wastes can dramatically improve the efficiency of the industrial ecosystem. The American consumer may have to stop heedlessly generating huge volumes of unsorted wastes, but living standards in the U.S. as a whole will not be affected. Moreover, landfills for municipal wastes are running out of space as rapidly as are those for industrial waste; consumers will soon find themselves facing the same economic incentives for waste reduction that producers face today.

Creating a sustainable industrial ecosystem is highly desirable from an environmental perspective and in some cases is highly profitable as well. Nonetheless, there are a number of barriers to its successful implementation. Corporate and public attitudes must change to favor the ecosystem approach, and government regulations must become more flexible so as not to unduly hinder recycling and other strategies for waste minimization.

Federal hazardous-waste regulations are a case in point. They sometimes make waste minimization more difficult than waste disposal. Because of the strict requirements for handling and documenting the treatment of wastes classified as hazardous, many companies choose to buy their materials through conventional channels rather than involve themselves in the regulatory process. A few states do encourage innovative treatment of wastes: California, for example, publishes a biannual catalogue that attempts to match waste generators with waste

buyers--manufacturers who need the materials they produce. About half a million tons of hazardous wastes that would otherwise have gone to landfills were recycled in 1987. A dozen other state, provincial and regional waste exchanges operate throughout the U.S. and Canada.

In addition to promoting innovative waste-minimization schemes, governments need to focus on the economic incentives for sustainable manufacturing. Increased landfill costs have forced companies to improve industrial process and reduce unrecyclable waste, but many small emissions are still controlled by classic end-of-pipe regulations that specify how much of each pollutant may be discharged. Companies must meet regulatory requirements, but there are no direct advantages for manufacturers who capture and treat low-level effluents or who shift to production processes with more benign by-products.

Conventional economic methods take into account only the immediate effects of production decisions. If a manufacturer produces nonrecyclable container, for example, taxpayers at large bear the increased landfill costs; if a power plant reduces emissions that cause acid rain, communities elsewhere are likely to reap the benefits. Returns to the manufacturer or utility are generally indirect.

Instead of absolute rules, economists have long advocated financial incentives to reduce pollution. These include investment or research credits, tax relief, or fees or taxes imposed on manufacturers according to the amount and nature of the hazardous materials they produce. Such measures can help pay for treatment or disposal; more important, they give companies an incentive to change their manufacturing processes so as to reduce hazardous-waste production. Fees and taxes for pollution make environmental costs internal, so that they can be taken into account when making production decisions [see "Toward a Sustainable World," by William D. Ruckelshaus, page 166].

Pollution fees have come under fire from environmentalists and industrialists as "licenses to pollute" and as "distortions of the market." Both criticisms are potentially valid. Companies can treat fees that are too low as a cost of doing business and pass them on to customers; fees that are too high may force companies to reduce emissions of specific pollutants without regard to other environmental effects or to financial burdens.

Suitably set charges or incentives, however, can be an effective means for manufacturers to incorporate societal costs of pollution and waste into their cost accounting systems. As in the case of rising landfill fees for hazardous wastes, cost feedback for other pollutants could make it more attractive to solve problems at the source rather than to destroy or dispose of effluents once they have been created. Such fees enable manufacturers to share in the overall economic savings accruing from reduced levels of hazardous materials. Providing economic incentives would harness manufacturers' strong competitive drive to reduce costs. Indeed, manufacturers who ignore this imperative perish from the marketplace, a situation that would not change if the societal costs of pollution were allocated to them.

Economic incentives alone are not enough to make the industrial-eco-system approach commonplace. Traditional manufacturing processes are designed to maximize the immediate benefits to the manufacturer and the consumer of individual products in the economy rather than to the economy as a whole. A holistic approach will be required if the proper balance between narrowly defined economic benefits and environmental needs is to be achieved. (Broadly defined, of course, economic and environmental goals are the same: bad places to live do not make for good markets.)

The concepts of industrial ecology and system optimization must be taught more widely. Current engineering and technological education either omit

these concepts entirely or teach them in such a limited way that they have little impact on the approaches taken to the environmental problems associated with manufacturing. Changing the content of technological education, however, will not be enough. The concepts of industrial ecology must be recognized and valued by public officials, industry leaders and the media. They must be instilled into the social ethos and adopted by government as well as industry.

Government regulation of emissions at the local, national and international level will continue to play a strong role in the transition from traditional methods of manufacturing to an industrial-ecosystem approach. The transition to an ecosystem approach would be accelerated by the early adoption of economic incentives as part of the regulatory system.

To make regulation as effective as possible, officials must be base their policies on sound technology and make allowance for technological change. Rules must be cast so as to encourage (or at least not discourage) the development of alternative processes and innovative methods for dealing with industrial by-products. Regulators must take advantage of industry's technological know-how so as to avoid counterproductive control measures. Such a wise regulatory framework will be almost impossible to construct unless government, industry and environmental groups abandon their current adversarial relationships and work together to solve their shared problems.

Even with an industrial-ecosystem approach in place, decisions about how best to allocate resources will not always be easy. Petroleum, for example, is not just a source of energy but also a raw material essential for manufacturing chemicals, plastics and other materials. Some analysts have argued that it should be used only as a raw material and not for energy. A similar argument could be made for using coal as a feedstock instead of as a fuel. On the output side, plastics can be burned for energy, recycled into new products or even reduced to their chemical constituents; it is not clear which choice is unequivocally sounder. Careful analysis of the consequences by "industrial ecologists" will be required to answer such questions.

The ideal ecosystem, in which the use of energy and materials is optimized, wastes and pollution are minimized and there is an economically viable role for every product of a manufacturing process, will not be attained soon. Current technology is often inadequate to the task, and some of the knowledge needed to define the problems fully is lacking. The difficulties in implementing an industrial ecosystem are daunting, especially given the complexities involved in harmonizing the desires of global industrial development with the needs of environmental safety.

Nonetheless, we are optimistic. The incentive for industry is clear: companies will be able to minimize costs and stay competitive while adhering to a rational economic approach that accounts for global costs and benefits. Equally clear are the benefits to society at large: people will have a chance to raise their visible standards of living without incurring hidden environmental penalties that degrade the quality of life in the long run. Remembering that people and their technologies are a part of the natural world may make it possible to imitate the best workings of biological ecosystems and construct artificial ones that can be sustained over the long term.

GRAPHIC: Photograph; Table; Chart; Caption: Estimated lifetimes of some global resources; Industrial-ecosystem cycle.; Platinum-group metal recycling

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Industrial Ecology Route To Slow Global Change Proposed

International industry-environment conference suggests ways to reconfigure industry and agriculture worldwide to halt damage to environment

Bette Hileman, C&EN Washington

Since the start of the Industrial Revolution, we human beings have been rapidly reconfiguring planet Earth. In many countries we still take lead from deep inside Earth, react it with ethyl chloride, and use the product to raise the octane level of gasoline. We then burn the gasoline, spreading the lead through the air into water bodies and soil in every corner of the globe. We mine coal and burn it, vaporizing the metals it contains, and thereby help raise mercury in fish to toxic levels in many lakes across North America. In producing fertilizer and burning fossil fuel, we break nitrogen bonds about as quickly as do natural ecosystems, so as to roughly double the amount of fixed nitrogen, as nitrates, globally. We naphazardly disperse these nitrates across forests, fields, lakes, and streams in every land.

Industrial ecology is the study of how we humans can continue rearranging Earth, but in such a way as to protect our own health, the health of natural ecosystems, and the health of future generations of plants and animals and humans. It encompasses manufacturing, agriculture, energy production, and transportation—nearly all of those things we do to provide food and make life easier and more pleasant than it would be without them.

For two weeks late last month, 51 invited participants from a wide variety of disciplines and 10 countries met in Snowmass Village, Colo., to consider broad questions concerning industrial ecology and global change and to recommend actions and research in this area. The meeting was organized by the Office for Interdisciplinary Earth Studies, part of the University Corporation for Atmospheric Research, based in Boulder, Colo. It was directed by Robert H. Socolow, head of the Center for Energy & Environmental Studies at Princeton University.

Several conferences on industrial ecology have been held during the past two years, but previous meetings have not included participants from so many different disciplines and countries. Nor have they made

a strong attempt to relate global environmental damage to industrial ecology or to develop recommendations for implementation and research in this area.

A surprising outcome of the recent Snowmass meeting was the nature of the discussion among the participants. When there were disagreements, they did not occur between environmental scientists and representatives from industry. Most of the conflicts stemmed from the participants' habitual ways of looking at issues, which, as it turned out, were very different for sociologists than for physicists.

A conflict occurred between those people who preferred to work from the bottom up—that is to try to solve problems in the current industrial system—and those who wanted to work from the top down. These latter individuals preferred first to decide on a vision for an ideal future environmentally sustainable society and then to reconfigure industrial activities to reach that goal.

Despite the disagreements, most participants came away from the meeting convinced they had benefited from the cross-fertilization of ideas. Industry representatives found they shared common approaches with those whom they least expected to agree—the environmentalists—in part because both shared a common sense of urgency about finding practical, workable, action-oriented means of preventing environmental degradation. That shared knowledge, which is leading to future research collaboration, is probably the most practical outcome of the meeting.

The primary aim of the Snowmass meeting was to think about ways of reconfiguring industrial activity to reduce harm to the human and natural environment at the global level. To this end, the participants assessed the vulnerability of several global environmental systems to human activity. They emphasized damage to the air and soil and were especially interested in effects that are in evidence throughout the world rather than those specific to particular regional ecosystems.

They looked at patterns of past global industrialization and prospects for future industrialization.



Photos by C&EN's Bette Hileman

Socolow: industrial ecology lies at intersection of industrial innovation and environmental science

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With this deeper understanding of the environmental damage that has taken place and of past and future industrial trends, they considered how to redesign industrial activity so that past disturbances are gradually reversed and future harmful disturbances are avoided.

At the meeting, participants learned that a number of companies have already begun to practice industrial ecology. For example, General Motors-Europe has committed to taking back and recycling its new Opel Astra automobiles at the end of their useful life. And Volvo has developed an index to rank the environmental compatibility of alternative designs of vehicle components, such as engines and bumpers.

The participants also judged that biomass fuels, grown renewably, have great potential to mitigate global warming. They explored some of the implications of transforming the economy from goods to services as a way to reduce adverse impacts on the environment. Concern for the environment need not constrain economic activity, the participants concluded. Rather, it can stimulate new technological innovation and economic growth.

Because of the global focus of the meeting, the attendees paid particular attention to several very damaging practices that have been abandoned in the industrialized world and yet are spreading rapidly in the developing countries. For example, chlorofluorocarbons (CFCs) are being phased out in the developed world, but a German company is building a factory to produce CFCs in China where their use is expected to expand greatly as allowed by the Montreal Protocol on Substances That Deplete the Ozone Layer. Also, the amount of tetraethyl lead added to gasoline is growing rapidly in the Third World, although the compound is no longer used or is being phased out in the U.S., Canada, and most of Europe. The participants concluded that more than knowledge of environmental damage and technological fixes are required to stop these harmful practices.

The term industrial ecology arose out of its relationship to biological ecology. In a biological ecosystem, nothing is wasted. All products of metabolism of one organism are useful to another, and the only external energy supply is sunlight.

Similarly, an ideal industrial ecological system would produce no waste and would be fueled by energy from sunlight. The waste from one process would be used as feedstock for another, and at the end of their useful lives final products would be recycled back into their original form or into something else that is as valuable as the original product. The overall system would not dissipate resources—or, in other words, deplete resources for future generations.

As defined by the meeting at Snowmass, industrial ecology concerns more than what goes on inside a factory. It encompasses the interrelationships among raw materials extraction, transportation of these materials, manufacture of products, and disposition of wastes from manufacture and packaging. It also concerns the transportation and disposition of the final products, whether they become useful raw materials for new products, and whether they harm human or wild ecosystems while they are being used. It includes agriculture as well. It asks whether food and animal feed are produced in a way that depletes or erodes soils and whether the agricultural inputs damage ecosystems.



Schlesinger (left): atmospheric changes could contribute to species losses. Schmoor: metals in soils could hurt agriculture

According to Thomas E. Graedel of the Environmental Chemistry Research Laboratory at AT&T Bell Labs, "Industrial ecology arises from the perception that human economic activity is causing unacceptable changes in basic environmental support systems." It seeks alternative approaches that will reduce greenhouse gas buildup, dissipative uses of heavy metals, dispersion of long-lived toxic chemicals, and excessive fertilization in agriculture.

Because it involves so many interrelationships, an ecological industrial system cannot be designed without knowledge from several scientific disciplines. "Industrial ecology lies at the intersection of two scientific communities—industrial innovation and environmental science," says Socolow. At the meeting he repeatedly emphasized the need for industry to become more aware of developments in environmental science and for environmental scientists to become more aware of the implications of new industrial practices for Earth as a biological and physical system.

Robert U. Ayres of the European Institute of Business Administration in Fontainebleau, France, discussed the human influences on the circulation of carbon, nitrogen, sulfur, and phosphorus between the land, the atmosphere, and the oceans. Ayres calls the circulation of these elements "grand cycles." Human activities have accelerated the cycling of these elements through the biosphere. Carbon is cycling about 5% faster, and nitrogen, sulfur, and phosphorus are cycling two to five times faster than they would without human intervention.

Because of fossil fuel combustion and deforestation, the concentration of carbon dioxide in the atmosphere is 25% higher than it was 200 years ago. On a global basis, intentional industrial nitrogen fixation in fertilizer production and unintentional fixation in high-temperature combustion are now about equal to biological nitrogen fixation, Ayres says. The emissions of sulfur dioxide from fossil fuel combustion are several times higher than emissions of sulfur gases from all other sources. He estimates that about twice as much phosphorus is mobilized by industry than is released in global rock weathering.

Several scientists at the conference discussed the specific vulnerabilities of global environmental systems to these disruptions in the grand cycles. For instance, V. Ramanathan of Scripps In-

Summer institutes focus on global-change factors

The subject for the meeting in Snowmass Village, Colo., "Industrial Ecology and Global Change," grew out of the desire of Earth system modelers for insight into how human activities affect global change. In response, the Office for Interdisciplinary Earth Studies, part of the University Corporation for Atmospheric Research, Boulder, Colo., as a service to the environmental community, decided to devote two of its annual summer institutes to these issues.

The 1991 summer institute addressed modifications to land cover, such as deforestation and urbanization, that affect global change. This

summer's institute addressed changes in the chemical characteristics of the environment (including the atmosphere, aquatic environment, and soil) resulting from economic activity that affect global change. From its initial emphasis on chemical changes to Earth's system, the 1992 institute evolved into an examination of opportunities for industries to become more responsive to averting environmental damage.

The institute was organized principally by a three-person executive committee consisting of Robert H. Socolow, director of the Center for Energy & Environmental Studies at

Princeton University; Thomas E. Graedel of the Environmental Chemistry Research Laboratory at AT&T Bell Labs; and William Moomaw of Fletcher School of Law & Diplomacy at Tufts University.

The institute was funded by the federal Committee on Earth & Environmental Sciences, an interagency group consisting of 14 federal departments and agencies that coordinate the U.S. Global Change Research Program. The central goal of this program is "to help establish the scientific understanding and the basis for national and international policy-making related to natural and human-induced changes in global Earth systems."

stitution of Oceanography, La Jolla, Calif., notes that humans have already increased the greenhouse effect, or warming effect from greenhouse gases, by 2 watts per square meter, or about 1.5% of the 150 watts per sq m of infrared radiation trapped by clouds and atmospheric gases. In contrast, solar output has varied by 0.5 watts per sq m, at most, during the past century. If the 1980s trend for greenhouse gases continues for another century, the atmospheric warming effect of greenhouse gases will be 8 to 10 watts per sq m. "No one can dispute that 8 to 10 watts per square meter is a major perturbation," Ramanathan says. The question is how soon and by how much that change in greenhouse effect will change Earth's temperature. "If we wait for model certainty [before taking action to control greenhouse gases], we are in for a big, sad surprise," he warns.

Human-induced changes in the atmosphere may already be reducing biological diversity and they are threatening to produce catastrophic changes in the future, says William H. Schlesinger of the departments of botany and geology at Duke University. At least three types of atmospheric changes could contribute to species losses: increased carbon dioxide, increased nitrates, and stratospheric ozone depletion.

The extra nitrate produced by industrial activity is delivered to natural ecosystems mainly through acid deposition, he says. It would be expected to fertilize natural forests, and indeed there is evidence that temperate forests may have accelerated their growth rates.

But there is also evidence that fertilizing natural systems leads to a loss of species diversity. For example, Schlesinger notes, "a long-time fertilized pasture in Great Britain showed a remark-

able reduction in plant diversity from 1856 to the present, as a large number of rare species were replaced by a small number of aggressive weedy species that assumed dominance in the community." Ecologists explain this loss of species by saying that "any addition of a resource to a natural community will lead to the dominance of the species that can use that resource most efficiently."

Similarly, doubling the level of carbon dioxide in the atmosphere is expected to cause losses in species because it, too, has a fertilizing effect. This is the case especially for plants that use the C_3 pathway for photosynthesis—those that initially incorporate carbon dioxide in their tissues as a three-carbon phosphoglyceric acid. Some biologists believe that the invasion of black grama grasslands (C_4 plants, which incorporate carbon dioxide as a four-carbon carboxylic acid) by creosote bush and mesquite (which are both C_3 plants) in New Mexico during the past century may be partly caused by the 25% increase in carbon dioxide levels, as well as by overgrazing.

Also, carbon dioxide in the atmosphere is expected to have an indirect effect on species. The global warming of 1.5 to 4.5 °C predicted from a doubling of greenhouse gases will likely cause very large spatial shifts in species, and the disappearance of large fractions of today's tundra and boreal ecosystems, Schlesinger says.

The loss of stratospheric ozone leading to an increase in exposure to ultraviolet light in the UV-B region is another atmospheric change that is expected to alter competitive relations among species, according to Schlesinger. Phytoplankton production in the ocean near Antarctica may a-



Nriagu: metal emissions to atmosphere still rising

Russia faces difficult development situation

Russia is in an especially difficult and critical situation in regard to sustainable development. There appears to be a very brief window of opportunity during which that nation could set itself on a more sustainable path.

Currently, Russia has many of the essentials required to move to a more energy-efficient economy. It has large natural gas reserves that could eventually provide the energy now produced by outdated nuclear and coal plants. It has a highly educated and technically trained work force. And it has some military technologies that could be converted to civilian use.

In particular, factories that make high-quality gas turbines for military aircraft could easily be converted to manufacture turbines for medium-sized electric power plants. According to Robert H. Socolow of the Center for Energy & Environmental Studies at Princeton University, "Russian factories that have serial production lines for military gas turbines are

ready to convert to gas turbines for stationary power. All the redesign issues have been thought through. But in the absence of [civilian] orders, these factories will revert to military production."

Over a 10-year period, power plants using gas turbines could replace the 14 or 15 Chernobyl-type nuclear reactors now in Russia and other nations in the Commonwealth of Independent States (formerly the Soviet Union). What is required to convert these factories is capital, especially joint ventures with Western corporations, Socolow says.

Russia also could conserve energy by insulating some fraction of its many uninsulated hot water pipes in district heating systems and by installing thermostats in a large fraction of its apartment buildings that have no thermostats.

But myriad obstacles stand in the way of making environmental improvements in Russia. The country is

going through enormous upheavals. Fifteen to 30% of the gross national product was formerly related to the military, says George S. Golitsyn of the Russian Academy of Sciences. Most of that sector is now being phased out. Inflation is running at 20 to 30% per month. Last year industrial output fell 9%, and this year it may fall an additional 25 to 30%, Golitsyn says. Much of the food produced is lost because of a lack of storage facilities. And unemployment is severe.

Unfortunately, "most Russians do not understand the meaning of economic reforms," Golitsyn says. "They know only that, since reforms have begun, there have been very large increases in prices. When people are not paid for several months, their patience can come to an end. There could be severe social events by the end of the year," he warns. "How and when we would start to scramble out of this, only God knows."

ready be reduced 6 to 12% as a result of a greater flux of UV radiation.

Schlesinger points out, however, that losses of some species will not produce major disruption to ecosystems, although losses of other, so-called keystone, species "have a disproportionate influence on the structure and function of communities." Unfortunately, biologists cannot predict with confidence which are the keystone species. As human activities cause species losses, Schlesinger warns, "it is as if we are slowly dismantling an intricate watch, all the while expecting that it will continue to function, without knowing when we will throw out the mainspring."

Metal emissions to the atmosphere have increased exponentially since the beginning of the 20th century. Jerome Nriagu of the National Water Research Institute in Burlington, Ontario, explains that even though toxic metal emissions have been reduced to some extent in the industrialized world since 1960, they continue to rise sharply in the developing world.

Nriagu considers lead, mercury, cadmium, and the metalloid arsenic the most dangerous for human and other life. The main sinks for these metals and the main sources of exposure for humans and other organisms are not the atmosphere, but soil and water. But the atmosphere serves as a primary route for their dispersion throughout the environment.

Nriagu believes that freshwater ecosystems are particularly at risk from toxic metal pollution because aquatic organisms are more sensitive to toxic metals than terrestrial biota and can more easily biomagnify pollutant metal concentrations up the food chain. "At the current industrial input rates, the abilities of many ecosystems to cope with toxic metal pollution are being rapidly depreciated and the existing margin of environmental safety for many organisms is disappearing rapid-

ly," he says. He is especially concerned about mercury. Mercury emissions, which come primarily from fossil fuel combustion, waste incineration, and latex-painted buildings, will keep increasing unless the principles of industrial ecology are applied widely.

Given the high degree of regulation of emissions where metals are used in production processes, it is not pollution control at the factory that will ultimately affect the environmental levels of metals, but the unregulated dissipative uses of metal-containing products, such as paint, tires, and batteries. William M. Stigliani of the International Institute for Applied Systems Analysis in Laxenburg, Austria, has found that nonpoint sources are now dominant sources for cadmium, zinc, and lead pollution in the Rhine Basin, compared with 1970 when factories and smelters were the largest sources.

Metal pollution is difficult to remediate in soils because metals cannot be made to decay biologically. The only way they can be removed is to be leached from the root zone by acidic rainwater, or to be taken up by vegetation. The metals, lead, cadmium, zinc, and mercury, and the



metalloid arsenic have increased in soil almost everywhere in the world since the start of the Industrial Revolution. Lead in U.S. forest soils is the only exception. Only since 1972, when tetraethyl lead use in gasoline began to be phased out, are reductions beginning to be seen in forest soils in the U.S.

Soil accumulation of metals could severely constrain agriculture in the 21st century, says Jerald Schnoor of the Center for Global & Regional Environmental Research at the University of Iowa. Most metals—with the exception of lead—are taken up by plants. So where metal contamination is high, it may be difficult to grow safe food.

Thomas G. Spiro of Princeton University's chemistry department and Valerie Thomas of Princeton's Center for Energy & Environmental Studies point out, however, that when assessing the risk from toxic metals it is important to consider exposure, bioavailability, and toxicity. People who live near lead mine tailings may be exposed to very high levels of lead but may not be at risk because the lead is locked away in the mineral matrix. Similarly, much of the cadmium in sewage sludge may not be bioavailable for plants because it is bound by the organic matter in the sludge. However, according to Peter Jaffe of Princeton's department of civil engineering and operations research, cadmium is absorbed more easily by plants if the soil pH falls below 6.

Soils, the principal sink for toxic metals, are also particularly vulnerable to other kinds of human activities. They are threatened by sulfates and nitrates from the atmosphere, persistent agricultural chemicals, hazardous wastes, land use changes and erosion, and climate change, Schnoor says.

If the levels of nitric and sulfuric acid in acid rain are high enough and the soil has low neutralizing capacity, the soil "can become depleted of the bases [such as carbonates] necessary to support a viable terrestrial ecosystem or agriculture," Schnoor explains.

Because of the soil erosion it often causes, tillage is the most damaging aspect of row crop agriculture, he says. Today's solutions, conservation tillage and no-till agriculture, are inadequate from the standpoint of industrial ecology

because they usually require larger applications of persistent pesticides (insecticides, herbicides, and fungicides).

Chlorinated organic pesticides tend to volatilize from soils and vegetation. The hydrophobic insecticides, such as DDT and its metabolites, aldrin/dieldrin, endrin, heptachlor, and lindane, are especially volatile and persistent. Schnoor says. These compounds travel mainly through the atmosphere and end up at high latitudes "in a sort of 'cold trap' effect," which reduces their volatility but allows them to build up through bioaccumulation in fish and mammals. Chlorinated insecticides have been largely phased out in the U.S., but in developing countries, large quantities are still being used. Globally, more DDT is now being produced than at any time in the past.

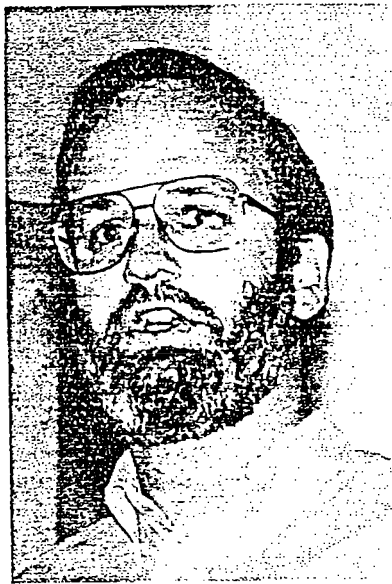
Chlorinated herbicides, such as atrazine and alachlor, are not so persistent or volatile as most chlorinated insecticides. But the combination of some degree of persistence and their high rate of application—1 to 3 kg per hectare per year to more than 165 million hectares in the U.S. alone—cause them to accumulate in groundwater. Most of the groundwater in Iowa, for instance, is contaminated with atrazine.

Soils are extremely important in the global warming equation, Schnoor says, because much more carbon is fixed annually by photosynthesis than is released each year in fossil fuel combustion. Even a small change in net storage or net release from photosynthesis resulting from changes in soils could greatly alter the amount of carbon absorbed and hence the amount of carbon added to or removed from the atmosphere each year.

Susan L. Anderson of the energy and environment division of Lawrence Berkeley Laboratory attempted to define whether toxic substances "simply cause a patchwork of regional insults" or whether they are now harming "the biosphere in ways that have profound global implications." She concludes that techniques for assessing low-level widespread effects of toxic agents on organisms are almost totally inadequate. "These problems must be addressed if significant global issues are to be characterized and resolved." Biomarkers are a promising way of "evaluating low-level effects of global pollution in situ, determining their potential cause, and examining the effects of specific toxic agents." Biomarkers could aid in predicting and assessing "how much chemical in specific tissues of an animal is too much," she says.

In addition, high priority should be given to research on the effects on organisms of UV-B radiation, Anderson suggests. This problem is more focused than studying widespread chemical contamination in diverse media.

In the industrialized countries, at least three trends are leading industry to have less of an impact on the environment per unit of output. One is that industries are using less materials per unit of value added in manufactured goods. In early stages of industrialization, manufactured items tend to be primitive, with most of the cost embedded in the bulk materials of their production. In later stages, a significant fraction of cost is likely to be embedded in sophisticated items like electronic controls, and resource use per unit of value added declines. Arnulf Gräßler of the International Institute for Applied Systems Anal-



Nelson (left): energy-savings projects pay off. Graedel (center): economic activity harms support systems. Paton: environmental issues affect product design.

ysis calls this trend the overall "dematerialization" of industry.

Similarly, when a country is beginning to industrialize, there is a large investment in basic materials industries like steel and cement, requiring large amounts of energy for each unit of output. Later on, Gröbler says, these energy requirements decline as economic output, on average, becomes more sophisticated and technological change improves the efficiency of industrial processes. Long before the oil price shocks in the 1970s, industry in the developed nations had begun to cut down on energy use per unit of output.

In addition, the costs of waste disposal in the developed world are forcing industry to work hard to reduce wastes. These costs are rising 10% annually, and threaten to become the dominant cost of production, says C. Kumar N. Patel, executive director of research, materials science engineering, and academic affairs at AT&T.

In contrast, some intractable conditions in developing countries make it difficult for industrialization to proceed sustainably. One major problem is that Third World countries often lack the resources to buy anything but obsolete and pollution-prone technologies.

In China, for instance, although some of the industrial equipment is highly energy efficient, most of it is very inefficient, according to Jiang Zhenping of the Energy Research Institute at the Chinese Academy of Sciences. Coal currently accounts for 70% of commercial energy consumption in China, and by the year 2000, coal production is expected to increase 40%. If China could afford to replace obsolete equipment with

efficient technologies, like updated boilers, and if it would invest heavily in energy-efficient equipment and appliances, it would not need to expand coal production nearly so fast, and consequently would reduce its rate of emissions of carbon dioxide, sulfur dioxide, and particulates.

Better yet, if China had the capital to invest in the infrastructure needed to utilize its very extensive natural gas reserves, it could lower its carbon dioxide emissions still further because per unit of energy, gas combustion produces about one half as much carbon dioxide as coal. But, Zhenping says, China lacks the capital to invest in natural gas.

Utilities in the Third World often impede sustainable development. They are usually the largest government sector and are run by a mature, powerful bureaucracy that is committed to supply-side thinking, according to Ashok Gadgil of the energy and environment division at Lawrence Berkeley Laboratory. Utility managers in the Third World usually believe there is nothing to gain from energy efficiency. Their judgment is reinforced by national policies to subsidize the cost of energy, giving customers little incentive to conserve energy. "There are a lot of gains to be made in developing countries from taking the least-cost planning approach increasingly being adopted in developed countries," Gadgil says.

Saleemul Huq, executive director of the Bangladesh Center for Advanced Studies, told the conference that there is a "real question whether Earth and its resources can sustain the conversion of all the world's developing countries into developed or industrialized countries." The lives of the people need to be improved, he says, but mimicking the development pattern of

German chemist proposes radical plan for waste management of consumer products

The current system of waste management for consumer products is impractical, too expensive, and environmentally unsound, says Michael Braungart, chemist at the Environmental Protection Encouragement Agency, an independent nongovernmental organization in Hamburg, Germany. He proposes a way to transform the system into one that is economically and environmentally sustainable.

He elaborates this concept by dividing consumer products into three categories according to their proposed method of disposal—consumption, service, and unmarketable products.

Consumption products are those items, such as food and detergent, that are used only once and whose waste is put into the environment. According to Braungart's proposal, these products would have to be biodegradable, noncarcinogenic, nonteratogenic, nonmutagenic, and, in the concentrations used, nontoxic.

Service products are durable goods that provide services, such as auto-

mobiles, television sets, and washing machines. Consumers would lease these products from the manufacturer. When the products are no longer usable, consumers would return them to the manufacturer, who would be responsible for disassembly and recycling. The products would be recycled primarily into what they were originally—a computer, for instance, would become another computer with only a few parts replaced. Products would not be recycled into less valuable items, such as park benches.

Unmarketable products are those that cannot be used or consumed in an environmentally sound way and for which no safe recycling technology exists. In the long run, these products should not be manufactured, Braungart says.

Until unmarketable products can be disposed of safely, they should be stored in warehouses, Braungart says. The producer of unmarketable products would be responsible for renting space for the used products in warehouses and eventually ensur-

ing their safe disposal. Braungart believes the warehouse system would motivate manufacturers to use materials made of environmentally safe chemicals that can be recycled with existing technologies into new products.

To some observers, these ideas for waste disposal sound radical and visionary. But, in fact, some rather similar concepts are now being tried and others are expected to be used in the near future. For example, Germany's federal environment minister, Klaus Töpfer, is working to transform the German society from a "throwaway" culture to one devoted to recycling. German regulations require manufacturers to take back 80% of the packaging they used on their products starting in July 1995 (C&EN, July 27, page 7).

"The international computer and auto industries are developing and implementing plans for disassembly plants," Braungart says. An automobile disassembly plant is already planned for a location not far from Hannover.

the North is not a viable option. "We need to rethink development patterns" and find ways of developing without harming the environment. "We have to think about a reasonable level of consumption for developing countries to aspire to." For example, the per capita meat consumption in the U.S., which is 52 times that in India, is not a reasonable goal for most of the Third World.

Basically, two kinds of approaches are now being used in manufacturing in the developed world to reduce the environmental impact of products or production processes. One is to redesign the products so they have less environmental impact during their useful life and disposal. Another is to reduce waste or energy use during manufacture.

The Louisiana division of Dow U.S.A. has been using the second approach. In 1981, the division initiated an energy-savings contest. As described by Kenneth E. Nelson, energy conservation manager at Dow, under the rules, anyone in the plant can be recognized for devising an energy-saving scheme.

At first, Dow employees believed that all the ways to save energy would be discovered in the first year or two of the contest. But the number of projects and the money they save has grown almost every year. According to audited results, the total group of projects has an average return on investment of about 230% per year, Nelson says. The program started small, but now each year's winning projects produce annual savings of \$20 million to \$25 million, and the total audited savings for the more than 500 projects completed thus far are more than \$107 million per year.

In 1986, waste projects under a national Dow program called "Waste Reduction Always Pays" were added to the contest. The annual return on investment for these projects is about 111%.

The contest has worked at Dow's Louisiana division, Nelson says, partly because it receives support from all levels of the organization, especially management.

Corporate environmental decisions used to be driven primarily by government regulations, addressing pollution control and remediation of wastes. Now, "more than ever before, customer demands and competitor initiatives are introducing environmental issues into decisions regarding product design," says Bruce Paton, a quality program manager at Hewlett-Packard.

"Customers are sending us questionnaires that ask: 'How much energy are you using to make products, how do you recycle products, and how much waste is produced?'" Paton says. And "some of our competitors are saying, 'We are recycling our computers.' These factors are motivating change at a much faster pace than we are used to. At the same time governments around the world are imposing broad new requirements that address the environmental effects of products and of the processes used to make and support them."

To respond to these concerns, Hewlett-Packard and other firms are exploring a new corporate objective called De-



Huq: need to rethink development patterns

sign for Environment (DFE). DFE is concerned with much more than the waste produced within the factory. It also involves product design (such as design for disassembly of products at the end of their useful lives), materials selection, concern for dissipative uses of toxic materials, and the environmental impacts of production by suppliers.

One aim of DFE is to design all products with materials that permit reuse or recycling. "Selection of proper materials can help make it possible to recycle plastic enclosures and many other parts," Paton says. Many computers are now being designed so they can be upgraded by exchanging circuit boards. DFE has a great potential for creating new efficiencies and improving product per-

formance and thus improving corporate profits, he adds.

Volvo has developed a new, related system for assessing quantitatively the environmental impact of its products. It is a "life-cycle analysis approach to evaluating products, incorporating environmental impacts due to manufacturing, use, and disposal of the vehicle," says Inge Horkeby, head of the environmental protection department at Volvo. It applies what Volvo calls environmental load units to each part of the vehicle. This allows product designers to select components that minimize environmental impacts.

Six factors go into determining environmental load units: the scope, distribution, frequency, durability, remediability of the impact, and the relative part of the impact caused by Volvo. The system can be used, for example, to evaluate whether a plastic composite or steel front end for a vehicle has less of an overall environmental impact.

A number of U.S. companies are now carrying out cooperative research to develop processes that will reduce the impact of manufacturing on the environment. One program, called the Environmentally Conscious Manufacturing Program (ECMP), is run by the National Center for Manufacturing Sciences, a nonprofit research and development consortium headquartered in Washington, D.C. with a membership of more than 160 corporations. Wayne France, head of the environmental science department at General Motors, says the program, begun in 1991 with a small budget, has expanded greatly. It has a projected budget of \$25 million for 1993. It has projects on a variety of topics ranging from solvent substitution to handling of metal-working fluids to reduced lead use in manufacturing. ECMP is looking into establishing a panel of outside experts to advise it on the environmental impacts of products and processes and on forthcoming government regulations.

In 1991, manufacturers also formed a vehicle recycling partnership to pursue R&D on recycling, reuse, and disposal of motor vehicles, France adds. Opel in Germany has announced that it "will take back free of charge the new Opel Astra for recycling" at the end of its useful life.

The conference participants suggest a number of ap-

practices that can be used to reduce the environmental impact of nonmanufacturing industrial activities. Robert C. Harriss of the Institute for the Study of Earth, Oceans & Space at the University of New Hampshire says aggressive programs in industrial ecology could arrest the increase in global atmospheric methane. Methane is the most rapidly rising of the greenhouse gases.

A first step in reducing methane growth would be to find and stop natural gas leaks in the world's cities, Harriss says. A new monitoring instrument, a tuned diode laser developed by Aerodyne, can be installed in a van, and used to take continuous measurements all over a city. It measures methane with a precision of 5 ppb, and because of its rapid time response (less than one second), it can locate methane sources very accurately. A second step would be to transform sources of methane pollution, such as landfills and sewage treatment facilities, into energy sources.

Today, biomass accounts for about 15% of the world's energy supply, 35% in developing countries. Robert H. Williams of the Center for Energy & Environmental Studies at Princeton University believes that biomass, grown renewably, can supply a much larger fraction of the world's energy and thus reduce greenhouse gas emissions substantially.

So far, biomass has been used in two ways for industrial purposes. Ethanol has been produced from grain and sugarcane, and agricultural and forest residues have been used to produce electricity in steam turbines. But, Williams says, there are several new ways in which biomass could be used cost effectively by exploiting advanced technology: gasification and electricity production using gas-turbine-based power systems, and direct use of liquid and gaseous biomass fuels in fuel cell vehicles.

Gas-turbine-based power systems are much more efficient and much less costly than steam turbine power systems at the modest scales (10 to 100 MW) needed for biomass power systems. "Electricity produced with biomass-integrated gasifier/gas turbine power systems not only offers major environmental benefits but would also be competitive with electricity produced from fossil fuels and nuclear energy in a wide range of circumstances," Williams says.

Liquid biomass fuels could be used in internal combustion engines for transportation, and hydrogen or methanol from biomass could be used as fuel in fuel-cell-powered cars, Williams adds. Even though the fuel would be more expensive than gasoline, the life-cycle cost of a fuel-cell car, which has near zero pollutant emissions, would be about the same as that of a traditional car because the fuel efficiency would be greater and the vehicle's power plant would last longer.

In the short term, forest residues of the pulp and paper industry and sugarcane bagasse and leaves could be used as a source of biomass, Williams says. In the long term, very extensive biomass plantations could supply large quantities of biomass energy. He projects that degraded lands suitable for reforestation in Latin America and Africa might be adequate to supply two fifths of the world's estimated liquid fuel needs by 2050. "Establishing biomass plantations on degraded lands would be a way of paying for their restoration," Williams says. But methods still need to be developed to recycle the nitrogen and phosphorus contained in the harvested biomass crops back to the plantation soil.

The participants at the Snowmass meeting met in three parallel working groups during the second week to try to

develop new approaches to redesigning industrial activities to promote sustainable resource use. To encourage corporations to produce sustainably, the working groups came up with several recommendations. One is that subsidies for virgin materials, such as oil or lead, must be reduced and the costs associated with obtaining, processing, distributing, and using materials, including the cost of damage to the environment, must be reflected in their prices.

Another is that institutions should be reformed to encourage product stewardship. To aid in this effort, cooperative research, development, and planning should be encouraged among corporations, and better ways to convey information on reuse and recycling of products should be developed. For example, self-reporting by industry to the public should include information about energy consumption, other operating costs, and disposal practices.

Moreover, service or leasing arrangements that reward companies for participating with users to minimize total energy use and environmental impacts should be encouraged. For example, service arrangements could be made between agrochemical companies and farmers to maximize the effective use of fertilizers, insecticides, and herbicides. The farmer would pay for the service, not the chemicals.

Some of the conclusions of the working groups focus specifically on accelerating the adoption of the principles of industrial ecology. The participants propose that some organization, such as the United Nations or World Bank, develop a clear and consistent environmental framework within which companies investing in developing and transitional countries can operate. The framework, for example, would help protect companies from liabilities associated with prior contamination at the sites of new investments. One part of this framework would be financial and technical support to citizen action groups. Another part would consist of targeted training for public authorities.

Still another would be to encourage independent information sources to broker relationships among technology and equipment suppliers, financiers, and developing country recipients, the participants conclude. Such a broker could help all parties deal with the multitude of social, political, and economic conditions resistant to innovation in both developed and developing countries.

The working groups say it is urgent to devise global institutions that can rapidly transfer the lessons learned in developed countries to the developing world, and vice versa. The mere existence of information about a hazard and the availability of cost-effective technology to reduce the hazard does not guarantee action. The appropriate institutions to initiate action need to have sufficient international prestige to overcome the inertia of bureaucracies and corporations that have been perpetuating environmentally damaging practices that should have been terminated years ago.

The participants urge putting more effort into trying to understand the potential limits, nonlinear responses, linkages, and surprises associated with human perturbations of natural cycles, such as the carbon, nitrogen, and sulfur cycles. A parallel area for increased effort is research on toxic compounds, where it is important to study the effects of the total system, rather than focusing on a single aspect, such as carcinogenicity. In addition, the working groups urge more support for the development of environmentally benign production processes and products. □

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TO:

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FROM:

NAME: Sarah Danaher
PHONE: 303-497-1648

MESSAGE:

Dear Mr. Lindseth,

The following information on the 1992 Global Change Institute (GCI) on Industrial Ecology includes a participants list and final program. Either Professor Socolow or I will be in touch with you regarding additional information which might be useful to you.

Thank you for your interest in our annual Institutes on global change issues. Also for your information, I have included a list of publications which are available from our office. Please let us know if we can provide more information to you.

Sincerely,

Sarah Danaher

Date Transmitted: 12 November 1992 No. Pages: 25 Approximate Time: 9:30am
If you do not receive all the pages, please call our verify phone number: (303) 497-1682. Number of pages includes this cover sheet.

UCAR/OIES, P.O. Box 3000, Boulder, Colorado 80307-3000, USA

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PUBLICATIONS AVAILABLE

OIES Periodicals:

EarthQuest, a quarterly newsletter produced by OIES covering developments and research opportunities in major national and international programs, reporting news for the government agencies and universities that will be involved in these emerging efforts. Free subscriptions and back issues are available.

Reports to the Nation on Our Changing Planet, a series of publications on global change sponsored by the NOAA Office of Global Programs. *The Climate System* (Winter 1991) was the first in the series. The second, *Our Ozone Shield*, is now available.

OIES Global Change Institute Volumes:

Trace Gases and the Biosphere, final report of the 1988 Global Change Institute held in Snowmass, Colorado, 8 - 19 August 1988, edited by Berrien Moore III and David Schimel. Global Change Institute, Volume 1; 1992.

Global Changes of the Past, final report of the 1989 Global Change Institute held in Snowmass, Colorado, 24 July - 4 August 1989, edited by Raymond S. Bradley. Global Change Institute, Volume 2; 1991. Available at cost for \$38 (US) each. Orders must be prepaid by check or money order made payable to UCAR.

Modeling the Earth System, final report of the 1990 Global Change Institute held in Snowmass, Colorado, 16 - 27 July 1990, edited by Dennis Ojima. Global Change Institute, Volume 3; 1992.

OIES Workshop Reports:

Opportunities for Research at the Atmosphere/Biosphere Interface, report of a workshop on atmosphere/biosphere interactions held in Boulder, Colorado. OIES Report No. 1; July 1985.

Climate-Vegetation Interactions, proceedings of a workshop held at NASA Goddard Space Flight Center, edited by Cynthia Rosenzweig and Robert Dickinson. OIES Report No. 2; December 1986.

Global Tropospheric Chemistry: Plans for the U.S. Research Effort, prepared by the Global Tropospheric Chemistry Program Committee. Only the executive summary is currently available. OIES Report No. 3; December 1986.

Arctic Interactions: Recommendations for an Arctic Component in the International Geosphere-Biosphere Programme, based on two workshops held in Boulder, Colorado, January and March 1987. OIES Report No. 4, September 1988.

Recommendations from a Forum on Data Management for Global Change, based on a Forum sponsored by the Interagency Working Group on Data Management for Global Change, November 1988, Baltimore, Maryland. OIES Report No. 5, March 1990.

Arid Ecosystems Interactions: Recommendations for Drylands Research in the Global Change Research Program, based on a workshop held in Boulder, Colorado, October 25-27, 1989. OIES Report No. 6, November 1991.

IGBP Publications:

Global Change System for Analysis, Research and Training (START), final report of a meeting at Bellagio, Italy, 3-7 December, 1990. IGBP Report #15; 1991.

Past Global Changes Project: Proposed Implementation Plans for Research Activities, an expanded explanation of the PAGES Project Plan described in IGBP Report No. 12 based on the deliberations of the First Meeting of the PAGES Scientific Steering Committee 11-13 March 1991. IGBP Report # 19; 1992.

Global Change Newsletter, produced by the IGBP Secretariat, to inform readers of the planning, development, and execution of the International Geosphere-Biosphere Programme. Back issues are available from OIES. For subscriptions, contact: IGBP Secretariat, Newsletter, Royal Swedish Academy of Sciences, Box 50005, S-104 05 Stockholm, SWEDEN.

A Study of Global Change, a brochure describing the International Geosphere-Biosphere Programme of the International Council of Scientific Unions.

Other Publications:

Earth System Science: A Closer View, final report of the Earth System Sciences Committee, NASA Advisory Council. January 1988. Accompanying posters are also available.

EOS: Mission to Planet Earth, a brochure outlining the Earth Observing System (EOS), Earth Probes, and related precursor research missions, in the context of the U.S. Global Change Research Program. February 1990.

Mission to Planet Earth: Tropical Rainfall Measuring Mission (TRMM), a brochure outlining the proposed TRMM satellite program now being studied jointly by the United States and Japan. 1989.

Oceanus, Vol. 29 No. 4 (Winter 1986/1987), entire issue devoted to changing climate and the oceans.

Our Changing Planet: A U.S. Strategy for Global Change Research, reports by the Committee on Earth and Environmental Sciences, to accompany the U.S. President's Fiscal Year 1991, 1992, and 1993 Budgets. Executive summaries are also available.

Research Strategies for the U.S. Global Change Research Program, report of the Committee on Global Change of the National Research Council. National Academy Press, 1990.

RISE: Radiative Inputs of the Sun to Earth, research plan for the 1990's on Solar Irradiance Variation by the Division of Atmospheric Sciences of the National Science Foundation. February 1990.

Scientific Assessment of Climate Change, the Policymakers' Summary of the Report of Working Group I to the Intergovernmental Panel on Climate Change. World Meteorological Organization/United Nations Environment Programme; July 1990. *Limited quantity available.*

The UCAR Climate System Modeling Initiative: Report of the First CSMI Workshop, January 1989.

The Vision: A Rededication of NOAA, A Report of the NOAA Panel on Climate and Global Change; January 1989. Accompanying posters are also available.

University Corporation for Atmospheric Research
OFFICE FOR INTERDISCIPLINARY EARTH STUDIES

1992 GLOBAL CHANGE INSTITUTE
Industrial Ecology and Global Change

Snowmass, Colorado
20 - 31 July 1992

Proposed Program

OVERALL PLAN

- Part I: Plenary: Tutorial Papers
Part II: Parallel Working Group Sessions
Part III: Plenary: Rapporteurs' Reports and Discussion

PART I: PROGRAM OF TUTORIAL PAPERS

MONDAY, JULY 20th:

What are the patterns and prospects of global industrialization?

Session One: 8:30 am - Noon

Moderator: Richard Somerville (Scripps Institution of Oceanography)
Rapporteur: David Angel (Clark University)

8:30 am	<i>Industrial ecology: blending insights from industrial innovation and environmental science</i>	Robert Socolow (Princeton University)
9:30 am	<i>Industrialization as a historical phenomenon</i>	Arnulf Gröbler (IIASA, Austria)
10:30 am	Break	
11:00 am	<i>Industry and environment: Implications of materials developments in the next decade</i>	Kumar Patel (AT&T)

Noon Lunch

Session Two: 1:30 pm – 5:00 pm

Moderator: Jackton Boma Ojwang (University of Nairobi)

Rapporteur: Daniel Deudney (University of Pennsylvania)

1:30 pm	<i>Patterns of development: Cross-national comparisons</i>	William Moomaw (Tufts University)
2:15 pm	<i>A developing country perspective</i>	Saleemul Huq (Bangladesh Center for Advanced Studies, Dhaka, Bangladesh)
3:00 pm	Break	
3:30 pm	<i>Economic determinants of future carbon dioxide emissions in the Russian Federation</i>	Yori Kononov (Siberian Energy Institute, Irkutsk, Russian Federation)
4:15 pm	<i>Energy efficiency in China: Past experience and future prospects</i>	Jiang Zhenping (Energy Research Institute, Beijing, China)

TUESDAY, JULY 21st:

What is known about global environmental vulnerability to human activity?

Session Three: 8:30 am – Noon

Moderator: James Galloway (University of Virginia)

Rapporteur: Daniel Lashof (Natural Resources Defense Council)

8:30 am	<i>Changing perceptions of vulnerability</i>	Robin Cantor (Oak Ridge National Lab) and Steve Rayner (Batelle Pacific NW Labs)
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9:30 am	<i>The atmosphere as a vulnerable environmental system</i>	V. Ramanathan (Scripps Institution of Oceanography)
10:30 am	Break	
11:00 am	<i>Soil as a vulnerable environmental system</i>	Jerald Schnoor (University of Iowa)
Noon	Lunch	

Session Four: 1:30 pm – 5:00 pm

Moderator: Theodore Panayotou (Harvard University)
Rapporteur: Steve Rayner

1:30 pm	<i>The vulnerability of biotic diversity</i>	William Schlesinger (Duke University)
2:15 pm	<i>The human dimension of vulnerability</i>	Robert Chen (Brown University)
3:00 pm	Break	
3:30 pm	<i>Ecotoxicology: Management and science</i>	Susan Anderson (Lawrence Berkeley Lab)
4:15 pm	<i>Assessing the toxicity of metals in the environment</i>	Valerie Thomas and Thomas Spiro (Princeton University)

WEDNESDAY, JULY 22nd:

How have patterns of industrial activity been shaped by environmental constraints?

Session Five: 8:30 am – Noon

Moderator: V. Ramanathan (Scripps Institution of Oceanography)
Rapporteur: Clinton Andrews

8:30 am	<i>Industrial ecology: Definition and implementation</i>	Thomas Graedel (AT&T)
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9:30 am	<i>Industrial metabolism and the grand nutrient cycles</i>	Robert Ayres (Carnegie Mellon University)
10:30 am	Break	
11:00 am	<i>Group Photo on Gatehouse Deck</i> <i>Urban and industrial carbon metabolism</i>	Robert Harriss (University of New Hampshire)
Noon	Lunch	

Session Six: 1:30 pm – 5:00 pm

Moderator: Olga Gritsai (Institute of Geography, Russian Academy of Sciences)
Rapporteur: Valerie Thomas

1:30 pm	<i>Resource extraction: Environmental and social science perspectives</i>	Stephen Bunker (University of Wisconsin)
2:30 pm	<i>Industrial activity and metals emissions</i>	Jerome Nriagu (National Water Research Institute, Canada)
3:30 pm	Break	
4:00 pm	<i>Metals loadings of the environment: A case study of the Rhine Basin</i>	William Stigliani, Stefan Anderberg (IIASA) and Peter Jaffe (Princeton University)

THURSDAY, JULY 23rd:

How might industrial activity be reconfigured in response to a deeper understanding of the associated disturbances of the environment?

Session Seven: 8:30 am – Noon

Moderator: Vladimir Kotlyakov (Institute of Geography, Russian Academy of Sciences)
Rapporteur: Frans Berkhout (Princeton University)

8:30 am	<i>"Designing for the Environment": Techniques and approaches</i>	Bruce Paton (Hewlett Packard)
9:15 am	<i>Industrial ecology in the manufacturing of consumer products</i>	Wayne France (General Motors)
10:00 am	Break	
10:30 am	<u>Roundtable:</u> <i>Case histories from industrial practices in leading international corporations</i>	<u>Chair:</u> Kumar Patel (AT&T) <u>Participants:</u> Michael Braungart (Environmental Protection Encouragement Agency, Hamburg, Germany) Inge Horkeby (Volvo) Kenneth Nelson (Dow Chemical)
Noon	Lunch	

Session Eight: 1:30 pm – 5:00 pm

Moderator: Monica Griefahn (Government of Lower Saxony,
Hanover, Germany)

Rapporteur: Steven Fetter (University of Maryland)

1:30 pm	<i>The role of bioenergy in a global sustainable energy system</i>	Robert Williams (Princeton University)
2:30 pm	Break	
3:00 pm	<i>Conversion and ecology: Potential and problems for the Russian Federation</i>	George Golitsyn (Institute of Atmospheric Physics, Moscow)
4:00 pm	<i>Integrating environmentally friendly technologies into the development process</i>	Ashok Gadgil (Lawrence Berkeley Lab)

PART II: WORKING GROUPS

FRIDAY, JULY 24th THROUGH THURSDAY, JULY 30th

WORKING GROUP A: Interactions of Human Activity with Basic Environmental Cycles

Goal: To bring together those who, working at various spatial scales, seek to clarify the interactions of human activity with the carbon, nitrogen, phosphorus, sulfur, and other mineral cycles and to explore reconfigurations of industrial activity in response to these insights. Specifically included are concerns for energy efficiency, renewable energy, methane management, nitrogen and sulfur management in combustion, and nitrogen and phosphorus management in modern agriculture.

WORKING GROUP B: Human Activity in the form of Exotic Disturbances of the Environment

Goal: To integrate the insights of groups working at the factory level, the industry-wide level, the regional (e.g., river-basin) level, and the global level—all seeking to understand the interaction of industrial activity with the environment, when the industrial activity takes the form of 1) processing of materials, such as metals, that have limited roles in basic biogeochemical cycles, or 2) introducing emissions, such as "toxic" organics, that are relatively absent in the natural environment.

WORKING GROUP C: Industrial Ecology: Conceptualization and Implementation

Goal: To create an improved framework, "industrial ecology," that integrates industrial practices with the insights of environmental science. Current frameworks describing the dynamics of industrialization and economic development almost completely neglect environmental issues: environment tends to be neither a driver nor a constraint. With the objective of accelerating innovative practices, critical paths toward implementation of industrial ecology will be identified.

PART III: RAPPORTEURS' REPORTS AND DISCUSSION

FRIDAY, JULY 31st

Rapporteur Reports at Plenary Session

University Corporation for Atmospheric Research
OFFICE FOR INTERDISCIPLINARY EARTH STUDIES

1992 GLOBAL CHANGE INSTITUTE
Industrial Ecology and Global Change

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as of October 28, 1992

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Industrial Ecology Route To Slow Global Change Proposed

Sarah Donaher
303 497 1648

International industry-environment conference suggests ways to reconfigure industry and agriculture worldwide to halt damage to environment

Bette Hileman, C&EN Washington

Since the start of the Industrial Revolution, we human beings have been rapidly reconfiguring planet Earth. In many countries we still take lead from deep inside Earth, react it with ethyl chloride, and use the product to raise the octane level of gasoline. We then burn the gasoline, spreading the lead through the air into water bodies and soil in every corner of the globe. We mine coal and burn it, vaporizing the metals it contains, and thereby help raise mercury in fish to toxic levels in many lakes across North America. In producing fertilizer and burning fossil fuel, we break nitrogen bonds about as quickly as do natural ecosystems, so as to roughly double the amount of fixed nitrogen, as nitrates, globally. We haphazardly disperse these nitrates across forests, fields, lakes, and streams in every land.

Industrial ecology is the study of how we humans can continue rearranging Earth, but in such a way as to protect our own health, the health of natural ecosystems, and the health of future generations of plants and animals and humans. It encompasses manufacturing, agriculture, energy production, and transportation—nearly all of those things we do to provide food and make life easier and more pleasant than it would be without them.

For two weeks late last month, 51 invited participants from a wide variety of disciplines and 10 countries met in Snowmass Village, Colo., to consider broad questions concerning industrial ecology and global change and to recommend actions and research in this area. The meeting was organized by the Office for Interdisciplinary Earth Studies, part of the University Corporation for Atmospheric Research, based in Boulder, Colo. It was directed by Robert H. Socolow, head of the Center for Energy & Environmental Studies at Princeton University.

Several conferences on industrial ecology have been held during the past two years, but previous meetings have not included participants from so many different disciplines and countries. Nor have they made

a strong attempt to relate global environmental damage to industrial ecology or to develop recommendations for implementation and research in this area.

A surprising outcome of the recent Snowmass meeting was the nature of the discussion among the participants. When there were disagreements, they did not occur between environmental scientists and representatives from industry. Most of the conflicts stemmed from the participants' habitual ways of looking at issues, which, as it turned out, were very different for sociologists than for physicists.

A conflict occurred between those people who preferred to work from the bottom up—that is to try to solve problems in the current industrial system—and those who wanted to work from the top down. These latter individuals preferred first to decide on a vision for an ideal future environmentally sustainable society and then to reconfigure industrial activities to reach that goal.

Despite the disagreements, most participants came away from the meeting convinced they had benefited from the cross-fertilization of ideas. Industry representatives found they shared common approaches with those whom they least expected to agree—the environmentalists—in part because both shared a common sense of urgency about finding practical, workable, action-oriented means of preventing environmental degradation. That shared knowledge, which is leading to future research collaboration, is probably the most practical outcome of the meeting.

The primary aim of the Snowmass meeting was to think about ways of reconfiguring industrial activity to reduce harm to the human and natural environment at the global level. To this end, the participants assessed the vulnerability of several global environmental systems to human activity. They emphasized damage to the air and soil and were especially interested in effects that are in evidence throughout the world rather than those specific to particular regional ecosystems.

They looked at patterns of past global industrialization and prospects for future industrialization.



Socolow: industrial ecology lies at intersection of industrial innovation and environmental science

Photo by Bette Hileman

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With this deeper understanding of the environmental damage that has taken place and of past and future industrial trends, they considered how to redesign industrial activity so that past disturbances are gradually reversed and future harmful disturbances are avoided.

At the meeting, participants learned that a number of companies have already begun to practice industrial ecology. For example, General Motors-Europe has committed to taking back and recycling its new Opel Astra automobiles at the end of their useful life. And Volvo has developed an index to rank the environmental compatibility of alternative designs of vehicle components, such as engines and bumpers.

The participants also judged that biomass fuels, grown renewably, have great potential to mitigate global warming. They explored some of the implications of transforming the economy from goods to services as a way to reduce adverse impacts on the environment. Concern for the environment need not constrain economic activity, the participants concluded. Rather, it can stimulate new technological innovation and economic growth.

Because of the global focus of the meeting, the attendees paid particular attention to several very damaging practices that have been abandoned in the industrialized world and yet are spreading rapidly in the developing countries. For example, chlorofluorocarbons (CFCs) are being phased out in the developed world, but a German company is building a factory to produce CFCs in China where their use is expected to expand greatly as allowed by the Montreal Protocol on Substances That Deplete the Ozone Layer. Also, the amount of tetraethyl lead added to gasoline is growing rapidly in the Third World, although the compound is no longer used or is being phased out in the U.S., Canada, and most of Europe. The participants concluded that more than knowledge of environmental damage and technological fixes are required to stop these harmful practices.

The term industrial ecology arose out of its relationship to biological ecology. In a biological ecosystem, nothing is wasted. All products of metabolism of one organism are useful to another, and the only external energy supply is sunlight.

Similarly, an ideal industrial ecological system would produce no waste and would be fueled by energy from sunlight. The waste from one process would be used as feedstock for another, and at the end of their useful lives final products would be recycled back into their original form or into something else that is as valuable as the original product. The overall system would not dissipate resources—or, in other words, deplete resources for future generations.

As defined by the meeting at Snowmass, industrial ecology concerns more than what goes on inside a factory. It encompasses the interrelationships among raw materials extraction, transportation of these materials, manufacture of products, and disposition of wastes from manufacture and packaging. It also concerns the transportation and disposition of the final products, whether they become useful raw materials for new products, and whether they harm human or wild ecosystems while they are being used. It includes agriculture as well. It asks whether food and animal feed are produced in a way that depletes or erodes soils and whether the agricultural inputs damage ecosystems.



Schlesinger (left): atmospheric changes could contribute to species losses. Schmoor: metals in soils could hurt agriculture

According to Thomas E. Graedel of the Environmental Chemistry Research Laboratory at AT&T Bell Labs, "Industrial ecology arises from the perception that human economic activity is causing unacceptable changes in basic environmental support systems." It seeks alternative approaches that will reduce greenhouse gas buildup, dissipative uses of heavy metals, dispersion of long-lived toxic chemicals, and excessive fertilization in agriculture.

Because it involves so many interrelationships, an ecological industrial system cannot be designed without knowledge from several scientific disciplines. "Industrial ecology lies at the intersection of two scientific communities—industrial innovation and environmental science," says Solow. At the meeting he repeatedly emphasized the need for industry to become more aware of developments in environmental science and for environmental scientists to become more aware of the implications of new industrial practices for Earth as a biological and physical system.

Robert U. Ayres of the European Institute of Business Administration in Fontainebleau, France, discussed the human influences on the circulation of carbon, nitrogen, sulfur, and phosphorus between the land, the atmosphere, and the oceans. Ayres calls the circulation of these elements "grand cycles." Human activities have accelerated the cycling of these elements through the biosphere. Carbon is cycling about 5% faster, and nitrogen, sulfur, and phosphorus are cycling two to five times faster than they would without human intervention.

Because of fossil fuel combustion and deforestation, the concentration of carbon dioxide in the atmosphere is 25% higher than it was 200 years ago. On a global basis, intentional industrial nitrogen fixation in fertilizer production and unintentional fixation in high-temperature combustion are now about equal to biological nitrogen fixation, Ayres says. The emissions of sulfur dioxide from fossil fuel combustion are several times higher than emissions of sulfur gases from all other sources. He estimates that about twice as much phosphorus is mobilized by industry than is released in global rock weathering.

Several scientists at the conference discussed the specific vulnerabilities of global environmental systems to these disruptions in the grand cycles. For instance, V. Ramanathan of Scripps In-

Summer institutes focus on global-change factors

The subject for the meeting in Snowmass Village, Colo., "Industrial Ecology and Global Change," grew out of the desire of Earth system modelers for insight into how human activities affect global change. In response, the Office for Interdisciplinary Earth Studies, part of the University Corporation for Atmospheric Research, Boulder, Colo., as a service to the environmental community, decided to devote two of its annual summer institutes to these issues.

The 1991 summer institute addressed modifications to land cover, such as deforestation and urbanization, that affect global change. This

summer's institute addressed changes in the chemical characteristics of the environment (including the atmosphere, aquatic environment, and soil) resulting from economic activity that affect global change. From its initial emphasis on chemical changes to Earth's system, the 1992 institute evolved into an examination of opportunities for industries to become more responsive to averting environmental damage.

The institute was organized principally by a three-person executive committee consisting of Robert H. Socolow, director of the Center for Energy & Environmental Studies at

Princeton University; Thomas E. Graedel of the Environmental Chemistry Research Laboratory at AT&T Bell Labs; and William Moomaw of Fletcher School of Law & Diplomacy at Tufts University.

The institute was funded by the federal Committee on Earth & Environmental Sciences, an interagency group consisting of 14 federal departments and agencies that coordinate the U.S. Global Change Research Program. The central goal of this program is "to help establish the scientific understanding and the basis for national and international policy-making related to natural and human-induced changes in global Earth systems."

stitution of Oceanography, La Jolla, Calif., notes that humans have already increased the greenhouse effect, or warming effect from greenhouse gases, by 2 watts per square meter, or about 1.5% of the 150 watts per sq m of infrared radiation trapped by clouds and atmospheric gases. In contrast, solar output has varied by 0.5 watts per sq m, at most, during the past century. If the 1980s trend for greenhouse gases continues for another century, the atmospheric warming effect of greenhouse gases will be 8 to 10 watts per sq m. "No one can dispute that 8 to 10 watts per square meter is a major perturbation," Ramanathan says. The question is how soon and by how much that change in greenhouse effect will change Earth's temperature. "If we wait for model certainty [before taking action to control greenhouse gases], we are in for a big, sad surprise," he warns.

Human-induced changes in the atmosphere may already be reducing biological diversity and they are threatening to produce catastrophic changes in the future, says William H. Schlesinger of the departments of botany and geology at Duke University. At least three types of atmospheric changes could contribute to species losses: increased carbon dioxide, increased nitrates, and stratospheric ozone depletion.

The extra nitrate produced by industrial activity is delivered to natural ecosystems mainly through acid deposition, he says. It would be expected to fertilize natural forests, and indeed there is evidence that temperate forests may have accelerated their growth rates.

But there is also evidence that fertilizing natural systems leads to a loss of species diversity. For example, Schlesinger notes, "a long-time fertilized pasture in Great Britain showed a remark-

able reduction in plant diversity from 1856 to the present, as a large number of rare species were replaced by a small number of aggressive weedy species that assumed dominance in the community." Ecologists explain this loss of species by saying that "any addition of a resource to a natural community will lead to the dominance of the species that can use that resource most efficiently."

Similarly, doubling the level of carbon dioxide in the atmosphere is expected to cause losses in species because it, too, has a fertilizing effect. This is the case especially for plants that use the C_3 pathway for photosynthesis—those that initially incorporate carbon dioxide in their tissues as a three-carbon phosphoglyceric acid. Some biologists believe that the invasion of black grama grasslands (C_3 plants, which incorporate carbon dioxide as a four-carbon carboxylic acid) by creosote bush and mesquite (which are both C_3 plants) in New Mexico during the past century may be partly caused by the 25% increase in carbon dioxide levels, as well as by overgrazing.

Also, carbon dioxide in the atmosphere is expected to have an indirect effect on species. The global warming of 1.5 to 4.5 °C predicted from a doubling of greenhouse gases will likely cause very large spatial shifts in species, and the disappearance of large fractions of today's tundra and boreal ecosystems, Schlesinger says.

The loss of stratospheric ozone leading to an increase in exposure to ultraviolet light in the UV-B region is another atmospheric change that is expected to alter competitive relations among species, according to Schlesinger. Phytoplankton production in the ocean near Antarctica may al-



Nriagu: metal emissions to atmosphere still rising

Russia faces difficult development situation

Russia is in an especially difficult and critical situation in regard to sustainable development. There appears to be a very brief window of opportunity during which that nation could set itself on a more sustainable path.

Currently, Russia has many of the essentials required to move to a more energy-efficient economy. It has large natural gas reserves that could eventually provide the energy now produced by outdated nuclear and coal plants. It has a highly educated and technically trained work force. And it has some military technologies that could be converted to civilian use.

In particular, factories that make high-quality gas turbines for military aircraft could easily be converted to manufacture turbines for medium-sized electric power plants. According to Robert H. Socolow of the Center for Energy & Environmental Studies at Princeton University, "Russian factories that have serial production lines for military gas turbines are

ready to convert to gas turbines for stationary power. All the redesign issues have been thought through. But in the absence of [civilian] orders, these factories will revert to military production."

Over a 10-year period, power plants using gas turbines could replace the 14 or 15 Chernobyl-type nuclear reactors now in Russia and other nations in the Commonwealth of Independent States (formerly the Soviet Union). What is required to convert these factories is capital, especially joint ventures with Western corporations, Socolow says.

Russia also could conserve energy by insulating some fraction of its many uninsulated hot water pipes in district heating systems and by installing thermostats in a large fraction of its apartment buildings that have no thermostats.

But myriad obstacles stand in the way of making environmental improvements in Russia. The country is

going through enormous upheavals. Fifteen to 30% of the gross national product was formerly related to the military, says George S. Golitsyn of the Russian Academy of Sciences. Most of that sector is now being phased out. Inflation is running at 20 to 30% per month. Last year industrial output fell 9%, and this year it may fall an additional 25 to 30%, Golitsyn says. Much of the food produced is lost because of a lack of storage facilities. And unemployment is severe.

Unfortunately, "most Russians do not understand the meaning of economic reforms," Golitsyn says. "They know only that, since reforms have begun, there have been very large increases in prices. When people are not paid for several months, their patience can come to an end. There could be severe social events by the end of the year," he warns. "How and when we would start to scramble out of this, only God knows."

ready be reduced 6 to 12% as a result of a greater flux of UV radiation.

Schlesinger points out, however, that losses of some species will not produce major disruption to ecosystems, although losses of other, so-called keystone, species "have a disproportionate influence on the structure and function of communities." Unfortunately, biologists cannot predict with confidence which are the keystone species. As human activities cause species losses, Schlesinger warns, "it is as if we are slowly dismantling an intricate watch, all the while expecting that it will continue to function, without knowing when we will throw out the mainspring."

Metal emissions to the atmosphere have increased exponentially since the beginning of the 20th century. Jerome Nriagu of the National Water Research Institute in Burlington, Ontario, explains that even though toxic metal emissions have been reduced to some extent in the industrialized world since 1960, they continue to rise sharply in the developing world.

Nriagu considers lead, mercury, cadmium, and the metalloid arsenic the most dangerous for human and other life. The main sinks for these metals and the main sources of exposure for humans and other organisms are not the atmosphere, but soil and water. But the atmosphere serves as a primary route for their dispersion throughout the environment.

Nriagu believes that freshwater ecosystems are particularly at risk from toxic metal pollution because aquatic organisms are more sensitive to toxic metals than terrestrial biota and can more easily biomagnify pollutant metal concentrations up the food chain. "At the current industrial input rates, the abilities of many ecosystems to cope with toxic metal pollution are being rapidly depreciated and the existing margin of environmental safety for many organisms is disappearing rapidly,"

he says. He is especially concerned about mercury. Mercury emissions, which come primarily from fossil fuel combustion, waste incineration, and latex-painted buildings, will keep increasing unless the principles of industrial ecology are applied widely.

Given the high degree of regulation of emissions where metals are used in production processes, it is not pollution control at the factory that will ultimately affect the environmental levels of metals, but the unregulated dissipative uses of metal-containing products, such as paint, tires, and batteries. William M. Stigliani of the International Institute for Applied Systems Analysis in Laxenburg, Austria, has found that nonpoint sources are now dominant sources for cadmium, zinc, and lead pollution in the Rhine Basin, compared with 1970 when factories and smelters were the largest sources.

Metal pollution is difficult to remediate in soils because metals cannot be made to decay biologically. The only way they can be removed is to be leached from the root zone by acidic rainwater, or to be taken up by vegetation. The metals, lead, cadmium, zinc, and mercury, and the



metalloid arsenic have increased in soil almost everywhere in the world since the start of the Industrial Revolution. Lead in U.S. forest soils is the only exception. Only since 1972, when tetraethyl lead use in gasoline began to be phased out, are reductions beginning to be seen in forest soils in the U.S.

Soil accumulation of metals could severely constrain agriculture in the 21st century, says Jerald Schnoor of the Center for Global & Regional Environmental Research at the University of Iowa. Most metals—with the exception of lead—are taken up by plants. So where metal contamination is high, it may be difficult to grow safe food.

Thomas G. Spiro of Princeton University's chemistry department and Valerie Thomas of Princeton's Center for Energy & Environmental Studies point out, however, that when assessing the risk from toxic metals it is important to consider exposure, bioavailability, and toxicity. People who live near lead mine tailings may be exposed to very high levels of lead but may not be at risk because the lead is locked away in the mineral matrix. Similarly, much of the cadmium in sewage sludge may not be bioavailable for plants because it is bound by the organic matter in the sludge. However, according to Peter Jafie of Princeton's department of civil engineering and operations research, cadmium is absorbed more easily by plants if the soil pH falls below 6.

Soils, the principal sink for toxic metals, are also particularly vulnerable to other kinds of human activities. They are threatened by sulfates and nitrates from the atmosphere, persistent agricultural chemicals, hazardous wastes, land use changes and erosion, and climate change, Schnoor says.

If the levels of nitric and sulfuric acid in acid rain are high enough and the soil has low neutralizing capacity, the soil "can become depleted of the bases [such as carbonates] necessary to support a viable terrestrial ecosystem or agriculture," Schnoor explains.

Because of the soil erosion it often causes, tillage is the most damaging aspect of row crop agriculture, he says. Today's solutions, conservation tillage and no-till agriculture, are inadequate from the standpoint of industrial ecology

because they usually require larger applications of persistent pesticides (insecticides, herbicides, and fungicides).

Chlorinated organic pesticides tend to volatilize from soils and vegetation. The hydrophobic insecticides, such as DDT and its metabolites, aldrin/dieldrin, endrin, heptachlor, and lindane, are especially volatile and persistent, Schnoor says. These compounds travel mainly through the atmosphere and end up at high latitudes "in a sort of 'cold trap' effect," which reduces their volatility but allows them to build up through bioaccumulation in fish and mammals. Chlorinated insecticides have been largely phased out in the U.S., but in developing countries, large quantities are still being used. Globally, more DDT is now being produced than at any time in the past.

Chlorinated herbicides, such as atrazine and alachlor, are not so persistent or volatile as most chlorinated insecticides. But the combination of some degree of persistence and their high rate of application—1 to 3 kg per hectare per year to more than 165 million hectares in the U.S. alone—cause them to accumulate in groundwater. Most of the groundwater in Iowa, for instance, is contaminated with atrazine.

Soils are extremely important in the global warming equation, Schnoor says, because much more carbon is fixed annually by photosynthesis than is released each year in fossil fuel combustion. Even a small change in net storage or net release from photosynthesis resulting from changes in soils could greatly alter the amount of carbon absorbed and hence the amount of carbon added to or removed from the atmosphere each year.

Susan L. Anderson of the energy and environment division of Lawrence Berkeley Laboratory attempted to define whether toxic substances "simply cause a patchwork of regional insults" or whether they are now harming "the biosphere in ways that have profound global implications." She concludes that techniques for assessing low-level widespread effects of toxic agents on organisms are almost totally inadequate. "These problems must be addressed if significant global issues are to be characterized and resolved." Biomarkers are a promising way of "evaluating low-level effects of global pollution in situ, determining their potential cause, and examining the effects of specific toxic agents." Biomarkers could aid in predicting and assessing "how much chemical in specific tissues of an animal is too much," she says.

In addition, high priority should be given to research on the effects on organisms of UV-B radiation, Anderson suggests. This problem is more focused than studying widespread chemical contamination in diverse media.

In the industrialized countries, at least three trends are leading industry to have less of an impact on the environment per unit of output. One is that industries are using less materials per unit of value added in manufactured goods. In early stages of industrialization, manufactured items tend to be primitive, with most of the cost embedded in the bulk materials of their production. In later stages, a significant fraction of cost is likely to be embedded in sophisticated items like electronic controls, and resource use per unit of value added declines. Arnulf Gröbler of the International Institute for Applied Systems Analysis



Nelson (left): energy-savings projects pay off. Graedel (center): economic activity harms support systems. Paton: environmental issues affect product design.

ysis calls this trend the overall "dematerialization" of industry.

Similarly, when a country is beginning to industrialize, there is a large investment in basic materials industries like steel and cement, requiring large amounts of energy for each unit of output. Later on, Grubler says, these energy requirements decline as economic output, on average, becomes more sophisticated and technological change improves the efficiency of industrial processes. Long before the oil price shocks in the 1970s, industry in the developed nations had begun to cut down on energy use per unit of output.

In addition, the costs of waste disposal in the developed world are forcing industry to work hard to reduce wastes. These costs are rising 10% annually, and threaten to become the dominant cost of production, says C. Kumar N. Patel, executive director of research, materials science engineering, and academic affairs at AT&T.

In contrast, some intractable conditions in developing countries make it difficult for industrialization to proceed sustainably. One major problem is that Third World countries often lack the resources to buy anything but obsolete and pollution-prone technologies.

In China, for instance, although some of the industrial equipment is highly energy efficient, most of it is very inefficient, according to Jiang Zhenping of the Energy Research Institute at the Chinese Academy of Sciences. Coal currently accounts for 70% of commercial energy consumption in China, and by the year 2000, coal production is expected to increase 40%. If China could afford to replace obsolete equipment with

efficient technologies, like updated boilers, and if it would invest heavily in energy-efficient equipment and appliances, it would not need to expand coal production nearly so fast, and consequently would reduce its rate of emissions of carbon dioxide, sulfur dioxide, and particulates.

Better yet, if China had the capital to invest in the infrastructure needed to utilize its very extensive natural gas reserves, it could lower its carbon dioxide emissions still further because per unit of energy, gas combustion produces about one half as much carbon dioxide as coal. But, Zhenping says, China lacks the capital to invest in natural gas.

Utilities in the Third World often impede sustainable development. They are usually the largest government sector and are run by a mature, powerful bureaucracy that is committed to supply-side thinking, according to Ashok Gadgil of the energy and environment division at Lawrence Berkeley Laboratory. Utility managers in the Third World usually believe there is nothing to gain from energy efficiency. Their judgment is reinforced by national policies to subsidize the cost of energy, giving customers little incentive to conserve energy. "There are a lot of gains to be made in developing countries from taking the least-cost planning approach increasingly being adopted in developed countries," Gadgil says.

Saleemul Huq, executive director of the Bangladesh Center for Advanced Studies, told the conference that there is a "real question whether Earth and its resources can sustain the conversion of all the world's developing countries into developed or industrialized countries." The lives of the people need to be improved, he says, but mimicking the development pattern of

German chemist proposes radical plan for waste management of consumer products

The current system of waste management for consumer products is impractical, too expensive, and environmentally unsound, says Michael Braungart, chemist at the Environmental Protection Encouragement Agency, an independent nongovernmental organization in Hamburg, Germany. He proposes a way to transform the system into one that is economically and environmentally sustainable.

He elaborates this concept by dividing consumer products into three categories according to their proposed method of disposal—consumption, service, and unmarketable products.

Consumption products are those items, such as food and detergent, that are used only once and whose waste is put into the environment. According to Braungart's proposal, these products would have to be biodegradable, noncarcinogenic, nonteratogenic, nonmutagenic, and, in the concentrations used, nontoxic.

Service products are durable goods that provide services, such as auto-

mobiles, television sets, and washing machines. Consumers would lease these products from the manufacturer. When the products are no longer usable, consumers would return them to the manufacturer, who would be responsible for disassembly and recycling. The products would be recycled primarily into what they were originally—a computer, for instance, would become another computer with only a few parts replaced. Products would not be recycled into less valuable items, such as park benches.

Unmarketable products are those that cannot be used or consumed in an environmentally sound way and for which no safe recycling technology exists. In the long run, these products should not be manufactured, Braungart says.

Until unmarketable products can be disposed of safely, they should be stored in warehouses, Braungart says. The producer of unmarketable products would be responsible for renting space for the used products in warehouses and eventually ensur-

ing their safe disposal. Braungart believes the warehouse system would motivate manufacturers to use materials made of environmentally safe chemicals that can be recycled with existing technologies into new products.

To some observers, these ideas for waste disposal sound radical and visionary. But, in fact, some rather similar concepts are now being tried and others are expected to be used in the near future. For example, Germany's federal environment minister, Klaus Töpfer, is working to transform the German society from a "throwaway" culture to one devoted to recycling. German regulations require manufacturers to take back 80% of the packaging they used on their products starting in July 1995 (C&EN, July 27, page 7).

"The international computer and auto industries are developing and implementing plans for disassembly plants," Braungart says. An automobile disassembly plant is already planned for a location not far from Hannover.

the North is not a viable option. "We need to rethink development patterns" and find ways of developing without harming the environment. "We have to think about a reasonable level of consumption for developing countries to aspire to." For example, the per capita meat consumption in the U.S., which is 52 times that in India, is not a reasonable goal for most of the Third World.

Basically, two kinds of approaches are now being used in manufacturing in the developed world to reduce the environmental impact of products or production processes. One is to redesign the products so they have less environmental impact during their useful life and disposal. Another is to reduce waste or energy use during manufacture.

The Louisiana division of Dow U.S.A. has been using the second approach. In 1981, the division initiated an energy-savings contest. As described by Kenneth E. Nelson, energy conservation manager at Dow, under the rules, anyone in the plant can be recognized for devising an energy-saving scheme.

At first, Dow employees believed that all the ways to save energy would be discovered in the first year or two of the contest. But the number of projects and the money they save has grown almost every year. According to audited results, the total group of projects has an average return on investment of about 230% per year, Nelson says. The program started small, but now each year's winning projects produce annual savings of \$20 million to \$25 million, and the total audited savings for the more than 500 projects completed thus far are more than \$107 million per year.

In 1986, waste projects under a national Dow program called "Waste Reduction Always Pays" were added to the contest. The annual return on investment for these projects is about 111%.

The contest has worked at Dow's Louisiana division, Nelson says, partly because it receives support from all levels of the organization, especially management.

Corporate environmental decisions used to be driven primarily by government regulations, addressing pollution control and remediation of wastes. Now, "more than ever before, customer demands and competitor initiatives are introducing environmental issues into decisions regarding product design," says Bruce Paton, a quality program manager at Hewlett-Packard.

"Customers are sending us questionnaires that ask: 'How much energy are you using to make products, how do you recycle products, and how much waste is produced?'" Paton says. And "some of our competitors are saying, 'We are recycling our computers.' These factors are motivating change at a much faster pace than we are used to. At the same time governments around the world are imposing broad new requirements that address the environmental effects of products and of the processes used to make and support them."

To respond to these concerns, Hewlett-Packard and other firms are exploring a new corporate objective called De-



Huq: need to rethink development patterns

sign for Environment (DFE). DFE is concerned with much more than the waste produced within the factory. It also involves product design (such as design for disassembly of products at the end of their useful lives), materials selection, concern for dissipative uses of toxic materials, and the environmental impacts of production by suppliers.

One aim of DFE is to design all products with materials that permit reuse or recycling. "Selection of proper materials can help make it possible to recycle plastic enclosures and many other parts," Paton says. Many computers are now being designed so they can be upgraded by exchanging circuit boards. DFE has a great potential for creating new efficiencies and improving product performance and thus improving corporate profits, he adds.

Volvo has developed a new, related system for assessing quantitatively the environmental impact of its products. It is a "life-cycle analysis approach to evaluating products, incorporating environmental impacts due to manufacturing, use, and disposal of the vehicle," says Inge Horkeby, head of the environmental protection department at Volvo. It applies what Volvo calls environmental load units to each part of the vehicle. This allows product designers to select components that minimize environmental impacts.

Six factors go into determining environmental load units: the scope, distribution, frequency, durability, remediability of the impact, and the relative part of the impact caused by Volvo. The system can be used, for example, to evaluate whether a plastic composite or steel front end for a vehicle has less of an overall environmental impact.

A number of U.S. companies are now carrying out cooperative research to develop processes that will reduce the impact of manufacturing on the environment. One program, called the Environmentally Conscious Manufacturing Program (ECMP), is run by the National Center for Manufacturing Sciences, a nonprofit research and development consortium headquartered in Washington, D.C. with a membership of more than 160 corporations. Wayne France, head of the environmental science department at General Motors, says the program, begun in 1991 with a small budget, has expanded greatly. It has a projected budget of \$25 million for 1993. It has projects on a variety of topics ranging from solvent substitution to handling of metal-working fluids to reduced lead use in manufacturing. ECMP is looking into establishing a panel of outside experts to advise it on the environmental impacts of products and processes and on forthcoming government regulations.

In 1991, manufacturers also formed a vehicle recycling partnership to pursue R&D on recycling, reuse, and disposal of motor vehicles, France adds. Opel in Germany has announced that it "will take back free of charge the new Opel Astra for recycling" at the end of its useful life.

The conference participants suggest a number of ap-

approaches that can be used to reduce the environmental impact of nonmanufacturing industrial activities. Robert C. Harriss of the Institute for the Study of Earth, Oceans & Space at the University of New Hampshire says aggressive programs in industrial ecology could arrest the increase in global atmospheric methane. Methane is the most rapidly rising of the greenhouse gases.

A first step in reducing methane growth would be to find and stop natural gas leaks in the world's cities, Harriss says. A new monitoring instrument, a tuned diode laser developed by Aerodyne, can be installed in a van, and used to take continuous measurements all over a city. It measures methane with a precision of 5 ppb, and because of its rapid time response (less than one second), it can locate methane sources very accurately. A second step would be to transform sources of methane pollution, such as landfills and sewage treatment facilities, into energy sources.

Today, biomass accounts for about 15% of the world's energy supply, 35% in developing countries. Robert H. Williams of the Center for Energy & Environmental Studies at Princeton University believes that biomass, grown renewably, can supply a much larger fraction of the world's energy and thus reduce greenhouse gas emissions substantially.

So far, biomass has been used in two ways for industrial purposes. Ethanol has been produced from grain and sugarcane, and agricultural and forest residues have been used to produce electricity in steam turbines. But, Williams says, there are several new ways in which biomass could be used cost effectively by exploiting advanced technology: gasification and electricity production using gas-turbine-based power systems, and direct use of liquid and gaseous biomass fuels in fuel cell vehicles.

Gas-turbine-based power systems are much more efficient and much less costly than steam turbine power systems at the modest scales (10 to 100 MW) needed for biomass power systems. "Electricity produced with biomass-integrated gasifier/gas turbine power systems not only offers major environmental benefits but would also be competitive with electricity produced from fossil fuels and nuclear energy in a wide range of circumstances," Williams says.

Liquid biomass fuels could be used in internal combustion engines for transportation, and hydrogen or methanol from biomass could be used as fuel in fuel-cell-powered cars, Williams adds. Even though the fuel would be more expensive than gasoline, the life-cycle cost of a fuel-cell car, which has near zero pollutant emissions, would be about the same as that of a traditional car because the fuel efficiency would be greater and the vehicle's power plant would last longer.

In the short term, forest residues of the pulp and paper industry and sugarcane bagasse and leaves could be used as a source of biomass, Williams says. In the long term, very extensive biomass plantations could supply large quantities of biomass energy. He projects that degraded lands suitable for reforestation in Latin America and Africa might be adequate to supply two fifths of the world's estimated liquid fuel needs by 2050. "Establishing biomass plantations on degraded lands would be a way of paying for their restoration," Williams says. But methods still need to be developed to recycle the nitrogen and phosphorus contained in the harvested biomass crops back to the plantation soil.

The participants at the Snowmass meeting met in three parallel working groups during the second week to try to

develop new approaches to redesigning industrial activities to promote sustainable resource use. To encourage corporations to produce sustainably, the working groups came up with several recommendations. One is that subsidies for virgin materials, such as oil or lead, must be reduced and the costs associated with obtaining, processing, distributing, and using materials, including the cost of damage to the environment, must be reflected in their prices.

Another is that institutions should be reformed to encourage product stewardship. To aid in this effort, cooperative research, development, and planning should be encouraged among corporations, and better ways to convey information on reuse and recycling of products should be developed. For example, self-reporting by industry to the public should include information about energy consumption, other operating costs, and disposal practices.

Moreover, service or leasing arrangements that reward companies for participating with users to minimize total energy use and environmental impacts should be encouraged. For example, service arrangements could be made between agrochemical companies and farmers to maximize the effective use of fertilizers, insecticides, and herbicides. The farmer would pay for the service, not the chemicals.

Some of the conclusions of the working groups focus specifically on accelerating the adoption of the principles of industrial ecology. The participants propose that some organization, such as the United Nations or World Bank, develop a clear and consistent environmental framework within which companies investing in developing and transitional countries can operate. The framework, for example, would help protect companies from liabilities associated with prior contamination at the sites of new investments. One part of this framework would be financial and technical support to citizen action groups. Another part would consist of targeted training for public authorities.

Still another would be to encourage independent information sources to broker relationships among technology and equipment suppliers, financiers, and developing country recipients, the participants conclude. Such a broker could help all parties deal with the multitude of social, political, and economic conditions resistant to innovation in both developed and developing countries.

The working groups say it is urgent to devise global institutions that can rapidly transfer the lessons learned in developed countries to the developing world, and vice versa. The mere existence of information about a hazard and the availability of cost-effective technology to reduce the hazard does not guarantee action. The appropriate institutions to initiate action need to have sufficient international prestige to overcome the inertia of bureaucracies and corporations that have been perpetuating environmentally damaging practices that should have been terminated years ago.

The participants urge putting more effort into trying to understand the potential limits, nonlinear responses, linkages, and surprises associated with human perturbations of natural cycles, such as the carbon, nitrogen, and sulfur cycles. A parallel area for increased effort is research on toxic compounds, where it is important to study the effects of the total system, rather than focusing on a single aspect, such as carcinogenicity. In addition, the working groups urge more support for the development of environmentally benign production processes and products.

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