# Materials and Energy Flows in the Earth Science Century

## A Summary of a Workshop Held by the USGS in November 1998

*By* William M. Brown III, Grecia R. Matos, *and* Daniel E. Sullivan, *Compilers*

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Title page. Globe with superimposed materials flow cycle.
Created for the workshop by Daniel E. Sullivan and William M. Brown

# Preface

The discipline of industrial ecology has been described as the "Science of Sustainability." Industrial ecology aims to understand human economies within an ecological context and design the use of materials and wastes so as to minimize—if not prevent—their impact on the Earth. To understand an economy in this context requires accounts that show physical flows of materials from the environment, through the economy, and out to the environment as wastes.

Human activities that affect the natural environment almost always change the natural flows of material within the Earth system. Human beings modify the Earth and its hydrology, extract minerals, move earth, erode and dredge, farm, manufacture, pollute, dissipate, and dispose. While we understand much of this human activity in broad financial terms, we understand very little of it in material terms—the actual factors that can degrade our environment. Material flow accounting aims to document the materials mobilized to serve the human economy—at whatever scale—and so serves industrial ecology and economic analysis.

This volume is a compilation of presentations made at the USGS Workshop on Material Flows and Industrial Ecology, held in Reston, Virginia, in November 1998. In that workshop, those working in the field of industrial ecology and material flow accounting—from the USGS, other government agencies, universities, nongovernmental organizations, and private enterprises—were invited to present examples of the power of this approach to help us understand human impacts on the environment. Because industrial ecology and material flow accounting require researchers to look at whole systems, including economic systems, in their physical manifestations, these presentations gave USGS employees new tools with which to approach their work and new opportunities to perform integrated science.

The USGS sponsored this workshop—in part to showcase how our emphasis on multidisciplinary science can facilitate a whole systems approach. Industrial ecology provides a framework for our integrated science activities. And those involved in industrial ecology research and material flow accounting count on the USGS for much of the data required to understand our planet as a whole and to apply this understanding to avoid possible unforeseen consequences of well-intentioned decisions.

These are powerful tools for those of us concerned with good stewardship of our planet and for sustaining economic opportunity for our people.

Charles G. Groat
Director
United States Geological Survey

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## Overview

### A Fresh View of Earth Systems Management

For the 21st century, the USGS and many others throughout government, academia, and the private sector carry a hopeful vision of better solutions to the problems of depleting natural resources and creating excessive wastes. Despite growing numbers of people and their associated demands for materials, energy, living space, and a healthful environment, there is cautious but broad optimism about meeting these challenges. The optimism stems from realizing scientific capabilities to understand global materials and energy flows, and recognizing that our societies can create remarkable efficiencies, both in the way we use materials and energy and how we reduce and treat waste products.

For this effort, investigators are engaging in whole system views of the human condition using the tools of *materials and energy flows accounting* and *industrial ecology.* Materials and energy flows accounting involves a thorough and holistic view of the materials flow cycle, wherein materials are tracked throughout their life cycle from extraction, through manufacturing, consumer use, reuse, recycling, and disposition. The energy inputs and losses associated with these activities are critical to comprehending the full picture of the materials flow cycle. Such accounting provides the data for industrial ecology and economic analysis, and serves interdisciplinary work on the intersection of human activity with the rest of the environment. Industrial ecology is the *"Science of Sustainability"* that views and analyzes industrial systems in much the same way that biological sciences treat ecosystems. Industrial ecology aims to understand human systems within an ecological context and design the use of materials and wastes so as to minimize their impact on the Earth. Socolow (this volume) described how practicing industrial ecology integrates industrial systems with the natural world. What industrial ecology offers the world is a fresh view of environmental management that sets priorities for concern, gives strong messages for rational policymaking, and transforms those who damage or destroy the environment into agents of positive environmental change.

Embracing principles of industrial ecology moves people toward creative solutions to problems of materials use efficiencies and eliminating waste. Cohen-Rosenthal (this volume) noted that these principles include connecting individual firms into industrial ecosystems, balancing inputs and outputs to natural ecosystem capacities, reengineering industrial use of energy and materials, and aligning policy with a long-term perspective of industrial system evolution. He explained differences between engineered and self-organizing industrial ecology. He showed practical ways to achieve new mechanisms, new hypotheses and goals for materials reuse, and he posed new questions for reducing materials impact. There is a hierarchy of materials transformation, from genesis and design for durability to waste disposal and releases to the environment. This hierarchy suggests a broad range of new technologies and business opportunities at all stages of materials transformation.

The principles of industrial ecology also lead to the reorganization of individual manufacturing facilities, and systems of such facilities, or eco-industrial parks. We are in a period of discovery with respect to organizational intelligence, and creating or nurturing businesses likely to participate in eco-industrial development. The discovery and consequent development must be based upon sound data, and developing new data on materials and energy flows at the local and regional levels. The development must relate to existing companies and resource-use patterns, and must be connected to market demands for environmental characteristics to be successful. There are now several experimental eco-industrial development sites in the United States, all guided by the common goals of decreasing pollution and waste while simultaneously increasing business success. These sites have in common a trend toward maximizing cooperative endeavors, and attempting to operate in particular materials/energy domains wherein a variety of alternative "upstream" and "downstream" connections can be made.

The views expressed by the workshop participants are also vital to the intentions of sustainability. Sustainability is an overarching idea that encompasses meeting the mutual goals of economic development and environmental protection for the purpose of fulfilling everyone's basic needs. The terms "sustainability" and "sustainable development" have evolved in the global policy arena since the terminology was first treated by the United Nations in 1972, and have become heavily integrated into shaping policies of the public and private sectors in the 1990's. Many participants referred to sustainability in their presentations, and provided a variety of explanations of the term. Palmer (this volume) discussed sustainability as the level of consumption of natural resources (water, food, soil, minerals, wood products, energy), and production of waste products that can be continued indefinitely by the human population. There is an "ecological footprint" of humans, which is the impact of people on the ecologically productive area of the Earth, and which can be roughly calculated. According to Palmer's ecological footprint calculations, in the world of 2050 with a global population of about 10 billion, our current levels of consumption of natural resources are not sustainable.

The U.S. Interagency Working Group on Sustainable Development Indicators (SDI's) has been studying SDI's since the beginning of the Clinton Administration. Heintz (this volume) related how the group is oriented toward producing a fully integrated set of indicators that show trends toward or away from sustainable development worldwide. Developing SDI's is important not only to focus on how well societies are doing now in terms of sustainable development, but also to focus on long-term endowments and liabilities. Thinking in terms of endowments helps people understand the idea of the stewardship and trusteeship for which societies throughout the world are all responsible. Fundamental to this thinking is that the materials now considered as waste should rather be considered an endowment of raw materials for the future. Thus, societies move away from producing waste and move toward systems that become more sustaining by using the endowments of their own or other systems. The attention being given to recycling, reuse, remanufacturing, deconstruction, and similar processes is the beginning of a recognition that materials extracted from the Earth and processed into various forms are still all around us, and are in fact an endowment. This generation and future generations will have the opportunity to draw upon these; therefore, these materials need to be included in our accounting. The new message of sustainable development, and the focus of work on sustainable development indicators, is on endowments to ensure that what is passed along to future generations is as good as or better than what was passed along to us. Part of the full range of endowments, processes, and current results directly involves activities of the USGS. Some of these are investigations of water use, exotic species, and the beginning of land-use change, and they encompass the intensities of use of materials and energy.

The U.S. Interagency Working Group on Industrial Ecology, Material and Energy Flows (IE Group) was established by the President's Council on Environmental Quality in March 1996. Berry (this volume) described the IE Group's overviews of the way material flows have changed society throughout human history, and materials flows in the 20th century. The IE Group stresses solutions to materials flow problems under the headings of recycling, remanufacturing, redesigning, and rethinking. Recycling deals with reprocessing and using materials from discarded products to manufacture new products, or reuse them. Remanufacturing treats disassembling and cleaning discarded goods, reconditioning and adding replacement components, and reassembling them into rebuilt products. Redesigning is intended to dramatically improve efficiencies of materials and energy uses in products and processes. Redesigning also makes recycling easier, and makes disposal less environmentally damaging. Rethinking asks us to consider ways to provide goods and services to meet human wants more efficiently. The IE Group encourages human societies to move toward sustainable solutions to our materials and energy flow problems. The pathway to sustainable communities, cities, and regions involves pollution control, process integration, whole-facility planning, and industrial ecology. The IE Group advocates seeking less energy intensity and less material intensity per unit of product or service, while achieving lower levels of environmental toxicity and risk.

The stage is set for the 21st century to be the century of the earth sciences in much the same way the 20th century has been the century of physics. Humankind has emerged in the past few decades as a powerful and, in some respects, a dominant geologic force on the planet. Our need for, and reliance upon, natural resources, our concern for environmental quality, our concern for human health that in many cases may have a basis on geologic phenomena, and our rising concern for the health of the planet all point toward the potential emergence of the earth sciences. Bohlen (this volume) argued that indeed the earth sciences should play a role in shaping the most important debate of the next century—what will be the global population, what will be the standard of living, and what will be the state of environmental health. This debate will not be decided in some grand forum, but rather by thousands of decisions made around the world by those who might not even realize they are engaged in the debate or even having an influence on it. Bohlen's essentials of the *Earth Science Century* are (1) a priority emphasis on the surface of the Earth as a coherent air, water, and land system; (2) unification of geologic, biological, and ecological sciences within a social science context; and (3) new and higher levels of collaboration of practitioners within the earth science community. Areas ripe for advance include understanding the Earth in real time, the structure and function of ecosystems, forward modeling of complex systems, the connectedness of seemingly unconnected processes, the implications of surface processes for the origin of life and extinctions, and understanding the surface and near surface of the Earth.

The USGS is building its scientific strategy to meet the needs of the Earth Science Century. One goal of this strategy is to advance the understanding of the Nation's energy and mineral resources in a global geologic, economic, and environmental context. The United States is among the world's leading producers of energy and mineral resources, and the Nation's economic security depends on maintaining adequate supplies from domestic and nondomestic sources. The Nation constantly faces decisions involving the supply and use of raw materials, substitution of one resource for another, and the environmental consequences of resource development. With respect to materials and energy flows, the USGS maintains a unique role within the Federal Government and the private sector in comprehensive assessments of mineral and energy resources.

A goal advocated by workshop participants is a much higher level of Earth systems management than has heretofore been practiced. Earth scientists and others recognize that humankind is becoming more and more of a dominant force with respect to the surficial processes of the Earth. Human beings modify the Earth's hydrological systems, extract minerals, move soil and rock, enhance erosion, dredge, farm, manufacture, pollute, dissipate, and dispose on massive scales. Traditionally, our societies have focused on such activities in broad financial terms, and have neglected a comprehensive understanding of the materials terms—the actual factors that diminish our chances for good stewardship of our planet and for supporting economic opportunity for our people. For the future, a comprehensive understanding of materials and energy flows on a global scale is essential—not only to recognize the scope of human activities on the Earth's surface, but also to manage those activities for sustainable economies and a sustainable environment.

This volume represents an effort to bring together the thinking of principals from the USGS, other Federal agencies, industry, academia, and international organizations about roles of the USGS in materials and energy flows research. The participants met in November 1998 to identify problems and explore partnerships by (1) examining the importance of materials and energy flows in United States and global economies; (2) reviewing national goals and policies that are based on materials and energy flows and sustainability precepts, and (3) envisioning integrated approaches to materials and energy flows research.

## The Government Role

The USGS, other government agencies, and the private sector have tracked materials and energy flows in a variety of ways and for different time periods for more than a century. The new and challenging undertaking for these entities is analyzing this vast body of information in the long-term, national and global context of industrial development, economy, and social change—and doing it in concert with each other. There are many roles in this undertaking, and there is a great mix of participants poised to take the work well beyond the realm of traditional Earth science investigations.

The role of Federal science in materials and energy flows research is a "big picture" understanding of processes. That understanding is necessary in making informed decisions about resources with sustainability as a priority. Materials assume a role of increased importance as population grows, and the built environment grows in a corresponding fashion. Attempts to maintain growth of the built environment under current practices risks unsustainable resource use which in turn can lead to ecosystem decline and habitat destruction. Therefore, it is incumbent upon Federal agencies like the USGS to pay particular attention to the growth in materials and energy demands foreseen in the coming century, and the consequences of those demands. Schaefer (this volume) argued that materials flow analyses probably should be an integral part of all USGS activities.

A real opportunity exists for an increased government role in supporting industrial ecology and more efficient uses of material and energy resources throughout the economy. Berry (this volume) discussed how the government might maintain and enhance the function of long-term collection and analysis of critical materials and energy flow data. The government could develop its research priorities in this arena in consultation with industry, nongovernmental organizations, and other key stakeholders. Government agencies might rethink regulations with respect to (1) definitions of waste, (2) incentives and disincentives for the more cost-effective use of materials, and (3) supporting recycling and remanufacturing. Agencies could set examples in revising their procurement policies, and develop guidance on what constitutes environmentally preferable products. The government also has major education functions, and can examine the impacts of taxes, subsidies, and various market-based incentives on materials use, disposal, and efficiency.

In January 1998, the National Research Council (NRC) held a Workshop on Material Flows Accounting of Natural Resources, Products, and Residues in the United States. The NRC study arising from the workshop intends to assess the utility of materials flow data for making informed decisions about materials use and the expected consequences of alternative decisions. The study will consider types of data that are readily available and types of data that should be obtained. Information on specific materials would be used as examples to illustrate how materials flow and reservoir data would be useful to various government agencies in directing policy topics, and to private organizations in making materials and process choices. Schiffries (this volume) noted that potential applications of materials flow information include developing suitable national indicators of materials and resources efficiencies, assessing the national capability for substituting materials as quickly as they are needed, and increasing the efficient use of materials by industrial sectors. Other applications include changing materials use and processing methods to mitigate environmental impacts, and managing undesirable materials that are removed from the natural environment together with desired materials. The NRC also will examine designing disposal sites, such as landfills, to make materials more easily extractable at a future date, improving recycled material source-user relationships, and making quality and quantity more predictable.

The Federal Committee on Environment and Natural Resources (CENR) has developed an initiative on "Integrated Science for Ecosystem Challenges." Fenn (this volume) described how this initiative incorporates materials flow in the context of developing, coordinating, and maintaining a national infrastructure to provide scientific information needed for effective stewardship of the Nation's natural resources. Examples include materials flow research within USGS programs on abandoned mine lands, wetlands loss studies in the oil fields of south Louisiana, and natural resources damage assessment studies in Texas. CENR priorities for FY 2000 include studies of invasive species, biodiversity, and species decline; harmful algal blooms, hypoxia, and eutrophication; habitat conservation and ecosystem productivity; and information management, monitoring, and integrated assessments.

## Research, Policy, and Corporate Issues

Potential research roles for the USGS and others involve collection and analyses of data relevant for treating important issues at a variety of economic and spatial scales. Cleveland (this volume) argued that the work must be targeted for end users in academia, government, private, and nonprofit sectors. It must involve less descriptive analysis and encyclopedic data collection, and more quantitative modeling and assessment. Practitioners should think in terms of a global ecosystem driven by economic subsystems. The economic subsystems require natural resources (energy and materials) and ecosystem services, create products, and produce degraded materials that must be assimilated as waste or recycled. Economic subsystems in today's world are overwhelming the natural systems, and growing to become the dominant physical forces acting within our fixed global environment. These forces invite research into understanding the historical patterns of the material and pollution intensity of Gross Domestic Product (GDP). They prevail upon researchers to understand the economic, technological, cultural, and institutional forces that are driving those patterns. Finally, they require researchers to understand what the historical trends and driving forces tell us about the future.

Cleveland introduced "dematerialization," or the decrease in demand for and use of materials by societies. Dematerialization may result from technical improvements that decrease the quantity of materials used to produce a good or service. It may result from substituting new materials with more desirable properties for older materials. It may be achieved by changes in demand and consumer preferences for products, by legislation, or by the saturation of bulk markets for basic materials.

Cleveland noted that there are vast differences in modeling capabilities for materials and energy flows. There is a National Energy Modeling System (NEMS) framework that treats the global energy picture in a thorough and consistent manner. However, no such framework exists for materials. Investigators should consider a National Materials Modeling System (NMMS) that focuses on measures of concern to decisionmakers, whether they be economic, human health and environmental, national security, or other concerns. The NMMS envisioned by Cleveland should use a problem-directed, scenario-based approach, and it should be integrative and multidisciplinary. The approach should be outward-looking in order to complement and interact with a variety of public and private groups that contribute to policy analysis, including other Federal agencies.

Rejeski (this volume) stressed that from a policy perspective, and in terms of understanding toxic substances, the United States has treated the obvious problems, but many others remain. New and different data collection and analysis techniques are necessary to fill the gaps. Flow of materials across political boundaries will become an even more important issue. Hazardous materials will increasingly be embodied in, and thereby dissipated through the use of products. Dangers lie in unchallenged assumptions, especially about driving mechanisms, and materials flow analyses could help policymakers change their thoughts about drivers. Current research suggests there are many different sources of materials pollution than were previously recognized. For example, the accumulated total of hazardous wastes from individual households is greater than that generated by industry for particular toxic materials.

Drake (this volume) offered a corporate perspective using the example of the automotive industry. The very nature of the industry requires that materials for the product must be plentiful, and that recycling these materials is an economic necessity. Currently, recycling helps to optimize the life cycle of automobiles, and 75 percent of materials in automobiles are recycled. Understanding materials flow helps planners integrate their thinking about improving recycling efficiencies. For example, there is a major push to make individual parts easier to disassemble in order to recycle them. The overall goals today are to reduce negative environmental impacts throughout industries, to increase efficiencies in disassembly, to develop materials selection guidelines that will improve recycling efficiencies, and to promote environmentally sound solutions to product disposal. Drake concluded that in the automotive industry today, there is no inherent contradiction between "environmental" and "business," and environmental stewardship is good business practice.

## The EPA, World Resources Institute and the World Bank

Industrial ecology principles are important keys to the future of environmental protection, and the U.S. Environmental Protection Agency (EPA) is just beginning its efforts in this arena. Allen (this volume) described many EPA projects in industrial ecology that span the spectrum of regional, national, and international issues, and issues surrounding individual industries and products. Notable among these are application of life-cycle management to evaluate integrated solid waste management, and taking a systems approach to tracking international flows of energy and carbon. At a regional scale, the EPA is investigating the Triangle J Industrial Ecosystem Park by developing an input-output analysis of 140 facilities in a six-county region of North Carolina to match resources used and disposed by these facilities. The EPA is also working on the eco-industrial park idea in other areas, and on materials flow applications in designing sustainable communities. At the scale of individual industries, the EPA maintains a toxic release inventory useful for understanding materials flow and industrial ecology, and promotes environmentally conscious design and commercialization of products and processes. Projects that focus on individual products include a garment and textile care program that investigates fiber and textile production and garment manufacture that can reduce the application of chemicals used in professional cleaning.

The World Resources Institute (WRI) is continuing its work on materials flows in industrialized nations. WRI is concerned with measuring changes in the amount of physical materials entering and leaving national economies, individual economic sectors, and watersheds. Rodenburg (this volume) suggested that these findings might change the way people view their environmental problems, and could play a role in identifying policy opportunities or in measuring progress towards sustainability. The WRI and EPA cooperatively developed the Total Material Requirement (TMR), which is the sum of total material input and hidden or indirect material flows, including deliberate landscape alterations. TMR is the total material requirement for a national economy, including all domestic and imported natural resources. The TMR gives the best overall estimate for the potential environmental impact associated with natural resource extraction and use. WRI is reviewing a variety of measures of the TMR for Germany, Japan, the Netherlands, and the United States.

Hamilton (this volume) showed how the World Bank group is attempting to expand its measure of the wealth of nations beyond an assessment of natural resources. Thus, the wealth of a nation must be seen increasingly as a broad composite of the value of natural resources, the well-being of the people, and the sustainability of the resources and well-being. Sustainability in this case describes well-being that does not decline over time. The World Bank is particularly interested in sustainability, in that the organization helps developing countries to develop further, and some of the development it sees is not sustainable. The policy implications suggest that given the large share of agricultural land in natural capital of low-income countries, sound management of this land is of great importance. Capturing and reinvesting economic rents from mineral and petroleum resources is a significant issue in many middle-income countries. Policy prescriptions for becoming a high-income country include depleting exhaustible resources and investing the rents effectively, managing renewable resources sustainably, investing in produced assets, and increasing investment in human capital. There is no guarantee that development based on harvesting bountiful natural resources will lead to development that is sustainable and equitable.

## Examining the Issues in Materials and Energy Flows

Breakout groups decided that, from a policy perspective, investigators should be developing credible and reliable indicators in order to foster responsible stewardship, reduce entropy, and reverse adverse impacts on human health and ecosystems. The major policy objective, couched in the form of a question, should be, "How can we ensure sustainability?" Investigators should define policy in a way that does not interfere with market goals, by considering how to handle the probability of increased competition for resources, and how to maintain access to resources as they become more scarce. They must open pathways to multi-use, high-efficiency systems through combining incentives and removing barriers. For example, societies must create markets for recycled and reused materials such as paper, buildings, roads, and oil. Additionally, the Federal Government should leverage its market position in terms of the environmental consequences of the purchases it makes. It should reduce impasses to public confidence and regulatory inefficiencies, mainly through making policy based on objective evaluation.

From a corporate perspective, Federal agencies should be making comprehensive information available to the corporate sector. Breakout groups suggested that agencies could reduce risk to investors through due process (fairness), decrease uncertainties, and use one-stop permitting. They should maximize access to resources for both small- and large-scale users of materials and energy flows information. Public land-use and environmental policies have made it difficult to access domestic resources, and these policies could be considered for revision. Agencies should promote networking among eco-industrial units in order to share and integrate proprietary or classified information. The government should promote the ability to share resources, particularly in the arena of hazardous/regulated materials where information exchange encounters many barriers. The government should consider mass balance audits or assessments to maximize profits. Finally, it should consider the appropriate roles for market forces. Where should the government dominate or intervene? How does the government value or account for negative externalities?

The USGS should foster or expand its function as an "integrator" of information from ecological, biological, and corporate disciplines. The USGS should capitalize on "scientific synergy," and the important separation it maintains from the regulatory sector. The USGS has a major role with respect to developing, maintaining, and consolidating databases. The USGS has a major role in involving data users in determining which questions the data are designed to answer; however, this role must be augmented by more aggressive partnering and networking with other agencies. There is a USGS role for providing data on the end uses of materials, and providing an historical data bank with ready access and analysis features. The USGS data must support research on such key processes as ecosystem structure and function, and urban systems, and provide knowledge to decisionmakers, both to attend to other-agency needs and as required by law.

Considerable overlap occurs in public policy, corporate, and sustainability issues. Among these categories, there will be shifts in time scales and priorities assigned to each issue. For example, sustainability addressed through public policy could require a longer term perspective than corporate treatment of the same issue. Likewise, corporate prioritization of a social issue would most likely be lower than public policy prioritization of the same issue. In evaluating issues, investigators should look both upstream at supplies and downstream at wastes within any part of the materials flow cycle.

Practitioners should identify where markets work well and where they do not work well, and concentrate on the latter. They should examine where government policies (including tax, fiscal, and land-use policies) do or do not support sustainability from a national perspective. There is the problem of identifying and responding to materials and energy flows issues globally. There is a need for information on natural flows and processes in order to evaluate the significance of anthropogenic flows. There must be a consistency of government policies, and ready availability of government data to the private sector and others who need it.

With respect to research, there is a need to build recognition of the issues surrounding materials and energy flows and sustainability. Building the recognition requires new levels of networking because of the interdisciplinary nature of the issues. The scope and size of the interest in these issues might be determined by a search of the World Wide Web.

Investigators must examine the major environmental problems globally, and prioritize these. They must review how a local entity or activity fits into the global perspective of environmental problems. Data at the local, national, and global levels must be used effectively to interconnect local activities with a global perspective. Materials and energy flows and their relations to sustainability constitute the basis for a new emerging science. This science is dependent upon the resources, economic, and other databases produced by the USGS and several other government agencies. The quality of databases needs to be improved to account for materials in imports, consistency of reporting, and methods for collecting more metadata. Data reporting that has heretofore been proprietary needs to be supplied or converted for universal access, whether voluntary or mandatory. The USGS needs to continue to evolve its activities from a focus on data collection to comprehensive data analysis.

## USGS Activities in Materials and Energy Flows

Current regional studies of mercury and hypoxia demonstrate strengths of the USGS and its partners. Gerould (this volume) described an Integrated Natural Resource Science Program to study problems believed to be caused by mercury in south Florida. This is a prototypical effort to involve diverse collaborators in many scientific fields in the study of a large ecosystem. The work emphasizes the necessity to consider the impacts of changing environmental conditions throughout the materials flow process for mercury. The USGS is part of a multi-agency partnership to assess hypoxia in the Gulf of Mexico, and to seek the sources of the problem. Hypoxia in this case refers to depletion of dissolved oxygen in gulf waters over a region as large as 18,200 square kilometers along the Louisiana-Texas coast. The indirect cause of oxygen depletion is thought to be nutrients (nitrogen and phosphorus) transported in solution from agricultural areas of the upper Mississippi River basin, particularly in Iowa, Illinois, Indiana, Ohio, and southern Minnesota. Scavia (this volume) discussed the scope of this problem, and the policy actions and science needs for its possible solutions. The problem illustrates a materials flow process with issues that bear upon and beyond the activities of 13 Federal agencies.

Phillips (this volume) outlined the USGS Chesapeake Bay Ecosystem Program. The 5-year effort begun in 1996 provides relevant information on nutrient and sediment conditions affecting the bay. The program also is investigating the response times and factors affecting nutrient and sediment dynamics, and selected living resources. This information was used in the evaluation of nutrient-reduction strategies in 1997, and will be used for the final assessment in the year 2000. The program attempts to clarify the principal factors affecting nutrient and sediment transport and their relation to the changes in the sources of these constituents in selected hydrogeomorphic regions of the watershed. The USGS is relating surface and subsurface characteristics to water quality and living-resource response over several temporal scales through studies in selected watersheds, and river and estuary reaches within hydrogeomorphic regions.

The USGS is considering merging economic modeling with Energy, Minerals, and other programs. Whitney (this volume) explained the philosophic, strategic, and product-enhancement rationales for developing energy/economic modeling in the USGS. Philosophically, geologic commodities are essential economic commodities. Strategically, the development of first-approximation models is vital for setting commodity and regional priorities in national and global energy supply studies. Finally, from a product-enhancement point of view, geologic information is more usable if investigators understand geologic, technological, and economic constraints on resource development. Thus, the USGS would do well to encourage economics as a “second language.” The USGS could conduct simple strategic modeling internally for identifying priority commodities and regions. It could also provide critical geologic data for economists, including quantity, quality, and environmental impact of development and use of resources. The USGS could build partnerships by collaborating with the experts on large-scale, long-term models, such as the National Energy Modeling System and models used by universities and industry.

Solley (this volume) described a little-noticed but potentially historic environmental turnabout wherein water use in the United States declined by about 10 percent from 1980 to 1995. This decline was concurrent with a population increase of 16 percent, and implies that people are finding ways to use water more efficiently. The decline in water use runs contrary to the conventional belief that water use rises with economic and population growth. The USGS has systematically tracked water use in the United States since 1950, and has noted some significant trends. Most of the increases in water use from 1950 to 1980 were the result of expansion of irrigation systems and increases in energy development. Higher energy prices in the 1970’s, and large drawdown in ground-water levels in some areas increased the cost of irrigation water. In the 1980’s, improved application techniques, increased competition for water, and a downturn in the farm economy reduced demands for irrigation water. The transition from water-supply management to water-demand management encouraged more efficient use of water. New technologies in the industrial sector that require less water, as well as improved plant efficiencies, increased water recycling, higher energy prices, and changes in the laws and regulations to reduce the discharge of pollutants resulted in decreased water use and less water being returned to the natural system after use. The enhanced awareness by the general public to water resources and active conservation programs in many States has contributed to reduced water demands.

The USGS has interests in patterns of mineral production and use in developing countries that will play key roles in attaining sustainable societies. One example of the situation is population growth rate compared with Gross Domestic Product (GDP) per capita. Using this comparison, many countries with the highest rates of population growth are also the countries with the lowest GDP per capita. Menzie (this volume) explained how the USGS also compared Japan, Republic of Korea, and the United States over the period 1965–95 with respect to several population and consumption trends. The rates of population growth are approximately the same for Japan and the United States; however, the growth in the Republic of Korea accelerated rapidly in the late 1960’s, and continues to outpace that of the United States and Japan. Correspondingly, the rate of aluminum consumption per capita in the Republic of Korea is rapidly approaching that of the United States and Japan in the late 1990’s, and the per-capita consumption of cement in the Republic of Korea accelerated past that of the United States and Japan in the mid-1980’s. By 1995, per-capita consumption of copper in the Republic of Korea exceeded that of the United States and Japan, whereas the Republic of Korea’s consumption of salt remained well below that of the other two countries.

The USGS is discovering that economic activities in developing countries will account for an increasing share of global materials flows. Increasing consumption by developing countries will result in significant increases in environmental residuals and significant changes in supply patterns. Developing countries will produce an increasing share of deleterious environmental residuals, including those that are purposely or accidentally emitted via air and water. Materials flows analysis by individual commodity explains reasons for and consequences of change, which is not possible if data are aggregated by physical quantity or value.

The USGS is studying the spatial dynamics of the Baltimore-Washington corridor, and trends and issues for materials flow in the region. Robinson (this volume) showed that construction aggregates are the most dominant mineral resources used in the United States. Aggregate mining is most intensive in the eastern United States, with Connecticut, Indiana, Maryland, Massachusetts, New Hampshire, New Jersey, Ohio, Pennsylvania, Rhode Island, and Virginia, reporting 1,500 to 5,000 tons mined per square mile during 1995. Upward trends in aggregate demand continue because of urbanization, growing transportation networks, and intensified use of land. The trends create issues of shifts in intensity of land use and economic activity, in resource needs and availability, and in rates of change of demand, quality of life, and resource management and use. The resource management issues are of primary interest to the USGS, and include lack of public awareness of processes needed to meet demand. The issues also include concentrating and consolidating the industry, sterilizing the resource and minimizing waste, and mismatches between markets and management units. The research response to these issues is encapsulated in a Mid-Atlantic Geology and Infrastructure Case Study. The study is identifying geologic sources of high-quality aggregate resources, and documenting the producers of aggregate, amounts of production, aggregate users, aggregate consumption, and aggregate recycling and disposition over the past 35 years. Part of the work is to develop and calibrate tools for forecasting regional aggregates demand and analyzing land-management planning with respect to aggregates.

## Directions and Opportunities for Research

There are opportunities for the USGS in analyzing materials flow distribution, and distribution studies can take advantage of USGS strengths. Such studies involve not only producing the numbers for materials, but also understanding the spatial distribution of materials throughout extraction, transport (specifically, environmental transport), and disposition. For some materials such as water, the natural flows will overwhelm anything that humans produce. In other cases, the industrial sources of a particular material such as cadmium will dominate. However, looking simply at input-output for a country, for example, is not sufficient, particularly if the interest is in effects of a toxic material.

Potential directions and opportunities for USGS research in materials and energy flows include an ecosystem focus in terms of structure and function, multiple impacts, nonlinear responses, scale, time, and place. Important research topics for ecosystems are hidden flows, remote effects of consumption, leakages in the materials flow stream, and proposing solutions to leakage problems. Researchers should be incorporating ecosystem services into our analysis of materials flow and sustainable development. Biological scientists are accustomed to looking at work of this type with a systems focus, and are valuable contributors in considering the ecosystem wealth that must be maintained in order to maintain our economic and materials systems of wealth. If researchers do not consider those basic ecosystem functions, they will be doing a disservice in the long term to our hopes of achieving sustainability of any kind of wealth.

Kirtland (this volume) discussed the importance of continuing education and communication about industrial ecology, sustainability, and materials and energy flows. The subject matter could be greatly enhanced by placing the information in a spatial context by mapping at all scales the flows, transformation, and uses of specific materials. Investigators should consider the vulnerability of eco-industrial infrastructures to natural hazards. They should understand and communicate the myriad interactions in industrial ecosystems to best position society for the realization of a sustainable future. They should look to miniaturization technology, and how high-design, low-materials products affect the recoverability and reusability of materials, and also lead to dematerialization. They should investigate how the flow and transformation of materials might change under climate and other global changes. Researchers need to look closely at how the transformation of materials affects the landscape. They should investigate how the flow and transformation of materials affect human health. Finally researchers need to be vigilant as they look for improvements in industrial systems. That vigilance will minimize the probability that societies succumb to the unintended and often ironic consequences of their actions.

The structure of the USGS Water Resources Division (WRD) positions it well for work in materials and energy flows. The WRD is geographically dispersed in each State throughout the Nation, and possesses multidisciplinary talent in all its principal offices. Issues of State, regional, and national importance can be readily addressed based on that organizational structure. Additionally, the WRD maintains contracts with a large number of partners; for example, the WRD had approximately 1,200 partnerships throughout the Nation in 1997. Ongoing WRD activities pertinent to materials flows include studies of nutrients, the transport and fate of certain metals, water quality in paved and unpaved areas, the effects of sewer systems on water resources, studies dealing with forest harvesting, calcium depletion, nitrogen cycling, and the geochemistry of mercury. Additionally, the National Water Quality Assessment (NAWQA) has generated many spinoffs, particularly with respect to nutrient evaluation; and WRD maintains a large program in monitoring and evaluating abandoned mine lands.

Plumlee (this volume) described how the USGS potentially can apply materials flow expertise that it has developed in the mineral-resources realm to other issues, including ecosystems, climate, hazards, and human health. Researchers should engage in “materials forensics,” looking carefully for the sources of materials and linking materials flow, for example, with geochemical tracers such as stable radiogenic isotopes. Earth scientists should perform “Earth system services,” such as investigating the role of natural hazards in materials flow. Finally, researchers should place the United States in its global perspective with respect to their investigations through the links of resources, climate, and environment that define the global context.

Throughout the Nation and around the world, research by the USGS and its partners continues to improve our understanding and awareness of materials and energy flows. Scientific advances will ultimately translate into new techniques for study, model policies for materials and energy uses, and other lessons with global applications. This workshop provided strong messages about rethinking our global environmental problems of the present and the future, and about advancing new directions for managing materials and energy flow systems of the Earth with the beginning of the 21st century.

# Introduction

## Challenges for the USGS in New Fields of Study

In November 1998, the USGS convened a special workshop on "Science, Sustainability, and Natural Resources Stewardship: The USGS and Research on Materials and Energy Flows." The workshop was held at the USGS National Center in Reston, Va. and attracted participants from a broad spectrum of disciplines, and many public and private agencies and organizations. The workshop ran for 3 days, with attendance varying from about 50 to 110 people. Approximately 175 people attended the workshop at various times throughout its course.

The workshop was termed historic by USGS Acting Director Tom Casadevall in his welcoming remarks, in part because of the unique and pioneering nature of the subject matter, and in part because of the uncommon mix of people attending the workshop. Routine tracking of materials and energy production and consumption has been an activity of the USGS for more than a century. However, analyzing these flows in the long-term, national and global context of industrial development, economy, and social change is a new and challenging venture for the USGS and its partners.

The study of materials and energy flows has great importance as a component of the emerging field of industrial ecology. Industrial ecology seeks to organize thinking about the massive, systematic transformations of materials and energy in modern economies, and provide a framework within which to improve knowledge and decisions about materials and energy use, waste reduction, and pollution prevention.

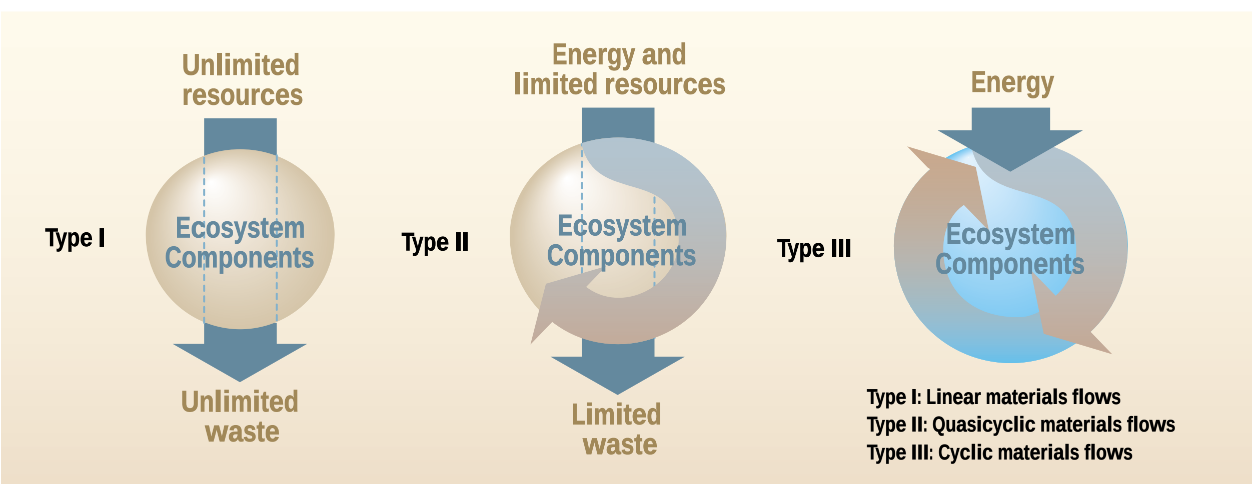
Studying materials and energy flows is also critical to the intentions of sustainability. The terms "sustainability" and "sustainable development" have evolved in the global policy arena since the terminology was first introduced by the United Nations in 1972. The terms have become heavily integrated into shaping policies of the public and private sectors in the 1990's. Sustainability is an overarching idea that encompasses meeting the mutual goals of economic development and environmental protection for the purpose of fulfilling basic needs for present and future generations. Its definition is deliberately vague to encourage appeal to many groups of people, and to urge them to create more substantive interpretations of sustainability. The USGS, for example, incorporates sustainability into its program plans, using sustainability and societal need as an impetus to acknowledge and investigate the increasing demand for natural resources as world population increases and the world economy expands.

The workshop brought together an extraordinary mix of people from disciplines and organizations, many of which historically have had little or no direct connections with the USGS and its work. The USGS was able to host some of the practitioners who created the field of industrial ecology, and to include public and private sector representatives who had never before visited the USGS.

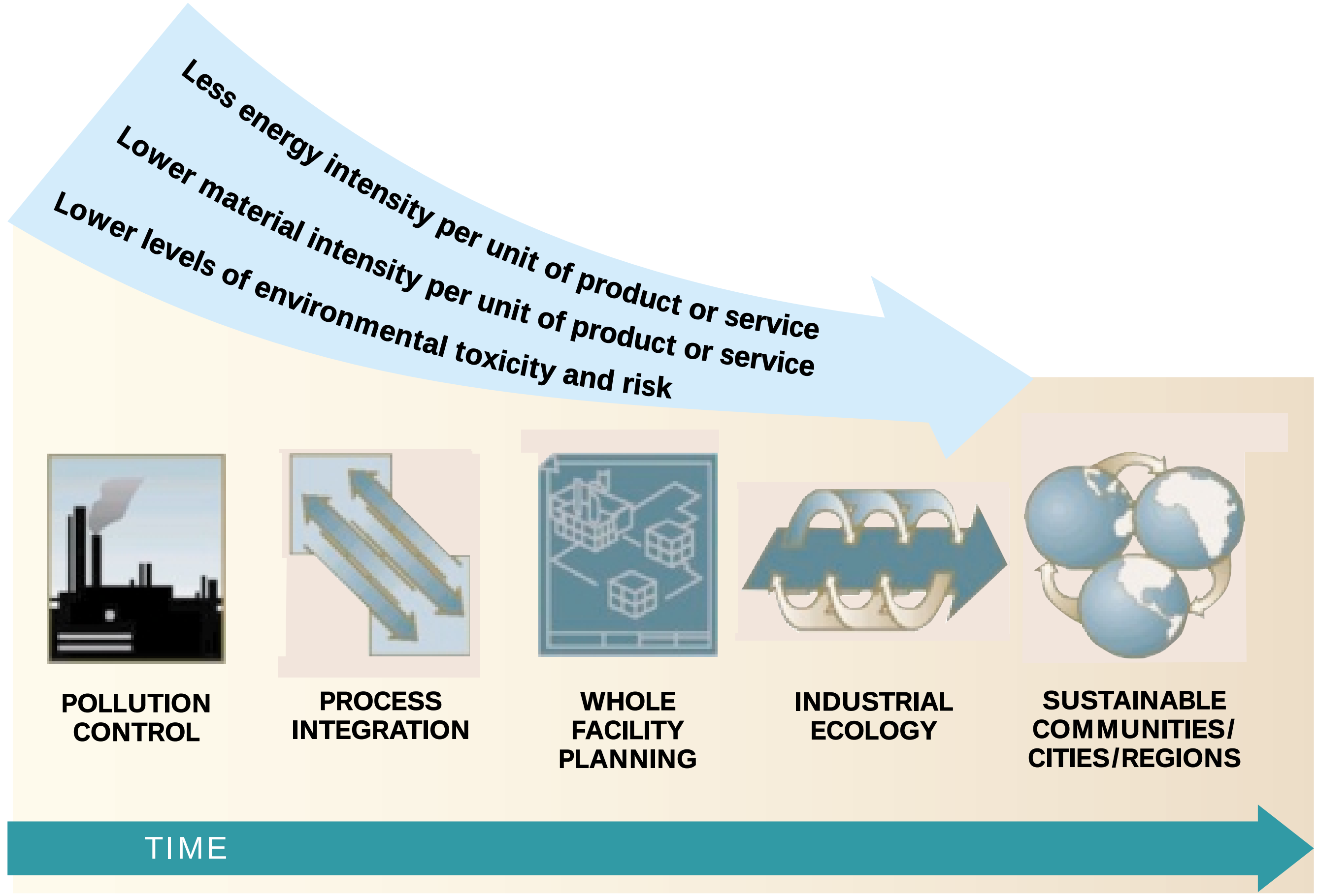
## Agenda Design

The workshop agenda was designed to:

- Bring participants toward common understanding of the history, concepts, and terminology of the domains of materials and energy flows, sustainability, and industrial ecology.
- Offer examples of work being done by the USGS and its guests, and to stimulate discussion and debate on the issues that evolved from these examples.




Industrial ecology takes its lead from the natural world, which comprises a range of living systems with different efficiencies. Ecologists call these Type I, II, and III systems. Some of these systems are very efficient at using materials and energy and reusing any remaining wastes. A Type III ecosystem can become almost self-sustaining, requiring little input to maintain basic functions and provide a habitat to thousands of different species. Modified from the Interagency Working Group on Industrial Ecology, Material and Energy Flows, 1998, p. 20.




Moving toward sustainable solutions. Adapted from the Interagency Working Group on Industrial Ecology, Material and Energy Flows, 1998, p. 21.

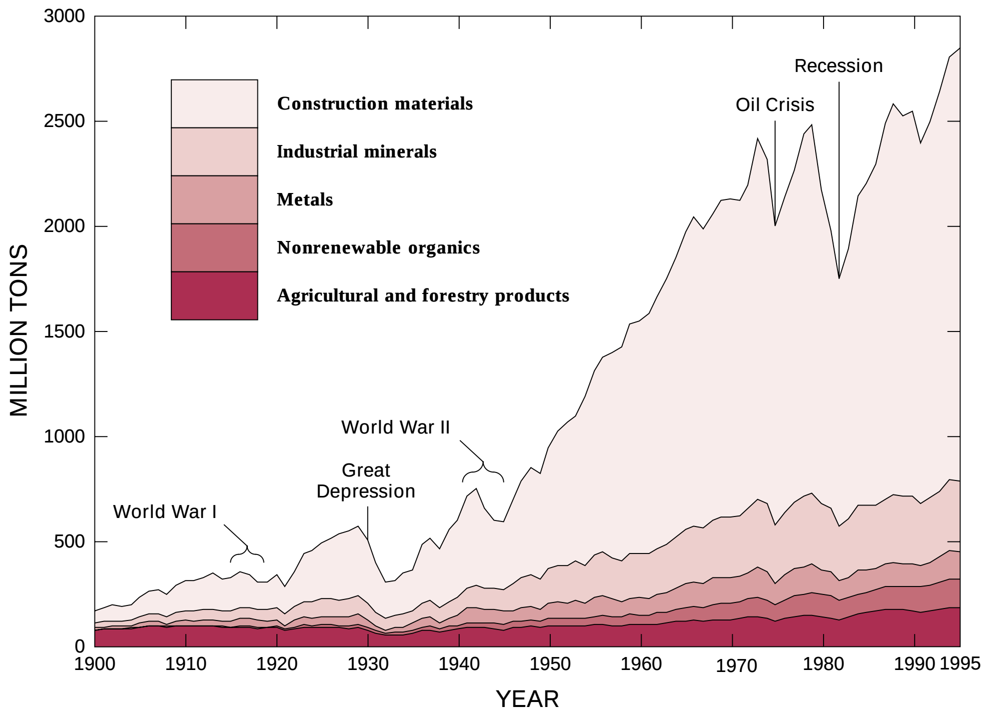
- Review and explain some of the historical, ongoing, and proposed work of the USGS that bears upon the issues developed at the workshop.
- Seek potential opportunities and directions for research on materials and energy flows by the USGS and its partners.

## The USGS Perspective

Tom Casadevall profiled the USGS as it stood in November 1998. The USGS includes more than 300 facilities, located in every State, Puerto Rico, and the Pacific Territories, as well as missions in a number of foreign countries. USGS regional offices are in Reston, Va.; Lakewood, Colo.; and Menlo Park, Calif. In 1998, the nationally distributed workforce numbered approximately 10,000 employees; in 1993—before the merger with National Biological Service (NBS) and portions of the U.S. Bureau of Mines (USBM)—the work force had more than 13,000 employees. The USGS is presently organized among the disciplines of geology (1,800 people), water (4,400 people), biology (1,600 people), and mapping (1,200 people)) and an office of program support. In January and October 1996, biological scientists from the NBS and minerals information specialists from the USBM were added to the skill mix of the USGS.

The USGS' appropriated budget for FY 1998 was $760 million. The FY 1999 budget was approved at $798 million; a 4.9 percent increase over 1998. From a constant dollar perspective, the USGS has been essentially flat-line funded for the past decade. In addition, the USGS receives approximately $300 million in reimbursable funds from other government agencies at the Federal, State, and local level. Many of these dollars are matched by USGS appropriated funds. The USGS does more than 20 percent of its work (about $155 million) for other Department of the Interior agencies, especially the land management agencies (National Park Service, Bureau of Land Management, and Fish and Wildlife Service). Acting Director Casadevall mentioned this aspect of USGS cooperation because it affects the way the USGS approaches its work and its science.

The USGS has been engaged in tracking materials and energy flows since creation of the agency in 1879. In the late 1800's, for example, the USGS began a statistical series on the production of individual metals and minerals for the United States, and measurements of the flow of water in our Nation's rivers. It can now be seen that USGS databases on resources and resource flows, compiled over the course of more than a century, have special meaning when examined in the long-term context of industrial development, economy, and social change. Now it is clearer how the use of minerals, energy, and water has taken the United States to where it stands at the beginning of the 21st century. The data can be compared to major events,




Use of materials in the United States, 1900-1995. Modified from Matos and Wagner, 1998, p. 110.

technological developments, and cultural change during the 20th century, and support some understanding of how those factors have helped or hindered the course of trying to maintain a productive yet livable environment for the inhabitants of our planet.

The USGS, particularly in recent years, has been exploring modern issues in materials and energy flows, sustainability, industrial ecology, and interrelations among the earth sciences, economics, and social sciences. The current USGS Strategic Plan stresses the agency's role in sound stewardship of the Nation's land and water resources, in assessing how land and water resources are being used, and in understanding of how possible changes in use might affect the national economy, the environment, and the quality of life for people.

The USGS is focusing on a horizon of some 10 years ahead on these issues. The agency is looking at changes in national demographics, the expanding influence of advances in scientific methods and technologies, and the continuing—and underlying—tension between the development of the Nation's natural resources and environmental protection.

The USGS is approaching the Nation's highest priority natural science problems increasingly from an interdisciplinary perspective. This perspective capitalizes on its vast array of scientific and technical strengths, and is a perspective well suited to the issues before this audience. Understanding sustainability, industrial ecology, and the cycles of resource flows demands the interdisciplinary approach.

The consolidation of the National Biological Service (NBS) and the minerals information activities of the former U.S. Bureau of Mines (USBM) into the USGS have given it a unique opportunity in the scientific community to integrate the physical and biological sciences, and to provide the American people with an even richer scientific program about the Earth. This consolidation in the mid-1990's has greatly augmented USGS strengths as a nationally distributed, multidisciplinary workforce capable of working anywhere in the Nation.

The USBM and the NBS have brought to the USGS additional long-term national databases on minerals and materials—on timber, waterfowl, and fisheries—that greatly enhance USGS abilities to take a more comprehensive view of materials and energy flows, and ideas about sustainability. These resources will augment the many databases the USGS currently maintains, and give it a superior capability to conduct long-term, broad-scale, multidisciplinary interpretive studies. The USGS plans to expand and continue these with objectivity and scientific excellence, as well as its strong heritage of collegial relationships and partnerships with the customers it serves.

The USGS is also seeking new ways to translate information into forms that can be used by makers of public policy, the business community, and individuals. The agency is well qualified to undertake this activity, because of its mix of scientific and technical skills and its capabilities to design and manage large geospatial investigations and databases, and because the USGS is perceived as credible, impartial and unbiased. In many disputes, the USGS is called on to play the role of honest broker.

The USGS Strategic Plan incorporates business activities that focus on materials and energy flows, sustainability, and the socioeconomic forces that interplay with the roles of Federal science. These activities are described within the contexts of Water Availability and Quality, Contaminated Environments, Land and Water Use, Nonrenewable Resources, and Biological Resources, and show a strong level of support for the concepts upon which this workshop is based.

For example, the USGS within the next few years will complete multidivisional studies of infrastructure resources in the Rocky Mountain Front Range, and in the Mid-Atlantic Urban Corridor. These studies emphasize both availability and materials flow of natural aggregate. The work will produce geospatial databases in a decision support system to assist land managers in planning, monitoring, and forecasting the flow of aggregate and related materials through use, reuse, and disposal.

The USGS also produces domestic and international reports for critical mineral commodities and monthly leading and coincident indices of metal industry activity and prices for the major domestic metals. The Federal Reserve Board, other economists, banks, and planners use these reports to analyze the effects of the business cycle on future production. Mineral commodity information and work on materials flow are used by a broad spectrum of policy makers in government and industry to analyze the materials flow through society and the economy and to make best use of our natural resources.

Casadevall mentioned that strategic planning is a process that the USGS takes seriously. This planning is a continuous process that forces the agency to look outward and inward, and respond to continuously evolving requirements. It is a process that provides a way to be constantly aware of the choices available to the USGS to ensure its health and relevance. It requires a constant dialogue with stakeholders, partners, and cooperators to be sure the USGS selects the best course at any point in time. Thus, the activities of the workshop are ideally suited and appropriate to the strategic planning process, and Casadevall commended participation in revealing the many routes and options available to the USGS on the issues before this audience.

The USGS continues to take a proactive role in providing science for a changing world. In the areas of mineral resource science, sustainability, and natural resources stewardship, much remains to be done to fill the many information gaps in the materials and energy flow cycles of our resources and to understand more fully materials and energy flow processes and how they are affected by economic, regulatory, and environmental decisions.

Casadevall thanked the participants for embarking upon this work, and hoped they would have many enjoyable and productive associations during the deliberations of the week.

## Industrial Ecology and A New Vocabulary for Emerging Fields of Study

### Do We Like Where We Are Putting Things?

The domains of materials and energy flows, sustainability, and industrial ecology are characterized by a fully modern and evolving vocabulary, and the terminology therein poses particular difficulties in communicating, whether among practitioners or those wishing to understand them. Thus, much of the first part of the workshop was devoted to introducing participants to materials and energy flows, industrial ecology, and sustainability, and their interrelations.

Robert Socolow of Princeton University asked the audience to consider what constitutes industrial ecology, and what it offers the world. Socolow defined the field as the self-conscious organization of production and consumption to reduce adverse environmental consequences of human activity. What industrial ecology offers the world is a fresh view of environmental management that sets priorities for concern, gives strong messages for rational policymaking, and transforms those who damage or destroy the environment into agents of positive environmental change.

Socolow noted that "industrial ecology" is a phrase people tend to like. It captures metaphorically a word that has a flavor of belonging to nature and a word that seems to belong to people's activities. He stated further that industrial ecology, and the matters of the workshop, promised to enlarge the system boundaries of what the life's work of investigators in the field is all about. Practitioners are now moving from a production focus—a supply focus—to a focus on use, and positioning themselves at various points along the flow stream to look upstream and downstream at processes and consequences.

Socolow spoke of a critical role for the USGS. That the USGS is deciding to hold this workshop and engage in this debate at this time is a signal of society's willingness to change its method of attack on managing the Earth. The USGS brings to this debate quality, openness, and clarity of presentation, which are huge assets for the process. Additionally, Socolow expected that within five years, there would be a new class of databases for looking at problems that heretofore have not been a part of the agenda of the USGS.

The thinking inspired by industrial ecology is moving us from concerns based on scarcity to concerns based on abundance, and practitioners are taking a fresh view of environmental management. They are moving away from environmental policing and controls using the thinking based on point sources, and wanting to find the "bad guys," especially in industry. Now they are using rationality, counting all the molecules in the materials flow stream, and thinking of industry as an agent of change. These are not brand new ideas, but they are fresh ideas that borrow from the metaphor of ecology. In this metaphor, nothing is wasted. Everything is used, and it is not just the flows, but also the consequences that matter. Therefore, it is a practice of looking at limited consequences, not just limited volumes. Practitioners are asking rational questions, and asking themselves, for example, if we as a global society really like where we are putting things.

The research community is only beginning to look at where to put carbon and nitrogen. In a review of the $CO_2$ problem, most of the carbon is going to the wrong places. This is happening to the extent that what once was "energy work" is now becoming "carbon work." How carbon is modeled is a good prototype for analyzing other materials. Practitioners are much further along in the industrial ecology of carbon than they are in the industrial ecology of most other materials.

Almost all of the work on carbon must be global. In 1945, the United States was using one-half of the world's fossil fuels. Today, even with increased national consumption, the United States is using one-quarter of the world's fossil fuels; thus, the world is "catching up" to the United States in terms of energy consumption. Therefore, what are the options for other countries in getting off the same energy consumption "ladder" as the United States? First, many more technological options are available to other countries today than there were for the United States during its development since 1945. It is reasonable for other countries to "play leapfrog" to aim for a more efficient economy, and bypass the inefficiencies and infrastructure that the United States must overcome in a more roundabout way.

Socolow described the Natuna, Indonesia, gas-field development as an example of planned carbon sequestration for a huge gas reserve in the South China Sea. To exploit this reserve, companies assumed from the beginning that they would need to sequester the carbon dioxide ($CO_2$). Knowing what to expect in volumes of $CO_2$ from the reserve, they simply could not release so much into the atmosphere. Therefore, they want to keep the separation of $CO_2$ from natural gas under control, and place the $CO_2$ back underground. This is a new and extremely important strategy, and it may be the most significant way in which society manages the $CO_2$ problem. There is a huge role for the USGS in helping to understand that problem. A large underground aquifer, about 2 kilometers below the surface, is available to contain the $CO_2$ that will come out of the gas extraction. Will the $CO_2$ stay in this aquifer? How will it be monitored? Questions of this type need to be global issues and governmental issues. Socolow was pleased to note that companies are now saying, "***we are in the carbon management business." The Natuna example represents a major step at the front end—the beginning of carbon management.

Socolow advocated Earth Systems Engineering for converting from running the Earth on carbon to running the Earth on hydrogen. He noted that nitrogen dioxide ($NO_2$) from the use of nitrogen fertilizer causes large rates of fixed nitrogen to be added to the environment. Fertilizer plants are fixing nitrogen at rates that are about the same as that of natural fixing by microorganisms. The volumes of nitrogen from fertilizer manufacturing dwarf the quantities resulting from combustion processes. Therefore, society is heading for a nitrogen-management regime. Socolow expressed the hope that the USGS sees this activity as its "territory," that is, that the USGS would take on tracking the fertilizer production over time. Although it is not a USGS tradition to determine on what crop the nitrogen is being placed, this might be something the USGS would want to consider. What happens on the field after the harvest? A complete industrial ecology of nitrogen is ahead of us as a research community.

In terms of how we like where we are putting things, we can probably only give a high grade to lead. Society has not been so successful with other toxic metals, and there is a long way to go to achieve successes similar to what has been achieved for lead. The mean lead concentration in human blood worldwide has declined significantly since the 1970's, and lead is being taken away from the places where it is dangerous and put in places where it can be more useful and less dangerous. The principal reason is that lead has been taken out of gasoline, but there is more to the story than gasoline. For example, there are changed policies about using lead solder in food cans and about the use of lead in paint.

However, a global redistribution of lead use has taken place. The United States uses about 45 percent of the gasoline in the world, while Africa uses a bare minimum by comparison. Currently (1999), there are 130,000 tons of lead in the gasoline sold in the world, of which the United States uses only 1 percent while Africa uses about 15 percent. Thus, there is a perversity in the international materials flow system where substances are recognized to be hazardous, but the response to their use is partial or incomplete. Socolow asserted that manufacturers tend to push lead flows harder in other parts of the world when they are prevented from selling lead in the United States.

Society has done well with the flow of lead in automobile batteries through recycling and reuse, and it has adopted intelligent policies and practices with respect to managing lead batteries of all types. Controls have really mattered in most cases.

***What Does Industrial Ecology Offer the World?***

Answer: A fresh view of environmental management

I. Priority for concern:

***Short-term insult → Habitability***

II. Message for policy:

***Political feasibility → Rationality***

III. View of the firm:

***Culprit → Agent of change***

What does industrial ecology offer the world? Modified from the workshop presentation by Robert Socolow.

The lead management system for batteries has the potential to become one of the first examples of a hazardous product managed in an environmentally acceptable fashion. The key criteria that an ideal recycling system for leaded batteries must meet are maximal recovery of batteries after use, minimal export of used batteries to countries where environmental controls are weak, minimal impact on the health of communities near lead-processing facilities, and maximal worker protection from lead exposure in these facilities. The use of lead in batteries is a recyclable use, because the lead remains confined during cycles of discharge and recharge.

Socolow concluded by saying that the next generation of USGS must look at workers' exposures, and not just environmental exposures within the materials flow cycle of lead. Investigators must also take into account exposures of workers abroad considering that 10 percent of car batteries are exported to be recycled. The battery industry in the United States is expanding its focus to include foreign plants and send them technical assistance. This is a good example of the way the materials flow system and research on it are moving perspectives beyond today's boundaries.

## Industry within Ecology and the Flows of Toxic Materials

Iddo Wernick of Columbia University offered historical perspectives on the work of the USGS and the former U.S. Bureau of Mines, and how this work contributes to modern understanding of materials and energy flows. From his perspective, the real opportunities for the USGS are in materials flow distribution. The USGS should be able to combine the different strengths it has including, for example, the resources within the group addressing minerals information activities, the group working with hydrocarbon in Menlo Park, Calif., and the mapping group that creates general products in geology that have a topographic base and therefore allow one to study materials distribution and earth systems.

This work accentuates USGS strengths by applying not only knowledge of the numbers of materials and numbers associated with different types of resources, but also knowledge of "cradle-to-grave" or "closing the loop" analyses. These concepts consider extraction of materials, environmental transport of materials and how materials flow from one area to another, and final disposition of materials either in landfills or other waste sites, or through other, more dispersed disposition of materials.

Industrial ecology is ready to consider both natural and industrial flows of materials. For some materials such as water, the natural flows will overwhelm anything that humans produce. In other cases, the industrial sources of a particular material such as cadmium will dominate.

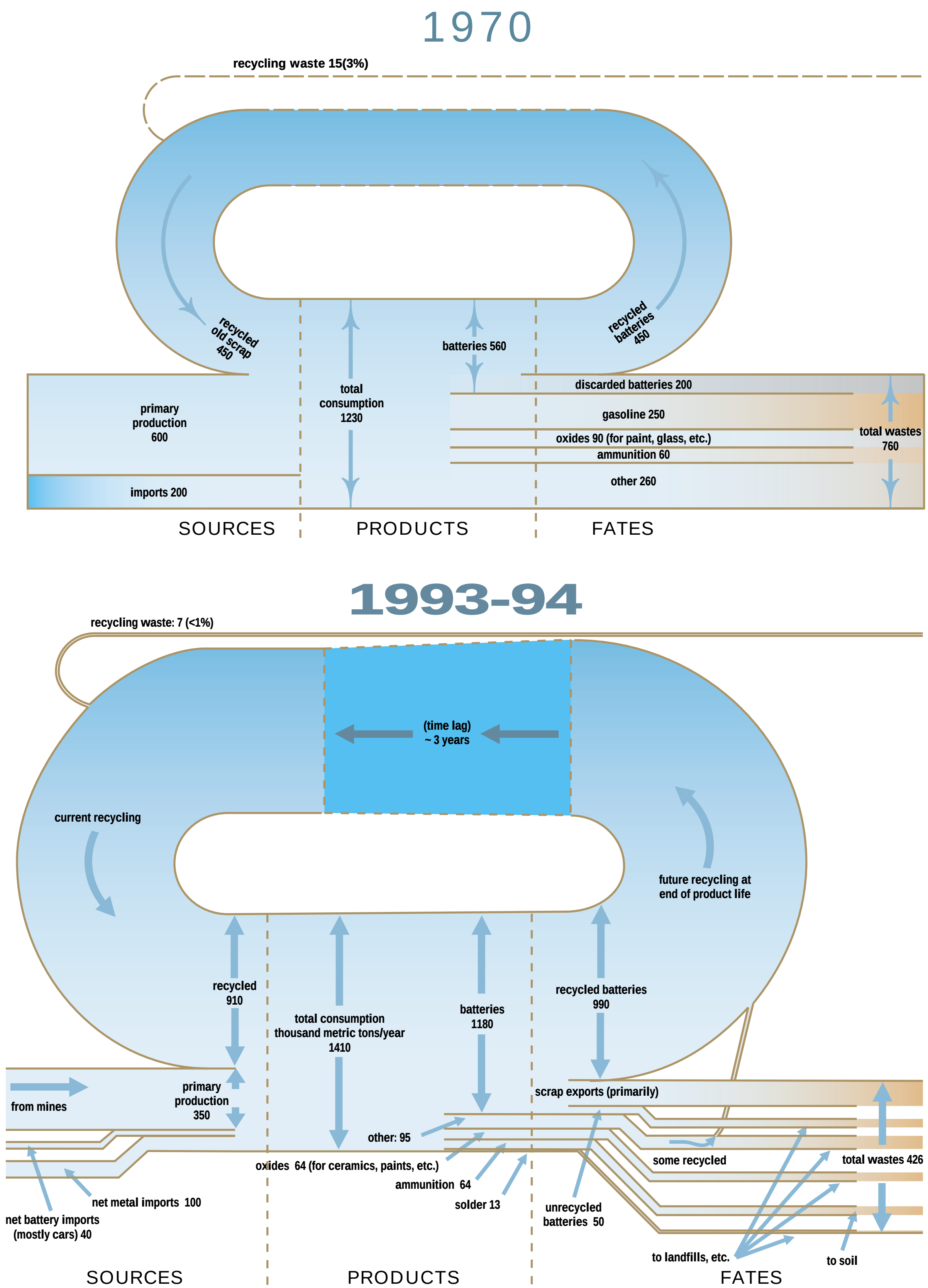
Wernick explained that industrial ecology is "industry as ecology," and that investigators should look at industrial systems as they look at ecological systems. Within this view, for example, waste of one part of industry flows into another part of industry and into "industry within ecology," so industry becomes part of the landscape. Industrial ecology recognizes the human species and its activity as being part of a natural world, and as trying to integrate within the natural world.

Wernick suggested a framework of looking at different types of materials and looking at the environmental consequences of the flows of those materials. For example:

- Materials flow of biogeochemical elements of the nutrients cycle: nitrogen, carbon, sulfur and phosphorus. The concern here is impacts on global climate and living things. For carbon, for example, the distribution is uniform in the atmosphere around the globe; for nitrogen there is a "local" concern compared to $CO_2$ emissions. The USGS in partnership with other agencies could even expand its assessment of nitrogen flows by looking at other sources and distributions such as animal waste and sewage sludge that could be recycled.
- Materials flow of construction and forest materials as they affect landscapes and surface hydrology. USGS interest has been in the distribution of construction aggregates, for example, and not so much with forest materials. However, forest materials flows entail consequences with respect to landscapes and surface hydrology. The runoff characteristics of forested land, unforested land, or paved land affect surface hydrology. Investigators need to couple the flow of materials that is going into structures, roads, and infrastructure with the patterns of timber harvest, and determine what those effects are on hydrology at different scales.
- Materials flow of metals and toxic materials as they affect human health, land contamination, and pollution of the environment. In this case, the distribution and form of emissions are relevant. For instance, if the lead emissions are in the form of slag, they are not nearly as urgent a health threat in terms of human exposure as lead emitted from the tailpipe of an automobile.

Wernick presented an example from the Rhine River basin in Western Europe, a heavily industrialized region. This work was begun by Stigliani and Jaffe (1993), who investigated the sources and flows of cadmium in the Rhine River basin. One of their main findings is the soil concentration of cadmium in agricultural soils in the region. It has tapered off in recent years as a result of controls, but the soils have become a reservoir for cadmium. This reservoir is available for release into the environment if the land use changes in the future and the soil acidity changes. Thus, there is the threat of an "ecological surprise" perhaps many years in the future based on what is happening with cadmium today. The USGS could go to this level of description or coordinate activities with other parts of the government to initiate studies that go beyond the traditional materials flow studies. The goal is to look at the interconnections of the different industrial structures, and to analyze the effects of emissions, the regional demand of the commodity, and the municipal waste treatment. This type of study integrates the human system with the natural system.

Another example of the environmental consequences of materials flows is a study by the U.S. Environmental Protection Agency (EPA) on deposition rates in Narragansett Bay in Rhode Island. EPA traced five metals (cadmium, copper, lead, nickel, and zinc) found on the Northeast continental shelf to both large marine ecosystems and watersheds. EPA looked at nitrogen runoff, total organic carbon, and phosphorus, and then correlated results with population as an index of the sewage effluents



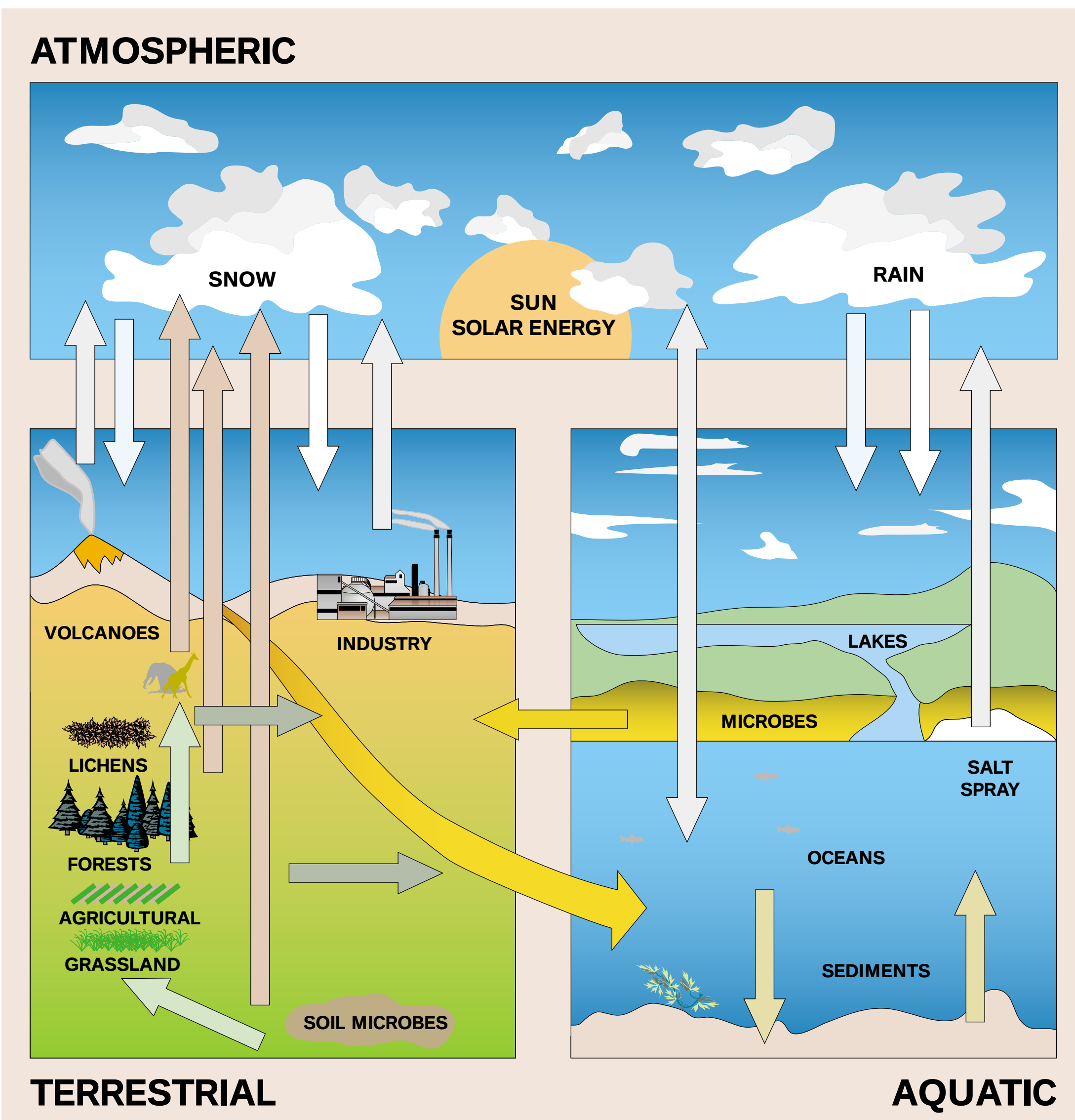

Lead flows, 1970 (top) vs. 1993–94 (bottom), from The Interagency Working Group on Industrial Ecology, Material and Energy Flows, 1998, p. 10.

of this area. The materials flows within this study are interesting from the point of view of contamination, nutrient loading, and the effect these have on ecosystems.

The final example used by Wernick was from a study done by the USGS in the Upper Midwest of the United States. This study examines the industrial ecology from the point of view of industry as ecology, where the waste products of an industry are used to supply another industry. As a result of the Clean Air Act, sulfur dioxide emissions had to be monitored and reduced to 1990 levels. Some coal companies had to find ways to lower their sulfur emissions; others had to install flue gas desulfurization (FGD) scrubbers. The product from the scrubbers is synthetic gypsum which, chemically, is the same as gypsum but contains some contaminants that the coal contains. The study identifies the different wallboard plants (major consumer of gypsum) and the power plants that installed the FGD scrubbers. The major issues in this study were to identify the composition of the material generated and whether it could be used by industry. The study also investigated the location of coal plants with respect to gypsum mines, gypsum plants, and utilities. A special consideration of transportation needs was also important in the results of the study. Wernick concluded with the observation that these kinds of analyses will be very helpful for locating potential reservoirs that could accommodate carbon sequestration.

## Sustainability and Ecological Footprints

A.R. (Pete) Palmer, Geological Society of America, defined sustainability as the level of consumption of natural resources (water, food, soil, minerals, wood products, energy), and production of waste products that can be continued indefinitely by the human population. Palmer described the “ecological footprint” of humans, which is the impact of people on the ecologically productive area of the Earth, and which can be roughly calculated. Its premise is that each of us has real areas of Earth’s surface dedicated to our consumption of food and wood products (footprints of the same name); to our use of land surface for buildings, roads, garbage dumps, and other uses (degraded land footprint); and to forests necessary to absorb the




Sulfur in the environment. Contributors of sulfur to the environment are many and diverse. Natural sources of sulfur include volcanoes, oceans, plants, and animals. Burning fossil fuels contributes most of the sulfur from industrial sources. Prepared by Joyce A. Ober, USGS.

excess carbon dioxide produced by our burning of fossil fuels (energy footprint).

Unlike the agriculture or construction infrastructure footprints, the energy footprint is not subject to the constraints of a specific area of land. It is a theoretical area of forest that would be needed to sequester the excess carbon (as carbon dioxide) that is being added to the atmosphere by the burning of fossil fuels to generate energy for travel, heating, lighting, manufacturing, and other purposes. Palmer stated his belief that if the excess is not sequestered, it will build up in the atmosphere and create the potential for a possibly catastrophic rate of global warming or other environmental stress. To evaluate sustainability, investigators must decouple the real demands on Earth generated by food, wood products, and degraded land needs from the theoretical demands generated by burning fossil fuels. They reflect different kinds of sustainability problems and are not additive. The sum of these footprints can be calculated and constitutes our ecological footprint. Palmer used footprint analysis to show that in the world of 2050, with a global population of about 10 billion, current levels of consumption of natural resources are not sustainable.

To understand the problem of a sustainable future for humanity, it is necessary to recognize the human context. These issues have to be part of public understanding in order to generate the commitment to change behaviors toward sustainability. We live in a universe of change in which rates and scales of change of the land are viewed as geologic in scope. Earth's ecosystems have had a long history prior to human presence. Nonetheless, humans are now both a component and product of Earth's changing ecosphere, and not separate from it. We live on a finite planet, with no realistic alternatives for living space. Present consumption of resources and of the environment to support our lifestyle is dependent to a large extent on exploitation of nonrenewable resources (oil, gas, coal, phosphates, ores of all kinds) that will begin to decline within the next century. Palmer expressed concern that humans are also beginning to over-exploit renewable resources (clean air, clean water—potable and irrigation, healthy soil, food—crops, meats, fish, forest) to the point that they could become nonrenewable.

The evidence that human-induced increases in atmospheric carbon dioxide are already detectable has spurred international concern reflected at the United Nations Framework Convention on Climate Change in Kyoto, Japan, during December 1997. The corollary of this evidence is that the natural global systems for carbon sequestration are not handling the human contributions fast enough. Only about half the carbon generated from burning fossil fuels can be absorbed in the oceans and existing terrestrial sinks. The most effective way to sequester the excess carbon would be to add appropriate amounts of new forest, because on a global scale, forests are the largest absorbers of $CO_2$ that can be increased. Energy footprint analysis shows that the amount of new forest needed is unrealistically huge, and thus no satisfactory mitigation seems to be available to limit the buildup of carbon dioxide in the atmosphere.

If the carbon dioxide problem is deemed severe enough, people can speed up attempts to find alternative energy sources that would reduce the amount of fossil carbon being added to the atmosphere. In the long run, the carbon dioxide problem will be reduced anyway by the practical exhaustion of the finite quantities of oil, gas, and coal on the planet. The supply of oil and its derivatives, upon which societies rely heavily not only for their obvious use in manufacturing and transportation, but also for pharmaceuticals, plastics, fertilizers and tires, will begin to decline by the middle of the next century or earlier. Oil and its derivatives may be practically and perhaps politically unavailable within the lifetimes of the grandchildren of young parents today.

All sustainability problems are population-driven. Palmer advocated working seriously to see that long-term global population stabilizes at 10 billion or fewer. While attempting to accomplish this, there is a need to preserve the best quality farmland from ravages of poor farming practice and conversion to alternative uses, such as housing developments and industrial parks. Water quality and soil degradation, and the capacity of the world's fisheries, are not involved in the footprint calculations, but are essential components of food production and human health.

A critical issue is to ensure and maintain adequate supplies of clean water for all people, and fresh water for all food production. People need to face up to the evidence of declining soil quality and the already troubling overfishing of the world's oceans. The political problem of declining petroleum supply and increasing world competition for this diminishing resource must be addressed. It is in society's best interests to break its petroleum addiction while it can still be done peacefully, and to develop sustainable consumption habits while it can still be done humanely.

## The Role of Federal Science

Mark Schaefer, Deputy Assistant Secretary—Water and Science, U.S. Department of the Interior (DOI), provided the Department's perspective on materials flow and its implications for natural resources policymaking. DOI is trying to increase awareness of materials flow and considers it a key element for achieving sustainability of natural resources. He called for Federal agencies like the USGS to pay particular attention to the materials and energy demands of the growth foreseen for the coming century, and the consequences of those demands.

Materials assume a role of increased importance as population grows. The global human population is now about 6 billion, and is expected to increase to about 10 billion by 2050. This implies huge demands for buildings, transportation systems, sewage systems, water supplies, and other infrastructure that will require minerals and materials. The rapid growth in both developed and developing countries poses many questions of equity and efficiencies in resource use.

Schaefer described two paths that we can take as a Nation: the unsustainable path and the sustainable path. The wrong path, one that is unsustainable, will be one of increasing energy consumption and materials use, declining ecosystems, habitat fragmentation, loss of biodiversity, and declining water quality. Alternatively, if people think about materials in a sustainable way, it will enable us to work toward stable ecosystems, preserving habitat, maintaining biodiversity, and improving water quality and quality of life over time. He argued for taking existing

UNDERSTANDING SUSTAINABILITY

Earth Science Concepts

Deep time
Planet Earth
Geologic scale
Geologic rates
Resources:
Renewable vs.
Nonrenewable

Ecological Footprints

Wood products
Food
Degraded land
Energy

Renewable Resources

Clean air
Clean water
Healthy soil
Food: Crops, meats, fish
Forests

Nonrenewable Resources

Oil, gas, coal
Phosphates
Ores of all kinds

Understanding sustainability. Modified from the workshop presentation by A.R. (Pete) Palmer.

programs and integrating them across agencies, while building partnerships with the private sector. Such integration will allow a comparative advantage for looking at the effects of materials with respect to water quality, habitat, and biodiversity, and at the environmental and economic optimization of natural resources. Understanding materials flows, and the use of Geographic Information Systems (GIS) and Decision Support Systems (DSS) are advancing rapidly. The USGS is making these resources available to the public both to fill current demand and to anticipate increasing demand over time.

Materials flow analyses are key to an integrated approach to ecosystem management. The integrated biological, physical, social, and economic sciences help us understand the nature of a problem. Investigators can couple this kind of information with geographical information, for example, on vegetative cover, hydrology, and geology. Presenting the information in a geographical fashion assists the ecosystem management process significantly. In the context of sustainability, taking advantage of incentives and market base to lead us on a sustainable path requires adequate understanding of materials flow. Making projections, and developing alternative scenarios for materials use are keys in achieving economic incentives toward sustainability.

Access and availability of data allow us to visualize different key signs of sustainability. For example, the move from discardable "pop tops" on aluminum cans to a more effective design for recycling, energy savings, and reductions in air pollution are all part of the big picture of materials flow for aluminum. Another sustainability issue is one of subsidy practices by policymakers that tend to be unsustainable over time. Schaefer argued that such practices occur because of a lack of understanding of where things are coming from, where they are going, and where they are ultimately ending up; that is, a lack of understanding of the materials flow process.

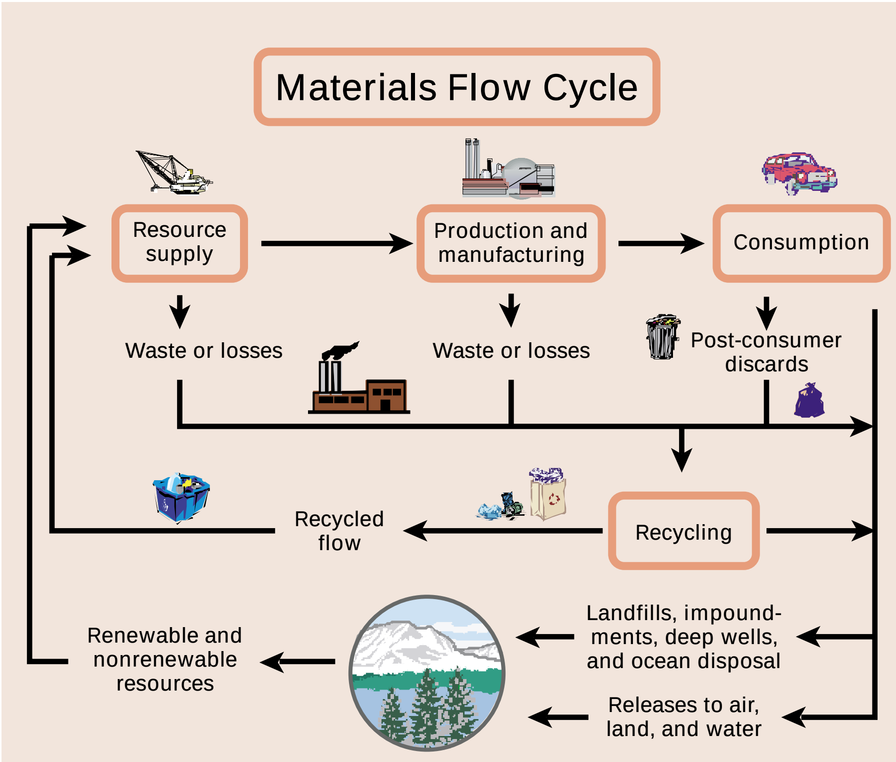
Schaefer discussed a USGS study on Urban Dynamics and Resources Demand in the mid-Atlantic region of the United States (p. **49**, this volume). The intention is to better understand the impacts of population growth and urbanization on landscapes and the environment since colonial times. Urban sprawl and population growth have been very rapid in recent decades in the Baltimore-Washington corridor. Materials flow in this region is important to understanding the differences between "smart growth" and random sprawl. The study takes into consideration availability of resources (in this case construction aggregates), and impacts on ecosystems, transportation systems, and environmental consequences.

Schaefer concluded that data and analysis for materials flows accounting are of the highest priority for the private sector, for the research community, and for the public. He described a need to expend more time dealing with potential users of this information to understand what their needs are, and to target USGS programs to fit those needs. Alternatively, agencies such as USGS must increase awareness by people for using information of this kind, and make information available in a format suitable for different audiences. With such awareness and information, changes in decisionmaking will occur over time.

The materials flow program could make a real difference in efforts to achieve sustainable use of resources by building a solid foundation, expanding the network of customers, building partnerships, and considering the needs of the users' community. Schaefer has been following the minerals information activities of the USGS since they were moved into the USGS following the closure of the U.S. Bureau of Mines. He suggested that instead of having a "materials flow program," materials flow analyses should be an integral part of all USGS activities. He was appreciative of work by USGS mineral commodity specialists on materials flow, and how they are building from their current work on reporting supply and demand in order to provide the data that supports the "big picture" of resource use.

## The Flow of Mercury in South Florida

Sarah Gerould of the USGS focused on the flow of mercury materials, mercury toxicity in humans, and a variety of means by which mercury becomes available to plants and animals throughout its flow cycles. She drew from a USGS study of mercury problems in an Integrated Natural Resource Science Program in south Florida. This is a prototypical effort to involve many collaborators in the scientific study of a large ecosystem.




The materials flow cycle. Image created by members of the Minerals Information Team, USGS. See, for example, Sznopek and Brown, 1998.

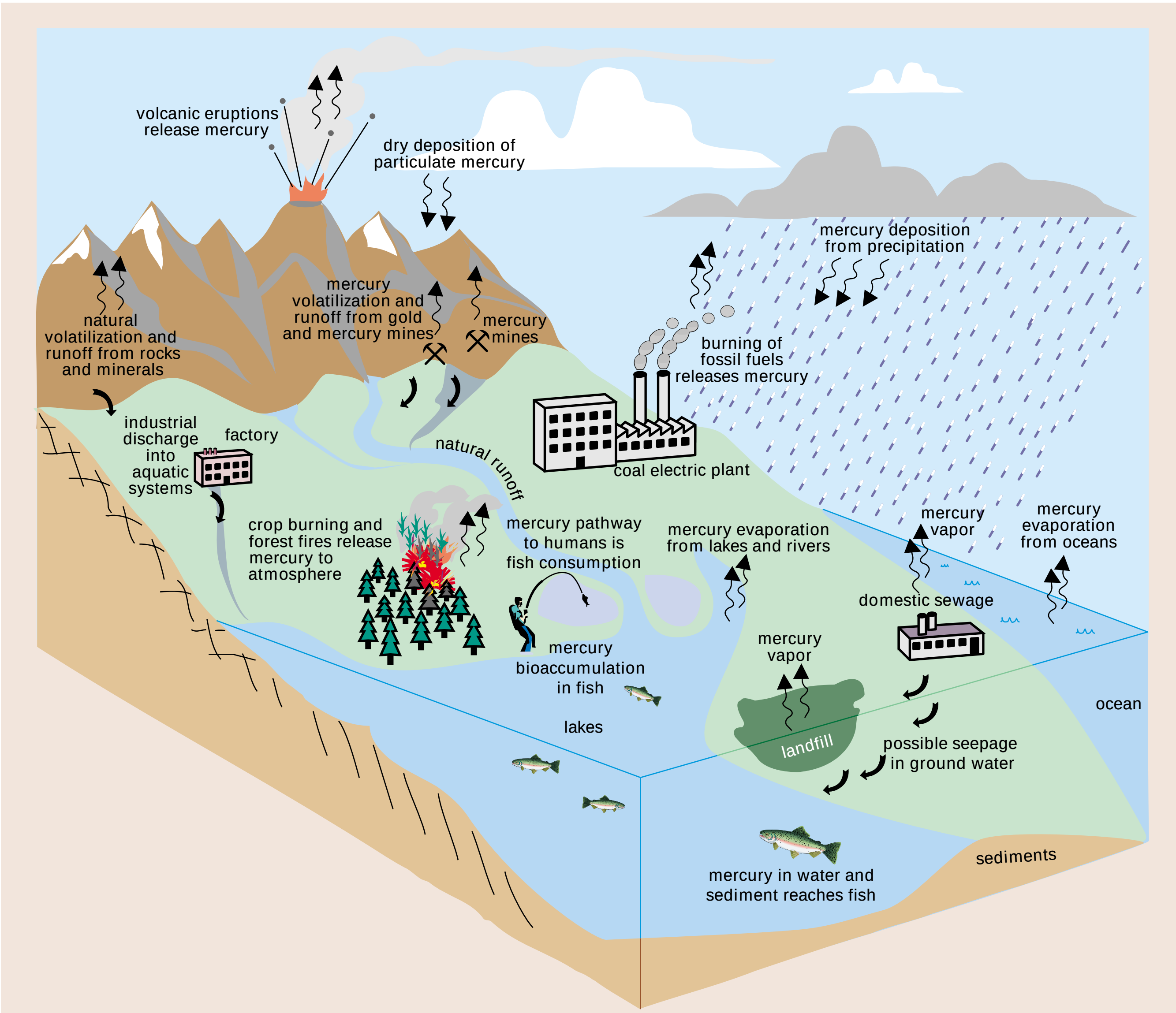
The work emphasizes the necessity to consider the impacts of changing environmental conditions throughout the materials flow process for mercury.

Mercury toxicity diminishes health conditions in humans. It could be a significant cause of renal impairment. It could affect hearing and vision, and cause speech and gait impairment, involuntary muscle movement, difficulty in chewing and swallowing, and fetal neurological abnormalities. Gerould stressed the concepts of bioaccumulation or biomagnification, wherein plants and animals do not readily eliminate higher concentrations of methyl mercury, the most toxic form of mercury. Thus, toxicity increases upward through the food chain, and accumulates in the water or sediment in which the organisms live. In this process, each member of the food chain accumulates mercury compounds that are passed on and concentrated in higher-level members. The concentrations can build from 0.05 to 1.0 parts per trillion in a body of water, to a range of 500–5,000 parts per billion in the sunfish and bass that may occupy that water. Biomagnification creates a risk of toxicity to those at the top of the food chain, and in many places where this process has shown high risk to humans, fish consumption and other recreational uses of water become reduced or prohibited. The amount of risk depends upon how much methyl mercury is in the food, how much is eaten, and how often it is consumed.

Mercury bioaccumulation is extensive in Florida. More than half the State's water bodies have restrictions due to high mercury levels in fish. Mercury levels in fish are particularly severe in the Florida Everglades, where health advisories recommend reduced or no fish consumption. The integrity of the ecosystem may be threatened through the food chain from fish to higher-level predators. Mercury bioaccumulation has also devastated bird populations and driven the Florida panther close to extinction.

Gerould pointed out that mercury in the south Florida aquatic ecosystem comes from atmospheric sources that are both natural (volcanic emissions, atmospheric mercury in air and rainwater) and human (combustion of municipal waste, agricultural and urban run-off in origin). The global background of mercury that is thoroughly mixed in the atmosphere has increased by at least two-fold since the Industrial Revolution, and the proportion of Everglades mercury derived from nearby sources is unknown. This problem is widespread in the United States, and investigators have to go beyond the sources to control the problem by controlling the environment that causes the methylation. This is done through manipulating fundamental biogeochemical processes. By understanding the biogeochemical processes that make methyl mercury available to the base of the food web, it may be possible to develop strategies that limit its bioaccumulation in top predators.

She concluded saying that materials flow studies should include analysis of the kinds of environments to which commodities and elements will flow. For example, methyl mercury is not a problem everywhere, but occurs in areas that are conducive to the methylation and not conducive to the dimethylation of mercury. More work must be done to understand the relative contributions of local and global mercury air sources, the role of microscopic plant and animal communities in mercury methylation and bioaccumulation, and the effects of exposure on wildlife. Control strategies remain to be developed among other research that challenges the USGS and its efforts in integrated science.



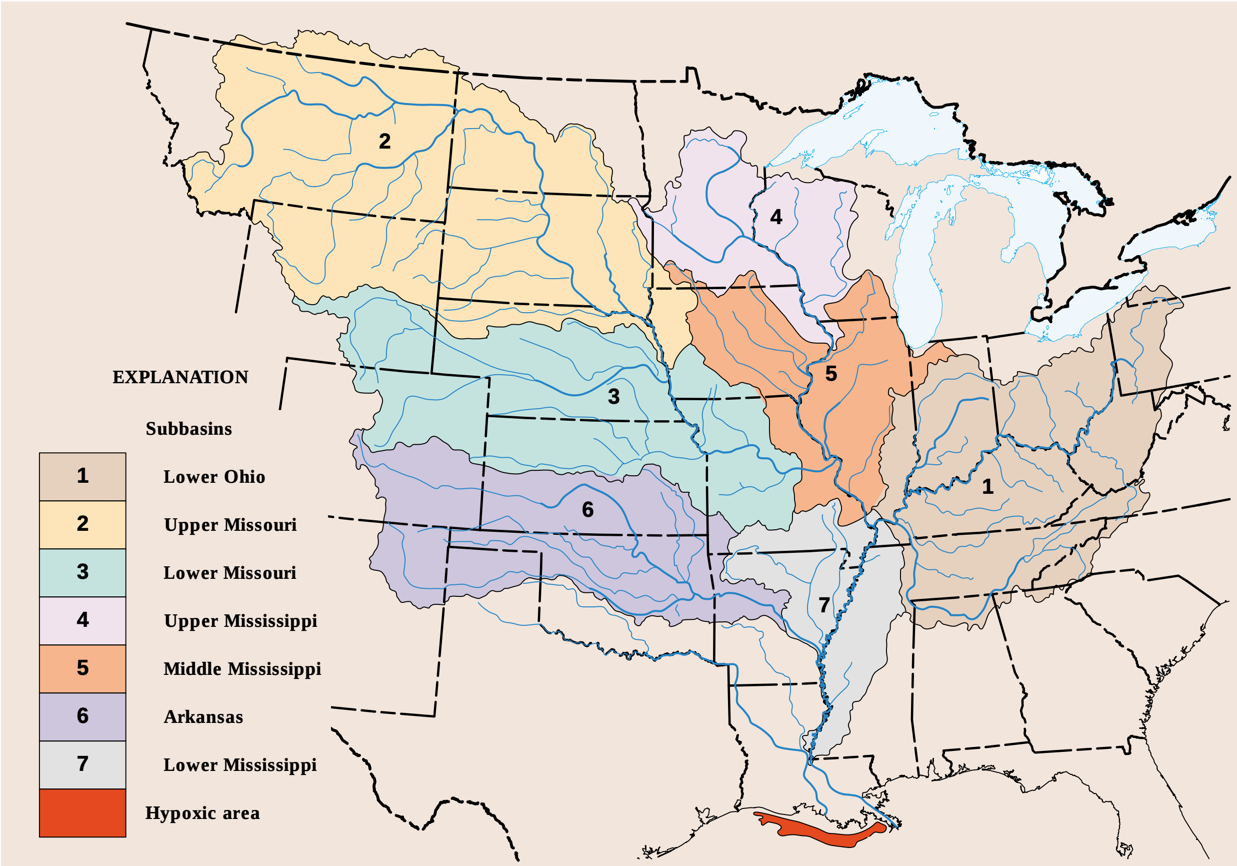

Mercury in the environment. Image prepared by Barbara J. Ramsey and John E. Gray, USGS.

## Nitrogen and Hypoxia in the Gulf of Mexico

Donald Scavia of the National Oceanic and Atmospheric Administration (NOAA) described a plan to assess hypoxia in the Gulf of Mexico. Hypoxia in this case refers to depletion of dissolved oxygen in water to levels less than 2 parts per million. Two parts per million dissolved oxygen is generally accepted as the limit for the survival and reproduction of most aquatic life. The Gulf of Mexico hosts almost half the Nation's coastal wetland and supports approximately 40 percent of its fishery landings. However, these resources are currently at risk from a variety of threats including increasing areas of low oxygen levels and loss of aquatic habitat and impacts on living organisms. The geographical scope of this problem, and the policy actions and science needs for its possible solutions illustrate a materials flow issue that bears upon the activities of 13 Federal agencies. Scavia stressed the importance of a complete materials flow assessment that can be used to predict trends that are based on policy options.

To provide a scale of the problem, Scavia showed that the Mississippi River Basin contributing to this problem covers 31 States, or about 40 percent of the continental United States. The impact is a hypoxic area in the Gulf of Mexico that in 1995 covered about 18,200 square kilometers. Organisms throughout the hypoxic region will either move to areas of higher dissolved oxygen, or will suffer stress and death if they are unable to leave.

The indirect cause of oxygen depletion is thought to be nutrients (nitrogen and phosphorus) emanating from agricultural areas of the upper Mississippi River Basin, particularly in Iowa, Illinois, Indiana, Ohio, and southern Minnesota. Generally, excess nutrients lead to increased algal production and increased availability of organic carbon within an ecosystem, a process known as eutrophication. This algal "overproduction" may sink to the bottom and decay, consuming most if not all of the available oxygen in these bottom waters. The oxygen depletion begins in late spring, reaches a maximum in mid-summer, and disappears in the fall.




Mississippi River Basin and Gulf of Mexico Hypoxic Area, 1997, by William Battaglin, USGS, using information from Nancy Rabalais, Louisiana Universities Marine Consortium (LUMCON).

About 60 percent of the nitrate transported by the Mississippi River is derived from less than 20 percent of the basin. Current sources of nitrogen for the Mississippi River Basin, include commercial fertilizers, animal manures, legumes, municipal and domestic wastes, and atmospheric deposition. The present use of nitrogen fertilizer in the basin is estimated to be about 6.6 million t (metric tons) per year and accounts for more than one-half the annual nitrogen input.

Scavia explained that NOAA has been asked to lead a scientific assessment by the Committee on Environment and Natural Resources (CENR, p. **29**, this volume). The assessment has led to public recognition of an important policy agenda. This assessment involved members of academia, and scientists from Federal and State agencies with jurisdictions both within and outside the Mississippi River Basin. The assessment provided:

- Characterization of hypoxia, including distribution, dynamics, and causes
- Ecological and economic consequences of hypoxia
- Sources and loads of nutrients transported by the Mississippi River to the Gulf of Mexico
- Effects of reducing nutrient loads to surface water within the basin and Gulf of Mexico
- Evaluation of methods to reduce nutrient loads to surface water, ground water, and the Gulf of Mexico
- Evaluation of social and economic costs and benefits of methods for reducing nutrient loads

Finally, Scavia enumerated important issues to address future similar problems. These include knowledge of the physical dynamics and controls on hypoxia, better information on impacts on fisheries, oceanography, quantifying dynamics ecologically and economically, finer resolution of source data about nutrient inputs, and modeling economic analysis for nonmarket dynamics. Investigators need to monitor, understand, and predict the movement of materials and the impact of these materials on ecosystems. He added that the movement and transformation of materials in the environment is the "sleeping giant" for the country.

## Major Issues in Materials and Energy Flows

### Research Issues

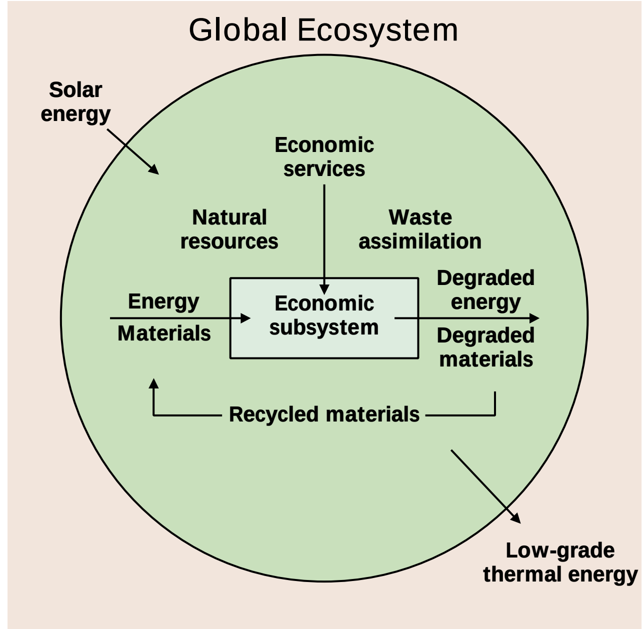
Cutler J. Cleveland of Boston University suggested potential research roles for the USGS. He invited collection of data relevant for important issues at a variety of economic and spatial scales, and wanted these data to be relevant to the community of end users in academia, government, private, and nonprofit sectors. He encouraged less descriptive analysis and encyclopedic data collection, and asked for more quantitative modeling and assessment.

He asked participants to think in terms of a global ecosystem driven by economic subsystems. The economic subsystems require natural resources (energy and materials) and ecosystem services, and produce degraded energy and materials that must be assimilated as waste or recycled. He noted that the economic subsystems in today's world are overwhelming natural systems, and growing to become the dominant physical forces acting within a fixed global environment. This process invites research into understanding the historical patterns of the material and pollution intensity of Gross Domestic Product (GDP). Its indications require us to understand the economic, technological, cultural, and institutional forces that are driving those patterns; and they raise the question of what the historical trends and driving forces tell us about the future.

Cleveland also described "dematerialization," or the absolute or relative reduction in the quantity of materials used and (or) the quantity of waste generated in the production of a unit of economic output. Dematerialization may result from:

- Technical improvements that decrease the quantity of materials used to produce a good or service. Well-documented examples include metal uses in the beverage container industry, and alternative materials use in automobile manufacture and in communications.
- Substitution of new materials with more desirable properties for older materials. Cleveland mentioned the cost-driven example of aluminum for copper in electrical conductors; the availability-driven example of metal substitutes for cobalt; the regulatory-driven example of substituting lighter for heavier materials in cars; and the functionality-driven example of optical fibers for metal wire in communications.
- Changes in the structure of final demand and consumer preferences for products. The mix of goods and services produced and consumed by an economy changes over time. This is due to shifts among sectors, such as the rise of the service sector, or shifts within sector, such as the increasing dominance of computers and other high-technology goods within the manufacturing sector. The general assumption is that the shift towards services and high-technology products reduces the quantity of material required to produce a dollar's worth of output. Changes in peoples' preferences also could lead to an increased emphasis on the nonmaterial aspects of consumer satisfaction.
- Saturation of bulk markets for basic materials. This line of reasoning holds that as an economy matures, there is less demand for new infrastructure such as bridges, roads, railways, steel factories, and so on, reducing the need for steel, cement, and other basic materials. Thus, economies become less "material intensive" as they mature.

He stressed that in spite of the spreading notion of a dematerialized economy, practitioners know very little about this overall issue. In order to start analyzing the social, economic, and environmental questions that relate to materials use, consistent and reliable data on materials consumption at various levels of aggregation, and different methods to model and test hypothesis are required. Cleveland presented the work done by the USGS on materials consumption over time and suggested that it should be supported with more staff and financial resources to improve documentation, control and availability of data, and modeling, especially when it is used by industrial ecology scientists and researchers throughout the country.




Economic subsystem of the global ecosystem. Modified from the workshop presentation by Cutler J. Cleveland.

Cleveland also questioned the notion of aggregating materials on a "weight" basis. He argued that there is no economic foundation for doing so, and that in most analysis of intensity of use the question being asked is an economic one: how much of a material is required to produce a unit of GDP? In most cases, analysts aggregate materials by weight with little or no discussion of the strengths, weaknesses, or implications for interpreting the economic or environmental significance of weight. He added that prices per ton of various materials vary enormously. More fundamentally, price differentials are explained by differences in attributes such as physical scarcity, impact resistance, heat resistance, corrosion resistance, stiffness, space maintenance, conductivity, strength, ductility, and other factors. These differentials indicate that users are interested in attributes other than mass. An aggregate index of materials based on weight ignores these other attributes. These variations in attributes among materials types also mean that materials are not perfect substitutes for one another. If only mass mattered and if all materials were perfect substitutes, the market would tend to price all material types at the same price per ton. Thus, aggregation by weight has a restrictive and unrealistic economic assumption in that it assumes perfect substitutability among material types.

The choice of materials by end users is an economic phenomenon determined by relative material prices, technology, income, and preference for certain attributes. It is reasonable, therefore, to expect that an index of aggregate material use should reflect the partial but imperfect substitutability among materials, and that the weights used to construct such an index should reflect the relative value end users place on various types of materials. The index that achieves this with the least restrictive assumptions is one used for aggregate prices and quantities called the "Divisia" index.

With regard to modeling and analysis, industrial ecology needs to move beyond descriptive analysis into more rigorous applications of quantitative tools from other disciplines to analyze the information. Input-output analysis is a tool well suited for analyzing materials use, and how structural changes in the economy and shifts to a service sector economy affect the material intensity of a specific sector and specific business services. Simulation models may respond to how dematerialization may affect energy consumption and hence carbon emissions in material-intensive industries.

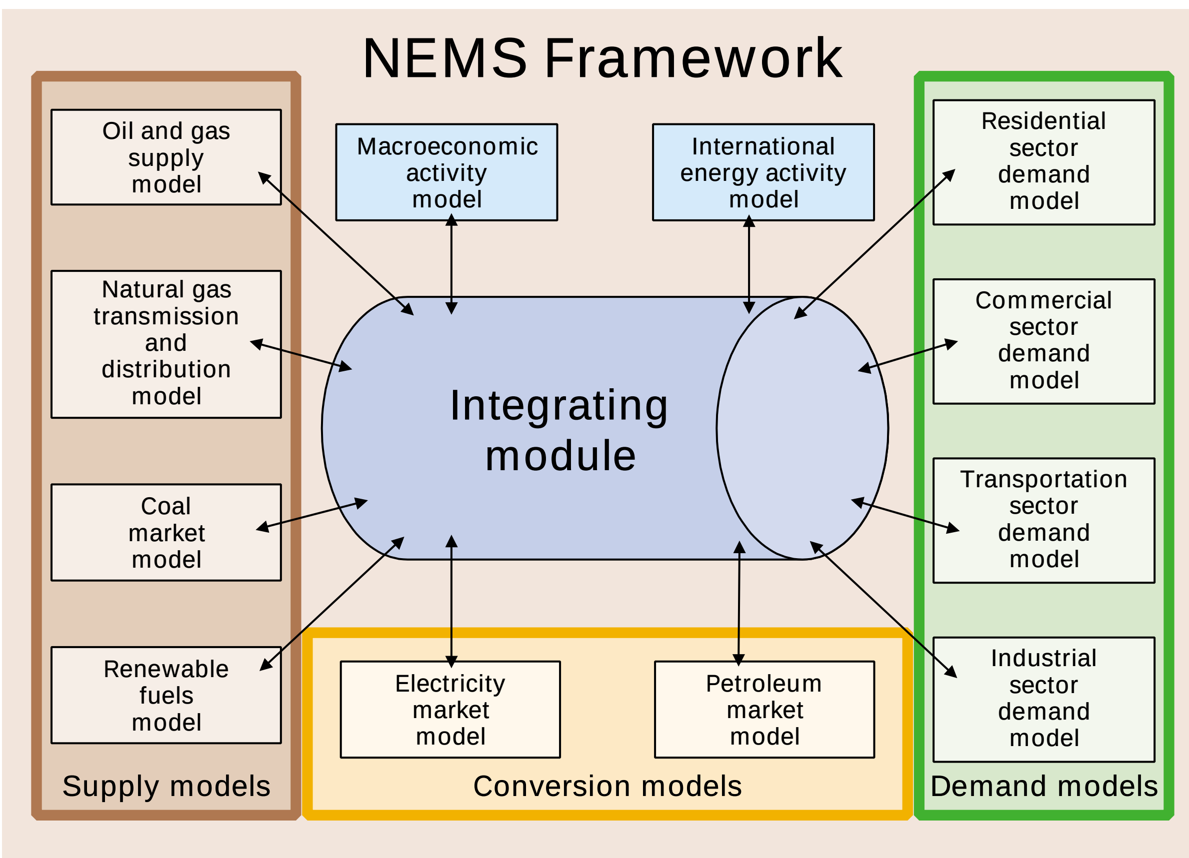
Cleveland noted the vast differences in modeling capabilities between materials and energy flows. There is a National Energy Modeling System (NEMS) framework that treats the global energy picture in a thorough and consistent manner. However, no such framework exists for materials. Cleveland proposed a National Materials Modeling System (NMMS) that focuses on measures of concern to decision makers, whether they be economic, environmental, human health, national security, or similar concerns.

He recognized the limitations of a NMMS framework due to materials characteristics. However, a comprehensive and quantitative set of analyses of 20–25 materials will provide a useful framework to generate different scenarios about materials use, and the effects of specific policies. The framework will help understand how these policies will affect the economy, the materials industry, and the environment in terms of the release of waste. The NMMS should use a problem-directed, scenario-based approach, and it should be integrative and multidisciplinary. The approach should be outward-looking in order to complement and interact with a variety of public and private groups that contribute to policy analysis, including other Federal agencies.

## Policy Issues

David Rejeski of the U.S. Executive Office of the Council on Environmental Quality, and Co-Chair (with David Berry, p. **25**, this volume) of the Federal Interagency Working Group on Industrial Ecology, Material and Energy Flows (IE Group), treated major issues in materials and energy flows from a policy perspective. He began with three examples (lead, arsenic, and silver) that support his arguments regarding policy on materials and environmental management.

He first spoke about lead, a known neurotoxin that was the target of strong regulatory constraints in the United States in the 1970's. The restrictions significantly reduced the use of lead in




National Energy Modeling System (NEMS) Framework, modified from the Energy Information Administration (EIA), and presented at the workshop by Cutler J. Cleveland as a model for discussing a National Materials Modeling System.

gasoline and paints, and consequently reduced lead dissipation into the environment. Currently, the dominant use of lead in the United States (180,000 t (metric tons) per year) is for lead-acid batteries, and a significant amount of the demand for lead is now met through recycling (estimates are between 93 and 98 percent). The infrastructure for recycling lead batteries in the United States is becoming more and more closed, and effective pollution control technologies have reduced the threats to populations living near secondary processors of lead. The challenge of further reducing human health risks has now been shifted elsewhere to countries where battery reclamation and secondary processing is done in facilities that often do not meet high environmental or occupational health standards. Rejeski noted that Indonesia, Taiwan, Thailand, and the Philippines imported 24,700 tons of lead-acid batteries in 1995. The system boundaries for the flow of lead are now global, and the policy debate has moved into the complex and often arcane world of international trade, treaties, and law.

The use of arsenic in the United States has remained relatively constant for the past 30 years at an average of about 20,000 t annually. The dissipative uses of arsenic have been strongly curtailed by the development of substitutes. Additionally, the U.S. Environmental Protection Agency (EPA) in 1987 and 1993 made decisions to prohibit inorganic arsenicals as nonwood pesticides and desiccants, and arsenic use migrated from agricultural applications into pressure-treated wood. The 5 billion board feet of pressure-treated wood produced each year contain chromated copper arsenate (CCA). This accounts for 90 percent of the worldwide arsenic demand and makes the United States the world's largest consumer of arsenic with, for example, two-thirds of global arsenic consumption in 1996. The domestic production of arsenic in the United States ended completely in 1985 when ASARCO Incorporated, the sole producer, closed its smelter. U.S. demand is now met entirely through imports, primarily from People's Republic of China, and from Chile, which is a growing provider. Thus, a toxic material is presently trapped in wood products with a life span of 25–30 years that are used in virtually every new home in America, and no recycling or recovery strategy is in place to deal with the end of the arsenic flow cycle. The wood can simply rot in place, be taken to landfills, or burned in incinerators that are approved and regulated by the EPA.

For silver, the story began in San Francisco where the Regional Water Quality Control Board discovered high levels of silver in the water, sediments, and tissues of fish and marine mammals in San Francisco Bay. A mass-balance study done by researchers at the University of California at Los Angeles found that one-half of the silver flowing through the U.S. economy, about 2,000 tons, was being mobilized from dentists' offices and photographic laboratories by flowing down municipal drains in fixer solutions. There are 98,000 dentists' offices in the United States, and thousands of photographic facilities. Eighty percent of these generate less than 5 gallons of silver-laden fixer solutions per month. The traditional regulatory system is not set up to deal with such high numbers of scattered small generators, and it is equally difficult for operators of these facilities to unravel the complexities of hazardous wastes regulation or justify the investment in recovery technologies for such small quantities.

Rejeski stressed that the lessons learned for environmental policy will increasingly depend on the ability to understand material leakages and substitution patterns and shifts, and to understand these systematically across space and time dimensions. The lessons clearly point to a world, well known in systems analysis that exists beyond easy solutions to problems. This is a world where the large point sources of contaminants have been treated, and what remain are lower-level, chronic problems that require continual vigilance and new data-gathering techniques. The lessons also point to ongoing or upcoming policy debates where industrial ecology and applied science could test their applicability. Rejeski stressed the dangers existing in unchallenged assumptions, especially about driving mechanisms, and that materials flow analyses will help policy makers change their thoughts about drivers.

Numerous lessons need to be learned about the issues of the flow of materials across international borders. There are two components to this. First, post-consumer waste, as illustrated in the example of lead, may result in transnational material leakages. These include wastes that are dumped or material reclaimed in countries with weak environmental laws. Such practices under weak regulation may virtually eliminate legitimate trade on scrap that would reduce the extraction of virgin materials. In cases like this, the reaction of the international-environmental community is toward regulation and control rather than understanding how the system works. The other component is the impact of one country's consumption and materials demand on primary extraction that has been moved offshore, as explained in the case of arsenic. Cross-boundary flows also raise serious equity issues between countries. Another example is the situation of smaller countries, such as The Netherlands and Japan, where a considerable amount of the material flows needed to support their economies takes place outside their borders (50 and 70 percent, respectively, for these countries versus 6 percent for the United States).

Another lesson has to do with the existing regulatory system. Undesirable materials are going to be increasingly embodied and dissipated in products that release chemicals into the environment. The reason for emissions by way of products is that for the past 25 years the United States has had an emissions policy, and has not had a product policy. This country does not have the analytical expertise, the data sets, information infrastructure or regulatory tools to craft and pursue a product-oriented approach to environmental management. This debate is at the core of deliberations over the future directions of the Toxic Release Inventory (TRI), considered by many to be the most successful information-based strategy implemented by EPA. However, the TRI does not focus on materials accounts. EPA is pursuing legislation that would expand TRI reporting to look at chemicals brought on-site, consumed during production, and sent off-site as products. This would potentially overcome deficiencies of existing reporting which, in one case, allowed a company to report 8 pounds of arsenic emissions while sending 300,000 pounds of arsenic off-site in wood products heading for places unknown.

The last lesson involves the dangers in unchallenged assumptions, especially about driving forces. Twenty-five years of environmental policy focused on emissions produced by industry has resulted in assumptions about the nature and causes of environmental problems that are rarely challenged, either by the public or by policy makers. The silver story caught people by surprise and provides some evidence that the environmental impacts of the service sector can be significant both as a cause and mobilizer of flows. The surprise was not only the discovery of a dissipative flow that had been missed, but that the service sector, long considered the environmentally benign partner in economic growth, was mobilizing the flows. The problem of not understanding where materials are coming from is that environmental management will apply the wrong levers to the wrong points in the system. The worst problem with respect to people engaged in environmental policy is to get them to think their way out of the old models. One of the greatest values of materials flow analysis is its role in confronting the old models and thereby engaging people in rethinking the way they look at the world.

As an example, there have been many holistic studies of materials flow (mass balance) for the San Francisco Bay in recent years. Those have resulted in new policies, pollution prevention programs, and financial incentive programs for improving watersheds tributary to the bay. One study found that for copper, 7 percent is derived from industrial sources, 7 percent comes from pipes used for water supply, and the rest is derived from the brake pads of automobiles. The copper is dissipated onto the roadways as brakes are used, and runoff from rainfall washes it into the bay. This finding led to a program called the "Brake Partnership," which is investigating new technologies and reengineering for brake pads to reduce the output of copper. Another study on mercury found that 50 percent of the mercury released into the environment comes from discarding household thermometers. Now a financial incentive program provides a discount on the price of a new digital thermometer when a mercury thermometer is brought in for exchange.

The work on materials flows leads us to the realization of a bigger set of actors and also a bigger set of solutions. The next wave of environmental protection is analytically going to be built largely on materials and energy flow analysis. The conceptual basis is going to be one of industrial ecology, and the human basis is not going to be industry alone. It will include the service sector and households, and it will have to question consumption patterns. Producing policy in this new environment and backing it up with the right science and the right analysis will be very difficult. Rejeski encouraged the USGS to be acutely opportunistic in a changing world and in the changing universe of environmental policy.

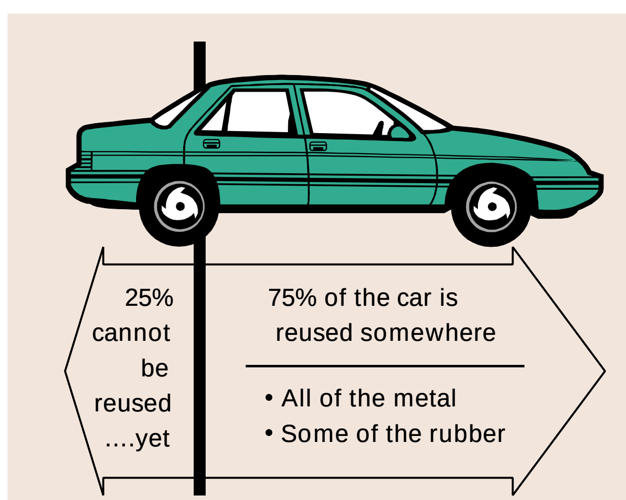
## Corporate Issues

Dean Drake of the Public Policy Center, General Motors Corporation, discussed major issues in materials and energy flows from a corporate perspective and specifically in relation to the automotive industry. He stressed that the very nature of the automotive industry requires that materials for the product must be plentiful, and that recycling these materials is an economic necessity. Manufacturing vehicles requires large amounts of raw materials. In 1992, the automotive industry used 75 percent of the natural and 58 percent of the synthetic rubber in the United States. Thirty-five percent of all iron and 14 percent of all steel used in the United States went into new cars and trucks. Forty-one percent of the platinum and most of the palladium and rhodium used in the United States went into catalytic converters. The industry also makes use of 70 percent of the lead, 19 percent of the aluminum, and 23 percent of the zinc used in the United States. Drake asserted that the automotive industry was engaged in environmental stewardship long before there was the broad awareness of it that exists today. The industry has been practicing this stewardship in its business of collecting scrap from old engine blocks and using virgin material only sparingly.

Today (1999), more than 75 percent of an old automobile (the metallic part) is recycled into either new automobiles or other consumer products. The main reason cars are made of steel is due to the recyclable characteristics of steel. Of the remaining 25 percent, about one-third is plastic, which goes to landfills. Drake noted that one of the greatest challenges facing the industry today is trying to find ways of recycling the plastic component. The approach is first to encourage recycling plastics generally, and then cutting materials costs by continually increasing the percentage of recycled plastics used in vehicles. The second part of the approach is to take steps in the design of vehicles to make it easier to recycle the plastics component.

The automotive industry in the United States today is composed of a vast network of large, medium, and small businesses. These are involved in providing inputs, selling and maintaining the product while it is in use, dismantling the product at the end of its life, and finding ways to recover and recycle the materials each vehicle contains.

The major United States automakers are working together with vehicle dismantlers and shredders in the Vehicle Recycling Partnership. The objectives of the partnership are to develop ways to make it easier to disassemble a vehicle to enhance recyclability, find ways to make the plastic portion of the vehicle more recyclable, and find new, high-value uses for recycled materials. Ideas generated by the partnership are often incorporated into vehicle design. For example, companies have been reducing the types of plastics used, and are




Most of the car gets recycled. Modified from the workshop presentation by Dean Drake.

putting identifying marks on plastic parts to make it easier for the disassembler to sort the part for eventual reuse. Automakers are finding new and creative applications for recycled materials in their vehicles' design. For instance, old plastic soda bottles find themselves reborn as headliners in luxury vehicles. For purely selfish business reasons, Drake stressed, the automobile industry would like to see the motor vehicle become even more recyclable than it is today, and use more recycled materials in the vehicles' construction.

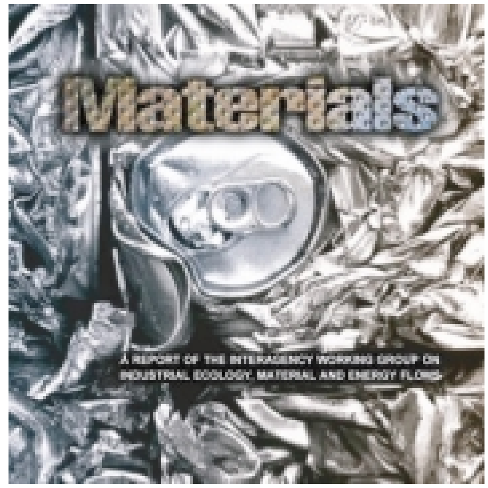
Policymakers are beginning to think in terms of whole systems rather than on a problem-by-problem basis. They started this integrated thinking perhaps because of their understanding of materials flows and the use of these materials. For example, cars today are increasingly using more plastics because they are lighter, and the industry must work toward complying with specifications for fuel economy. More stringent fuel economy targets mean that less steel gets used and that the car could become less recyclable. The energy that is saved through improving fuel economy must be balanced against energy costs involved in using oil to create plastics.

Drake concluded that the overall goals of the industry today are to reduce negative environmental impacts throughout the automotive industry, to increase efficiencies in disassembly, to develop materials selection guidelines that will improve recycling efficiencies, and to promote socially responsible and economically achievable solutions to vehicle disposal. He noted that the automotive industry today is dominated by the philosophy that there is no inherent contradiction between "environmental" and "business," and that environmental stewardship is good business practice.

## National and International Activities in Materials and Energy Flows

### The Federal Interagency Working Group on Industrial Ecology, Material and Energy Flows

P. Patrick Leahy, Chief Geologist, USGS, moderated the morning session, and introduced David Berry. David Berry is a member of the USGS, and also is a Co-Chair (with David Rejeski, p. **22**, this volume) of the U.S. Interagency Working Group on Industrial Ecology, Material and Energy Flows (IE Group). The IE Group was established by the President's Council on Environmental Quality in March 1996 and includes participation from eight Federal agencies. These are the Department of Agriculture, Department of Commerce, Department of the Interior, Department of Energy, Environmental Protection Agency, Department of Housing and Urban Development, Department of Transportation, and International Trade Commission. The IE Group recently published the report, "Materials," and this document was distributed to all workshop participants. The report is an overview of the way material flows have changed society throughout human history, and focuses on materials flows in the 20th century. It describes the materials flow cycle, and treats consumption of raw materials and the intensity of materials use.




Cover of the report, "Materials," by the Interagency Working Group on Industrial Ecology, Material and Energy Flows (1998).

It provides examples of materials flows of silver, lead, and arsenic in the U.S. economy, and how the flow cycles have changed for these materials over time because of changing policy and economic variations.

The report stresses solutions to materials flow problems under the headings of recycling, remanufacturing, redesigning, and rethinking. Recycling deals with reprocessing and using materials from discarded products to manufacture new products. Remanufacturing treats disassembling and cleaning discarded goods, and reassembling them into rebuilt products. Redesigning is intended to dramatically improve efficiencies of materials and energy uses in products and processes, and makes recycling easier. Rethinking asks us to consider the way goods and services are provided to meet human wants more efficiently.

The IE Group report encourages human societies to move toward sustainable solutions to materials and energy flow problems. The pathway to sustainable communities, cities, and regions involves pollution control, process integration, whole-facility planning, and industrial ecology. The group advocates seeking less energy intensity and less material intensity per unit of product or service, while achieving lower levels of environmental toxicity and risk. Fundamental to this venture is the idea that the materials now considered as waste should rather be considered society's endowment of raw materials for the future. Thus, society moves away from producing waste and moves toward systems that sustain themselves using the endowment of their own or other systems.

The report discusses the government's role in supporting industrial ecology and a more efficient use of materials and energy resources throughout the economy. The government should maintain and enhance the function of long-term collection and analysis of critical materials and energy flow data. The government needs to develop its research priorities in this arena in consultation with industry, nongovernmental organizations, and other key stakeholders. The government needs to rethink its regulations with respect to definitions of waste, incentives and disincentives for the more cost effective use of materials, and supporting recycling and remanufacturing. The government needs to set examples in revising its procurement policies, and develop guidance on what constitutes environmentally preferable products. The government also has major education functions to fulfill, and can examine the impacts of taxes, subsidies, and various market-based incentives on materials use and efficiency.

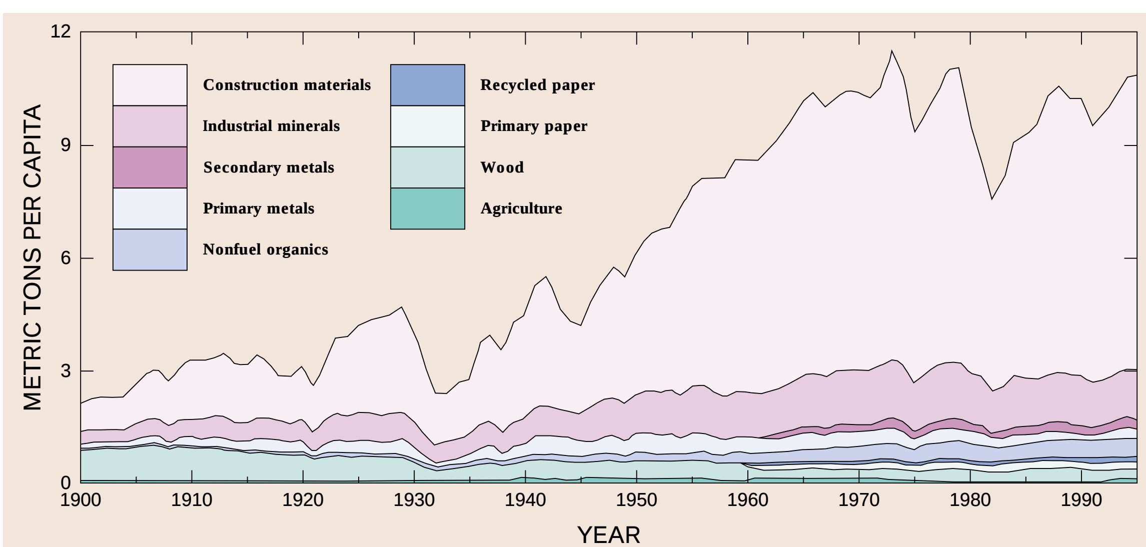
Berry indicated his pleasure with the way the workshop was unfolding, and acknowledged those responsible for making it happen. He then referred to the Interagency Working Group on Sustainable Development Indicators that reports to the White House Council on Environmental Quality. This group, which Berry directs, is creating a set of Sustainable Development Indicators (SDI's) for the United States. The indicators include the economic, social, and environmental endowments that we inherit from the past, and which we use and pass on to the next generation. Among the 40 indicators in the report, one is the chart showing materials use in the United States over the course of the 20th century (p. **10**, this volume). Berry noted that the individual work of mineral commodity specialists, publications experts, and data analysts is reflected in the chart. He emphasized that despite the worldwide publication and significance of this chart, the public is unaware that the data used to create it come from the USGS. They are also unaware of the extraordinary effort that went into creating the chart. The chart represents the best data set in the world for this type of information. It is a statement of the century-long impact of the United States on the environment, and it is an icon of what the United States is doing and the trends it is setting. Additionally, the chart is only one of many similar indicators that attempt to demonstrate what investigators mean by sustainable development.

Berry acknowledged the audience for the very special work that was being done, and advanced the idea that this line of work is a manifestation of our connection with our global ecosystems. This work tells us that we are contemplating as a whole what we are doing to the global environment, and that that increased awareness of our species and our relationship to the entire web of life in and of itself is a part of ecosystem evolution. The information supports our increased awareness and sometimes brings news about negative trends. There are concerns about the use of arsenic in this country. Nevertheless, the United States is increasing imports of arsenic used in pressure-treated wood. This wood is used for landscaping, decks, and playgrounds. When the wood eventually breaks down into the nearby soil, it poses a risk to the people most likely to be there. These are our children. This is the type of problem that needs to concern us, but knowing about the problem allows us to consider solutions.

Berry expressed concerns about the unwillingness of the United States, as represented by the decisions of the U.S. Congress in recent years, to conduct natural resources accounting of the state of nonrenewable natural resources, let alone renewable resources. In most developed countries the states of these resources are shown as satellite accounts to the National Accounts such as Gross Domestic Product (GDP), and need to be maintained as appropriate information for anyone making decisions about resources for the future. Berry stated his hope that the Congress can become more aware of the usefulness of information on materials and energy flows.

## Sustainability Indicators and Our Materials Endowment

David Berry then introduced Theodore Heintz to continue the discussion. Heintz is Chief of Economics, Office of Policy Analysis, Office of the Secretary of the Interior, Washington, D.C. Heintz offered a new report on the work of this group, located on the World Wide Web at http://www.sdi.gov. The work on SDI's has been in progress since the beginning of the Clinton Administration, and is oriented toward producing a fully integrated set of indicators of sustainable development for the United States. The World Commission on Environment and Development issued the 1987 report, titled, "Our Common Future," which is known as the Brundtland Report for its




Intensity of materials use by population, 1900-1990, modified from Minerals Information Team, USGS by the U.S. Interagency Working Group on Sustainable Development Indicators, 1998, p. 31.

chairman, Gro Harlem Brundtland, then Prime Minister of Norway. Although the concept of sustainable development is not new, the common use of the term today can be attributed to its definition in the Brundtland Report: "***to meet the needs of the present without compromising the ability of future generations to meet their own needs."

The purpose of developing SDI's is not only to focus on how well societies are doing now, but also to focus on long-term endowments and liabilities. Heintz advocated using the term "endowments" as a means for getting away from the jargon of economists, who would use the word "capital" in the same context. Thinking in terms of endowments helps us get at the idea of the stewardship and trusteeship for which people throughout the world are all responsible. For example, managers of endowments have the responsibility to manage them in a way that produces income to support the activities for which the endowment was created. The managers also must preserve the endowment itself, and pass it along to the future.

Societies draw on their natural resources endowments today using economic, environmental, and social processes to produce current results, and these processes also change the endowments as they are passed along to the future. These processes constitute investment and depreciation, when thought about in economic terms. Societies use up their capital, and draw it down if they do not invest in it. Investment is important to overcome depreciation. Applying this to natural resources, social institutions, and patterns of behavior, societies want to ensure that they are not depreciating their natural capital and not ignoring their social capital.

Materials are an important aspect of the global endowment. Mineral deposits can be thought of as a starting point, and these are clearly endowments that begin in the environment. The key is that materials do not cease to be an endowment once they are extracted from the Earth. This concept becomes more important with the realization that practitioners are moving into the full world of human activities wherein these activities are such a large part of the processes of the larger global ecosystem. Materials, because they never disappear, are always going to be a part of the endowment. Sometimes materials are in fact liabilities, or a negative form of endowment. It is not just the materials flows that are going to be important; it is also where the materials are at various points in time.

The attention being given to recycling, remanufacturing, deconstruction, and similar processes is the beginning of a recognition that materials extracted from the Earth and processed into various forms are still all around us, and are in fact an endowment. Future generations will have the opportunity to draw upon these; therefore, these materials cannot be left off our accounting. An important source of the information on that endowment and where it is located is the kind of information that comes out of the studies that have been talked about during the workshop.

The new message of sustainable development, and the focus of work on sustainable development indicators, is on endowments so our generation can ensure that what is passed along to future generations is as good as what was passed along to us. The progress report contains 40 indicators, which cover the full range of endowments, processes, and current results. They involve other activities of the USGS, such as water use, exotic species, and the beginning of land-use change. They involve the intensities of use of materials and energy. Heintz urged the audience to see this work in its full form, and to connect to it.

Heintz stated the need for an "integrating layer" above the scientific research that is traditionally performed by the USGS. USGS investigators are very successful in their individual disciplines, and the agency should not attempt to tailor the disciplines or all of USGS scientists to perform assessments that require integration. "Science integration" is a function in itself that requires very special abilities and direction. [Ann-Marie Johnson of Computer Sciences Corporation elaborated on Heintz's comments in a breakout session. She referred to the concept of integrating layers, such as the "microworlds" treated by Senge (1994, p. 313–338), as avenues to science integration.]

Heintz summarized that the USGS was originally formed to map out the opportunities of the New World as European settlers moved west on the North American continent. Surveying was fundamental to the new Nation. It was a search for opportunities, and the understanding needed to take advantage of opportunities. Society is doing this again with information that feeds into sustainable development indicators. Investigators are trying to understand where materials are coming from, how they are being transformed, the magnitude and natures of the flows, and where the stocks of materials are being built up as a result of those flows. All of that kind of information is a survey of future opportunities, because society is passing these materials along in new forms to future generations. There is a need to shift from relying on virgin sources of materials to relying more and more on the endowments of materials that are around us as a result of our previous activity. The survey activity that needs to be done in order to be aware of and to evaluate the opportunities for future generations to use those endowments will come out of the kind of materials work being discussed at the workshop. The discussions are about a long-run transformation of industrial economies. This is not something that is going to occur over 5 or 10 years, but it could be as fundamental as the Industrial Revolution. There are very interesting discussions about essentially converting industrial economies from linear flows into completely closed flows. That is a broad and distant vision, but all the steps along the way are the kinds of opportunities that should be surveyed.

David Berry concluded the session with some insights about the nature and use of information produced by USGS. The agency must ask itself how it is going to do more than it is already doing with the data surrounding the commodities it currently studies. The USGS is being asked how it is going to be able to fulfill some or any of the demands it is getting from academia, the corporate world, and other sources. Nonetheless, the information that is already coming from the USGS is making a huge contribution throughout the world. For example, whether or not the United States shows up at an international meeting, the participants talk about the work the United States, through agencies like the USGS and others, is doing in materials flow accounting for commodities, whether or not it is doing materials flow accounting as one of our national accounts. A huge part of what is needed is what the USGS is doing already, and it only needs to be reframed and presented for exactly what it is.

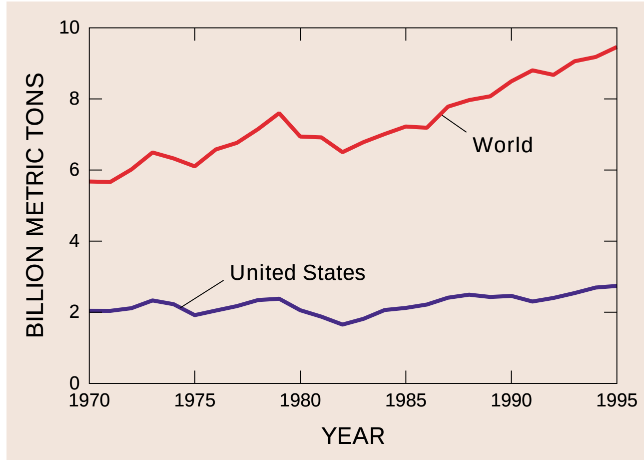
The IE Group is intended to facilitate partnerships, particularly when one party has neither the data nor the expertise to make an assessment about the complete materials flow study of a particular commodity, including the waste flows. The people in the EPA who compile data on lead and other heavy metals in the waters of the northeastern United States (p. **13**, this volume) would like to have more connection to the lead commodity specialist in the USGS. It might be too much to expect a lead specialist to know all aspects of the entire materials flow cycle of lead, but other good sources of information are available. For example, General Motors could easily provide information that an automobile contains certain percentages of glass, steel, copper, lead, and other materials. That is a source of information that is different from typical USGS sources. The USGS can use such partnerships.

These are not the only demands for the work that is being discussed here. Thus, it is definitely fair to say that this work needs more support. If the work is useful and valuable, then those who place value upon it should support the work. In the breakout sessions, when participants would be having the conversation about what this means, Berry urged participants to be very real in assessing: here are the opportunities; here is the difference this work makes; and here are the difficulties and problems and constraints with implementing. Therefore, if difficulties arise, they can be addressed, and if help is needed, the steps can be initiated to help.

## The National Research Council and Materials Flows Accounting

P. Patrick Leahy presented a brief example of the magnitude of materials flows the United States will be required to consider. The U.S. Congress has considered a major transportation bill to increase development of infrastructure in the United States. This is mostly reconstruction of transportation infrastructure and requires significant amounts of aggregate. The need for aggregate to implement the Federal legislation will increase by 20 percent. This says that in the next 25 years the United States will need as much aggregate as it needed in the previous century. Investigators clearly will be asked to find new sources of aggregate, but the requirements stress the increasing importance of recycling aggregate. The Federal Government has not yet looked at these requirements in detail; thus, Leahy suggested that it is time for a real wakeup call with respect to the demands for aggregate created by the law.

Craig M. Schiffries of the Board on Earth Sciences and Resources, National Research Council (NRC), reported on a January 1998, NRC Workshop on Material Flows Accounting of Natural Resources, Products, and Residues in the United States. The NRC was seeking input from universities, Federal agencies, and private industry on the feasibility and types of studies it might conduct with respect to materials flows. Schiffries presented a draft statement of the task before the NRC, and asked participants for their review and comment. [The participants elected to perform a review of the draft NRC statement during breakout sessions later in the day. The results of these sessions are reported in the section, "Responding to the Challenges: The




Measurement of the amount of materials consumed in the United States and the world, 1900-1995. World consumption of materials is growing at a rate that is nearly double that of the United States. The United States currently consumes about one-third by weight of reported total materials consumption. Modified from Matos and Wagner, 1998, p. 114.

Work of Breakout Groups" beginning on page **39**.] The task is a joint activity of the Board of Earth Sciences and Resources, the Board on Environmental Studies and Toxicology, and the National Academy of Engineering Program Office.

The proposed NRC study would assess the utility of materials flow data for making informed decisions about materials use and the expected consequences of alternative decisions. The study would consider types of data that are readily available and types of data that should be obtained. Information on specific materials would be used as examples to illustrate how materials flow and reservoir data would be useful to various government agencies in directing policy topics, and to private organizations in making materials and process choices.

As part of its assessments, the NRC committee will be asked to consider the adequacy or utility of materials flow information for addressing the following issues:

- Identifying sources of materials, how they are being used, and how they are being recycled, reused (including remanufactured), and disposed
- Identifying the extent to which materials flows and reservoirs can be characterized to at least one significant digit
- Identifying information of highest priority for use by government agencies, the private sector, the research community, and the public
- Integrating existing data and developing new data for making informed private and social decisions, including cost aspects of these decisions
- Standardizing accounting procedures, especially the terms, definitions, and formats of data
- Identifying opportunities to close materials loops, especially in cases where leakages present significant environmental impacts

The NRC is also considering the following applications of materials flow information:

- Developing suitable national indicators of materials and resources efficiency

- Assessing the national capability of substituting materials as quickly as they are needed
- Increasing the efficient use of materials by industrial sectors, for example, forest products, chemicals, medical services, and other uses
- Changing materials use and processing methods to mitigate environmental impacts
- Managing “hitchhiker” materials, such as cadmium with zinc, in different ways than parent resources are managed
- Designing disposal sites such as landfills to make materials more easily extractable at a future date
- Improving recycled material source-user relationships and making quality and quantity more predictable

## Integrated Science for Ecosystem Challenges

Dennis Fenn, Chief Biologist of the USGS, reported on the work of the USGS Biological Resources Division (BRD) and the Federal Committee on Environment and Natural Resources (CENR) Initiative on “Integrated Science for Ecosystem Challenges (ISEC).” The BRD, through its research centers, field stations, and cooperative research units throughout the United States, conducts materials flow research in several areas.

Fenn discussed the role of materials flow accounting in understanding ecosystem functions and processes. Most ecologists are familiar with energy flows based on the pioneering work of Howard and Eugene Odum, whose energy flow models dramatically changed the way we view ecological systems. Fenn presented one model of energy and nutrient flux within ecosystems as an example, and he then compared this method of materials accounting with the Life Cycle Assessment (LCA) used by many mineral and energy analysts. He suggested that organisms and environmental quality are effective “indicators” of leakages and inefficiencies in mineral and energy flow cycles, and that BRD’s various biological monitoring programs and capabilities enhance the position of the USGS to track flows of materials used by our society. Fenn cited examples of materials flow research within USGS programs on abandoned mine lands, wetlands loss studies in the oil fields of south Louisiana, and natural resources damage assessment studies in Texas.

The CENR Initiative involves a CENR/ISEC team of 38 members representing 10 Federal agencies. Five CENR Subcommittees focus on ecological systems, toxic substances, air quality, natural disasters, and global change. The CENR Integrated Science initiative incorporates materials flow in the context of developing, coordinating, and maintaining a national infrastructure to provide scientific information needed for effective stewardship of the Nation’s natural resources. Strategic priorities for the initiative include developing new knowledge and synthesizing existing information, understanding the effects on ecosystems of multiple stressors, and providing advanced models and information technologies to improve assessments and forecasts, and ensure informed policy options. Fenn listed CENR priorities for FY 2000, which included studies of invasive species, biodiversity, and species decline; harmful algal blooms, hypoxia, and eutrophication; habitat conservation and ecosystem productivity; and information management, monitoring, and integrated assessments.

## The Environmental Protection Agency and Industrial Ecology

Derry Allen, Counselor to the Assistant Administrator for Policy, Office of Policy, U.S. Environmental Protection Agency (EPA), described current EPA projects related to industrial ecology. EPA projects in industrial ecology span the spectrum of large-scale issues (international, national, and regional issues); industry issues; and product issues.

At the international level, these projects include:

- International Materials Flows, wherein the EPA Office of Policy is working with the World Resources Institute. The project developed three case studies of international materials flows used at the Dialogue on Production and Consumption held in April 1999 by the United Nations Commission on Sustainable Development.
- Climate Program, wherein the EPA is taking a systems approach to tracking flows of energy and carbon.

At the national level, projects include:

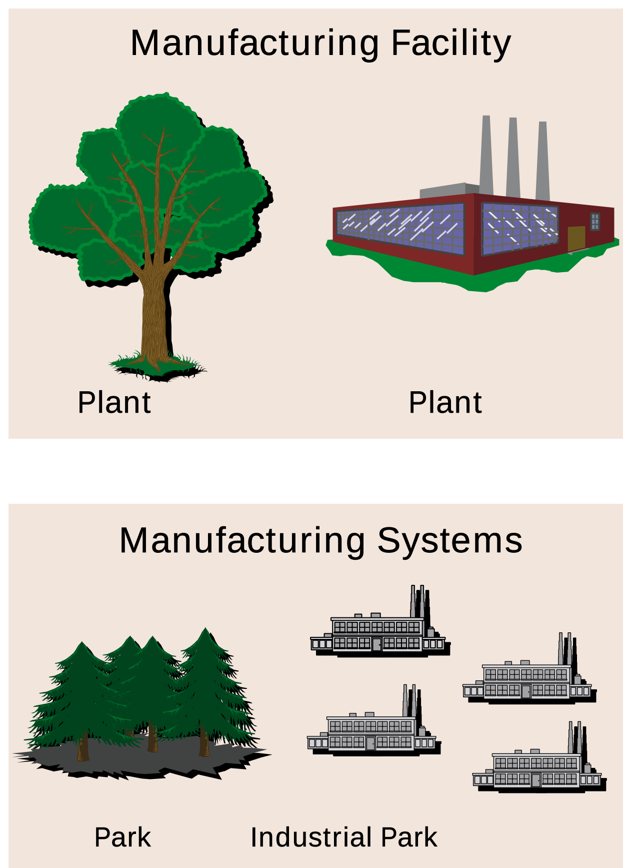
- Participation in the Interagency Working Group on Industrial Ecology, and Material and Energy Flows (IE Group). Current work includes improving presentation of government data, and examining federal procurement as an opportunity to drive industrial ecology in different product areas.
- Materials Flows in the United States, wherein EPA is in the second phase of an agreement with the World Resources Institute (p. **31**, this volume) to examine all material inputs and outputs of the U.S. economy, including products, emissions, and wastes. The first phase of the project introduced a new measure of materials flow, the Total Materials Requirement (TMR). The TMR is the sum of the total material input and the hidden or indirect materials flows, including deliberate landscape alterations. It is the total material requirement for a national economy, including all domestic and imported natural resources. The TMR gives the best overall estimate for the potential environmental impact associated with natural resource extraction and use.
- Resource Conservation and Recovery Act (RCRA) Vision Project, which involves a fundamental reexamination of current U.S. waste management systems to develop an “unconstrained” conceptual framework for RCRA s future using a 20- to 30-year time horizon.
- Application of Life-cycle Management to Evaluate Integrated Solid Waste Management, which develops the tools and information needed by State and local governments to evaluate alternative strategies for considering costs and life-cycle emissions.
- Methodologies for Measuring Waste Reduction, which is a 1995 project to demonstrate how to quantify the amounts of chemicals in “waste,” using chromium and toluene as case studies. Methodologies included a “top-down” approach based on life-cycle/materials flow and a “bottom-up” approach based on analyzing data in existing EPA databases.
- Definition of Solid Waste, in an attempt to determine what the RCRA regulations should define as waste and what should be viewed as byproduct.

• Accounting for Emissions in Measures of Technical Change and Efficiency. This three-part project estimates technical change and changes in efficiency when emissions are generated, collection of emissions data by production unit, and estimating marginal abatement costs of air pollutants.
• Strategies for a Sustainable World, which involves planning a workshop to assess opportunities to encourage technological breakthroughs that would advance sustainable development.
• President's Council on Sustainable Development, wherein EPA has been an active participant and has taken a variety of steps to enhance an industrial ecology perspective.

At a regional scale, the EPA is investigating:
• The Triangle J Industrial Ecosystem Park by developing an input-output analysis of 140 facilities in a six-county region of North Carolina to match resources used and disposed by these facilities. The EPA is also working on the eco-industrial park idea in other areas, and on materials flow applications in designing sustainable communities.
• Designing Industrial Ecosystems Tool (DIET), which involves developing a decision support tool for planning an eco-industrial network or park. The user sets planning objectives, and DIET optimizes the combination and sizes of facilities, and projects environmental and economic costs and benefits.
• Industrial Ecology, Pollution Prevention (P2) and the New York/New Jersey Harbor, wherein a consortium of government agencies, the research community, and other stakeholders are taking an industrial ecology approach to address origins of environmental problems in the harbor, and possible remediation strategies. Led by the New York Academy of Sciences, this consortium hopes to demonstrate how the industrial ecology model can influence policy formation.

At an industry scale, EPA projects include:
• Toxic Release Inventory, which collects significant information on industry emissions useful for understanding materials flows and industrial ecology.
• Design for the Environment, wherein EPA works with industries to develop sustainable practices and products. This project emphasizes looking throughout the manufacturing process, upstream and downstream beyond the immediate company.
• Environmental Accounting Project, which focuses on materials tracking and cost accounting. The project develops environmental accounting techniques and principles, focuses on materials management, and reviews best practices in life-cycle analyses of materials.
• Technology for a Sustainable Environment, a joint program with the National Science Foundation (NSF) that funds basic research in industrial ecology. The program includes six projects on green design. These include green chemistry (solvent substitution, and reaction modification), green engineering (bioprocessing, catalysis improvement), a project on life cycle analysis, and a project on input/output analysis.
• Air Engineering, Life-Cycle Analysis, and P2, for verifying commercially ready products such as furniture coatings, and monitoring greenhouse gases and chlorinated fluorocarbons.
• Green Engineering, which is the environmentally conscious design and commercialization of products and processes. Current focus includes curriculum, workshop, and software development.
• Industry Roadmapping, or visioning "roadmaps" to the year 2020 for several energy-intensive industries, including aluminum, chemical, pulp and paper, steel, and glass industries.

At the product scale, EPA is involved in:
• Garment and Textile Care Program, which uses an industrial ecology approach to look beyond professional cleaning to fiber and textile production and garment manufacture that could, for example, reduce the demand for cleaning fluids.
• Product Stewardship—Battery Takeback, which implements the Mercury-containing and Rechargeable Battery Management Act of 1996. The program goal is getting 75 percent of nickel-cadmium (NiCd) batteries (and other batteries) into recycling, and to phase out the use of mercury in batteries.
• Sustainable Technology, where the EPA Sustainable Technology Division at the National Risk Management Research




Manufacturing facility and manufacturing systems, showing an analogy between ecological systems and eco-industrial parks. Modified from the presentation at the workshop by Edward Cohen-Rosenthal, Work and Environment Initiative, Cornell University.

Laboratory, Cincinnati, Ohio, has several important projects on green chemistry, economics, and life-cycle analysis.

- Green Chemistry, which promotes the design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances throughout the life cycle of the product or process.
- Federal Purchasing Guidelines, which attends to a 1993 Executive Order on purchasing by Federal agencies. The Order mandates considering the entire life cycle and environmental preferability of materials purchased by Federal agencies.
- WasteWise Program, which is a voluntary program through which more than 800 business, government, and institutional partners set their own goals and report their accomplishments in waste prevention, recycling, and buying or manufacturing recycled products. The program is an initiative of the President's Climate Change Action Plan.
- Product to Service Transition, which explores issues in rethinking product ownership and responsibility issues with carpeting, chemicals, computers, and packaging.
- Facility Synergy Tool (FaST), which is used for planning industrial ecosystems. A search-and-match database generator matches the inputs to facilities to the product and non-product outputs of other facilities. This effort focuses on creating buyer-supplier networks.

Allen concluded that industrial ecology principles are important keys to the future of environmental protection, but that the EPA is just beginning its efforts in this arena.

## Resource Flows: The Material Basis for Industrial Economies

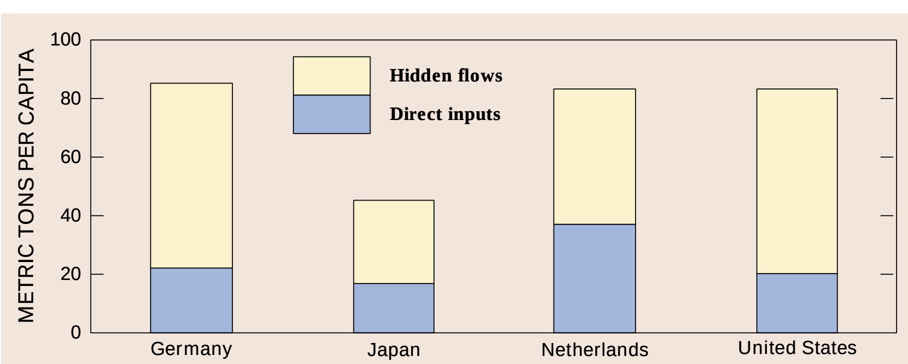
Eric Rodenburg, a researcher with the World Resources Institute (WRI) at the time of the workshop and now with the USGS, reported on ongoing work on materials flows in industrialized nations. The work of WRI is concerned with measuring the changes in the amount of physical materials entering and leaving national economies, individual economic sectors, and watersheds. These indicators might change the way people view their environmental problems, and could play a role in identifying policy opportunities or in measuring progress towards sustainability.

Rodenburg described an anthroposphere dominated by humans, and the flow of materials therein as including extraction, transformation, transfer, use, emissions, storage, and disposal. He also introduced the Total Material Requirement (TMR), which is the sum of the total material input and the hidden or indirect material flows, including deliberate landscape alterations. The total material requirement for a national economy includes all domestic and imported natural resources. The TMR gives the best overall estimate for the potential global environmental impact associated with natural resource extraction and use.

WRI has been looking at a variety of measures of the TMR for Germany, Japan, the Netherlands, and the United States. These measures include direct inputs and hidden flows as a proportion of TMR, domestic and foreign components of TMR, trends in TMR per capita since 1975, and overall material intensity index (TMR divided by Gross National Product, or GNP). WRI is also tracking the primary contributions to TMR by country and over time. These include metals and industrial minerals, construction materials, infrastructure excavation, fossil fuels, renewables, and erosion.

Rodenburg distributed handouts that described the first phase of work on materials flows reported in the 1997 WRI Report, "Resource flows: The material basis for industrial economies." Prepared by WRI and colleagues in Germany, Japan, and the Netherlands, the report proposes preliminary indicators on materials inputs to economies and points to some of their implications.

- The Total Materials Requirement (TMR) indicator is the physical materials used by a national economy, and comprises the sum of domestic and imported primary natural resources and their hidden flows. The per person requirement appears to be leveling off at about 75 to 85 metric tons per year in Germany, the Netherlands, and the United States. Japan's requirement is about 45 metric tons per person per year.
- Hidden flows matter. Overburden from mining, earth moved for construction, and soil eroded from the land are commonly not considered in environmental analyses because they are not priced. However, they account for almost three-quarters of materials flows by weight in the United States, and are major sources of sedimentation of water bodies, contamination of runoff, habitat losses, and other types of environmental damage.




Direct inputs and hidden flows as a proportion of Total Material Requirement (TMR). Modified from the World Resources Institute, 1997, p. 29.

- Fossil fuel use is overwhelmingly the largest contributor to the TMR in Germany, the Netherlands, and the United States, and is the second-largest contributor in Japan.
- Policies matter. Agricultural flows in the United States decreased as the Conservation Reserve Program paid farmers not to farm highly erodible lands, and infrastructure flows shrank as the Federal Interstate Highway System was completed. Private construction is a growing source of U.S. flows related to infrastructure construction. Information on materials flows may point to the need for new policies.
- To the extent that environmental damage from hidden flows is not included in commodity prices, the countries that benefit from using natural resources are not the same ones that pay the costs of using them. For smaller countries, the proportion of the TMR that occurs outside the country, and is usually not included in prices, ranges from 35 to 70 percent. The United States is more self-sufficient, but important extractive flows (such as those of oil and bauxite, and their environmental impacts) occur in other countries to support use of materials in the United States.
- The materials intensity of economies can be calculated by comparing the TMR with the Gross Domestic Product (GDP). The environmental ministers of the 29 members of the Organisation for Economic Cooperation and Development agreed in April 1998 "***to promote innovative approaches, such as eco-efficiency, aiming to achieve substantial improvements in resource productivity, for example by a factor of 4 and eventually of 10." To generate $100 of income in Germany, the Netherlands, or the United States now requires about 300 kilograms of natural resources, including hidden flows. A fourfold reduction translates into an intensity of 75 kilograms per $100 of GDP. The Carnoules Declaration, issued by a group of environment and development leaders, calls for cutting global nonrenewable materials flows by half in a time frame of 30-50 years. To do this, they suggest reducing material intensity in industrialized countries to 30 kilograms, a tenfold decrease in current material intensity.

Rodenburg concluded by discussing future directions for WRI studies. WRI now intends to look at indicators of material output, comprising stocks, dissipative use, emissions, wastes, and recycling. They will review material balances for energy, nutrition, construction, and other factors in the total economy and by economic sectors such as agriculture, forestry and forest products, electronics, automobiles, and energy utilities. They will be analyzing weighting schemes, and the intersection of materials flows with various policies. Rodenburg noted that for these activities to continue, the Federal Government must be actively engaged in them, and that the USGS is uniquely placed to play a major role in this work.

## Expanding Measurements of National Wealth

Kirk Hamilton, representing the World Bank, discussed the concept of measuring the wealth of nations, expanding upon his earlier work with John A. Dixon for the International Development Association and the International Finance Association of the World Bank. Hamilton stressed expanding the measure of wealth beyond an assessment of natural resources. Thus, for the wealth of a nation he advocated a broader composite estimate of the value of natural resources, the well-being of the people, and the sustainability of resources and human well-being. The World Bank is particularly interested in sustainability. The organization helps developing countries to develop further, but it sees that some of the development is not sustainable. The modern view taken by the World Bank is to inquire not only about the nature of wealth, but also how to sustain it. Questions of sustainability link directly to policy concerns in natural resource management and the use of resource rents as a source of development finance.

Sustainable development has never lacked definitions, but perhaps the simplest equates it with well-being that does not decline over time. From this it is a natural leap for economists to think in terms of the stocks of assets—natural and man-made—that support well-being. Because concerns about sustainability are by their nature concerns about the future, this suggests that wealth, broadly conceived, is fundamental to the question of sustainable development.

However, some components of natural wealth will always be both intrinsically important and difficult to value in economic terms—the life-support functions of natural systems, biological diversity, and the ozone layer are the sorts of examples of critical natural capital that come to mind. Environmental economists are learning more about how to value marginal damages to critical natural capital. This is not the same as bringing it into a complete set of wealth accounts. Therefore, economists concentrate on the instrumental or use values of natural wealth. In this, they attempt to value, or calculate the opportunity cost of, such important elements of natural capital as nontimber forest benefits and protected areas.

Measuring the total wealth of a country necessarily involves some assumptions of heroic proportions. The first choice a wealth accountant confronts is the discount rate: a social rate of 4 percent per annum is used throughout the measurements that the World Bank makes in the publication, "Monitoring environmental progress: Expanding the measure of wealth." Total wealth is the sum of the following components from the "wealth accountant's tool kit":

- Minerals and fossil fuels are valued by taking the present value of a constant stream of resource-specific economic profits (the gross profit on extraction less depreciation of produced assets and return on capital) over the life of proved and probable reserves.
- Timber is valued as the present value of an infinite stream of constant resource rents where the rate of harvest is less than annual natural growth (the mean annual increment). Where timber harvest is not sustainable because harvest exceeds growth, a "reserve life" is calculated and the timber resource is treated in the same manner as a mineral.
- Nontimber benefits of forests are valued by assuming that 10 percent of forested area will yield an infinite stream of benefits in the form of nontimber products such as hunting, recreation, and tourism. Per-hectare values of nontimber benefits vary between $112 and $145 in developing and developed countries.

- Cropland is valued as an infinite stream of land rents, where land productivity is projected by region up to the year 2025 and held constant thereafter. Individual rental rates for rice, wheat, and maize are multiplied by production values at world prices to arrive at per-hectare unit rents for cereal lands; other arable land is valued at 80 percent of this rate.
- Pastureland is treated similarly to cropland—rental rates are derived from the value of beef, pork, milk, and wool production at world prices.
- Protected areas are valued at their opportunity costs at the per-hectare rate for pastureland. Fish are excluded from the analysis, partly for data reasons and partly because poor management has driven rents to zero in so many of the world's fisheries.
- Protected assets are calculated using a perpetual inventory model, with investment data and an assumed life table for assets being the major inputs. Urban land is valued as a fixed proportion of protected assets.
- Human resources are measured residually. The wealth value of returns to both labor and capital is measured as the present value of the following: non-agricultural GNP, plus agricultural wages, minus rents on minerals and fossil fuels, and minus depreciation of produced assets. Agricultural wages include proprietors' income and exclude resource rents; agriculture includes hunting, fishing, and logging. The present value is taken over the mean productive years of the population: the lesser of 65 years of life expectancy at age one, minus the mean age of the population. Subtracting produced assets, derived from the perpetual inventory model, and urban land from this present value yields the value of human resources at current exchange rates. This is then revalued using the purchasing power parity rate to obtain the final value of human resources.

In the modern analysis of wealth, agricultural land is the dominant natural resource across all income classes, making up more than 50 percent of natural capital, excepting that of the Middle Eastern oil exporters. Natural capital is important regionally, making up more than 10 percent of total wealth in the Caribbean, East and southern Africa, West Africa, Eastern Europe and Central Asia, South Asia, and the Middle East. Human resources are the dominant component of wealth, constituting between 40 and nearly 80 percent of the total in all regions.

The policy implications suggest that given the large share of agricultural land in natural capital of low-income countries, sound management of this land is of great importance. Capturing and reinvesting economic rents from mineral and petroleum resources is a significant issue in many middle-income countries.

While some evidence suggests that the most resource-intensive economies have grown more slowly than others since the 1970's, in the end the transformation of resource wealth into income growth depends on sound policy—in particular, the effectiveness of public investment of resource rents. Chief among the quality investments available to governments is investment in human capital—in both the education and health sectors.

The analysis of aggregate wealth presented here ignores the distribution of wealth within countries. Issues for many countries will therefore include not only the management of existing wealth, but also the policies affecting its distribution. Analyzing aggregate wealth also masks the important contribution of social capital to economic development.

How does a low-income, resource-exporting country transform itself into a high-income country? No single policy prescription exists, but elements of the answer must include depleting exhaustible resources and investing the rents effectively; managing renewable resources (forests, fisheries, and agricultural land) sustainably; investing in produced assets; and increasing investment in human capital.

Natural wealth can be an important source of development finance, but there is no guarantee that development based on harvesting bountiful natural resources will lead to development that is sustainable and equitable. Only sound policies can transform the former into the latter.

## Creating the Future: Industrial Ecology in the Earth Science Century

### Applying Industrial Ecology

Edward Cohen-Rosenthal of the Work and Environment Initiative, Cornell University, discussed industrial ecology and economic opportunity. He began with statistics on selected wasteful aspects of modern society. People are discarding materials at a rate of more than 2,000 pounds per person per day in the United States to support our consumer society. The average American worker spends more than 9 hours per week in an automobile. Ninety-three percent of the materials Americans buy and consume are disposed, and not recovered and made into salable products. Eighty percent of the products Americans use are discarded after a single use. Only 3 percent of the energy requirement for an incandescent light bulb is actually used in illuminating the bulb. This illustrates enormous opportunities for improvement.

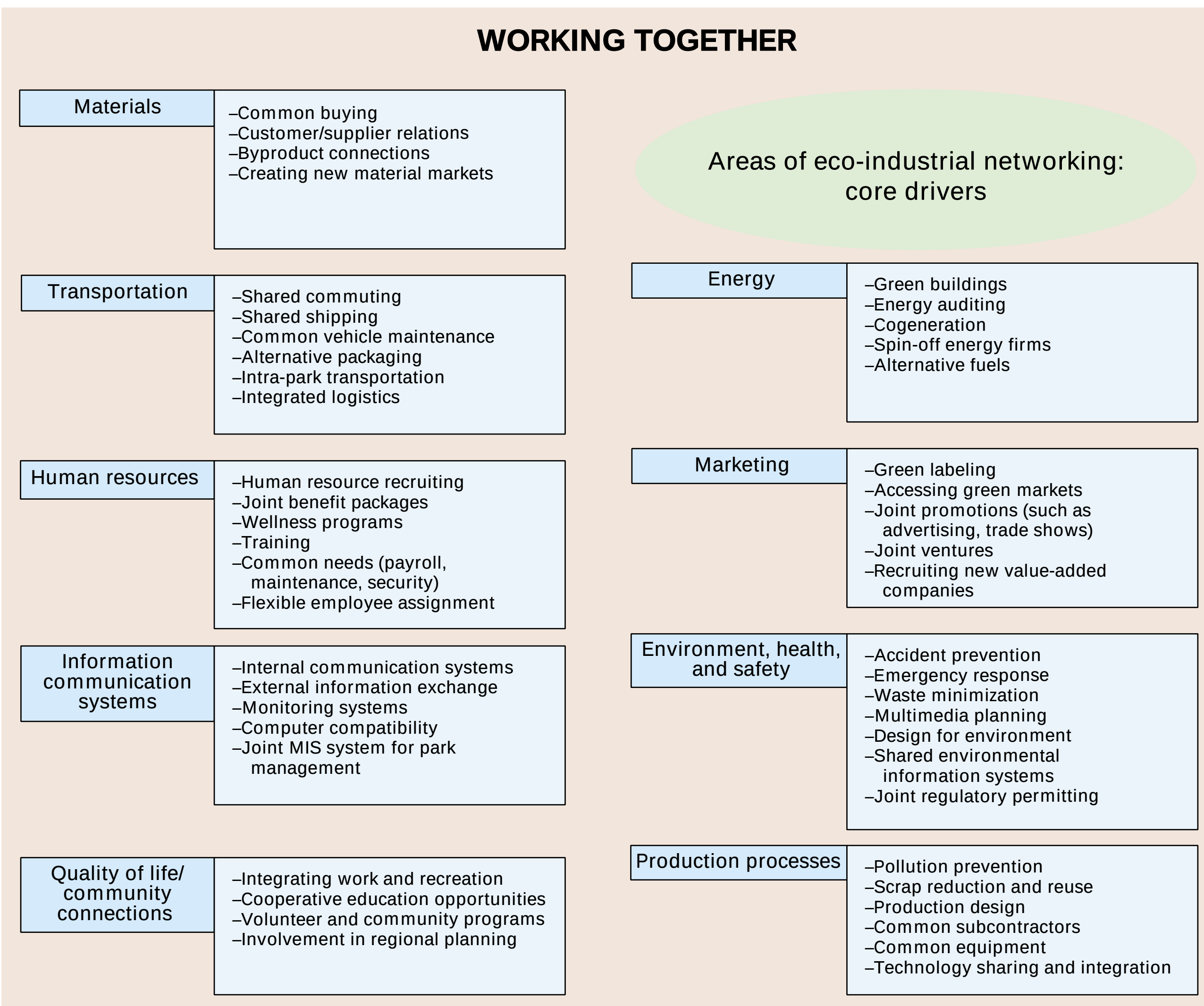
The move away from negative aspects of materials use and waste involves embracing principles of industrial ecology. These principles include connecting individual firms into industrial ecosystems, balancing inputs and outputs to natural ecosystem capacities, reengineering industrial use of energy and materials, and aligning policy with a long-term perspective of industrial system evolution. Cohen-Rosenthal stressed raising awareness of possible connections, and using data and social processes to stimulate imagination, invention, and serendipity to maximize webs of interdependence. This leads to creating conversion mechanisms that expand the range of connections. When looking to make quantum level improvements in resource efficiency, the goal is to foster higher levels of system integration and ecosystem adaptation. When looking to maximize the levels of materials and energy reuse, the goal is to create lower orders of complexity to develop value-generating materials and energy.

The basic goals of materials reuse encompass getting beyond today's practices of "bury or burn"; reintroducing materials and energy into productive use with the minimum requirements for energy and waste; seeking the highest value-added reuse of materials before taking easier routes; and breaking down materials to their next level as a first option for reuse. Researchers should first ask about the reasons materials are used, and if they are necessary in the first place. Additional strategies are to look for aggregate impacts of small changes along with expanding larger technological intervention; to increase functionality and value; to reduce materials and energy embedded in design and products; to examine the entire process; and to recognize that no one solution solves all problems.

Cohen-Rosenthal described a materials transformation hierarchy: genesis, ambient energy capture, design for durability, repair, reuse, remanufacture, disassembly, recycling, compounds, molecular reuse, nanotechnology, energy conversion, waste disposal, and release to the environment. This hierarchy provides economic opportunities at all levels. Technologies and business opportunities occur at all stages of materials transformation. Opportunities arise for technologies using materials that would otherwise be considered waste or be dissipated. There are potential services for aggregating and transporting materials. Some breakthrough technologies will provide opportunities, and there are possibilities with respect to regeneration of healthy ecosystems. Making shifts in resource use requires shifting our thinking to the overall systems level.

These principles also lead to the reorganization of individual manufacturing facilities, and systems of such facilities, or eco-industrial parks. Practitioners are in a period of discovery with respect to organizational intelligence, and creating or nurturing businesses likely to participate in eco-industrial development. Such businesses will be characterized by markets emphasizing environmentally safe products; use of quality recycled materials and less hazardous materials; expansion capacity based on regional diversification; and a concern for the environment expressed in the core values of the company, public commitment to environmental improvement, and partnerships with environmental groups and environmental business initiatives.

The discovery and consequent development can be enhanced by sound data, and by developing new data on materials and energy flows. These data should include industrial resource patterns, quantification of municipal solid waste, residual assets, and gaps in the supply-customer chain at the local




A model of collaborative possibilities within an industrial ecosystem. Modified from the presentation at the workshop by Edward Cohen-Rosenthal, Work and Environment Initiative, Cornell University.

and regional levels. If industrial ecology is to have a positive effect on the surrounding ecosystem, it must relate to existing companies or resource-use patterns. Reducing the overall environmental footprint requires extracting wastes that otherwise would have been externalized. It could also be done through operational improvements to reduce environmental impact or increase resource efficiency. Capitalizing on beneficial niche connections provides opportunities in the niche, and can enhance other businesses, the local community, and environmental protection. The larger the percentage of total cost represented by primary materials and energy, the more business will be interested in industrial ecology applications. The more visible the environmental performance of a company or the connection to market demands for environmental characteristics, the more the company will be interested in industrial ecology applications.

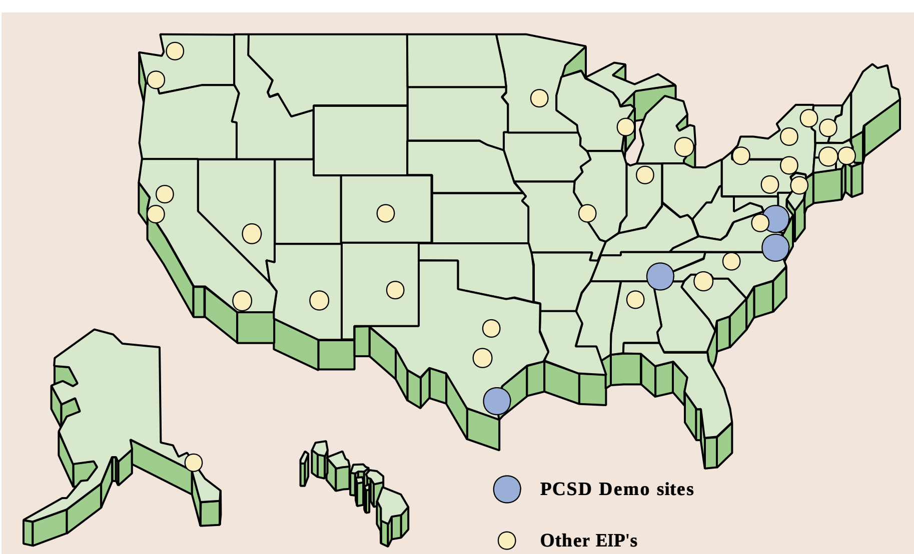
Many experimental eco-industrial development sites now exist throughout the United States, all guided by the common goals of decreasing pollution and waste while simultaneously increasing business success. These sites have in common a trend toward maximizing cooperative endeavors, coupled with an attempt to operate in particular materials/energy domains wherein "upstream" and "downstream" connections are more probable. Examples of these domains include metals, organic materials, aggregate, and energy. Cohen-Rosenthal concluded by focusing on data needs at the company level. Companies need very specific data on the quality, concentrations, and volume of materials and energy flows. These data need to be timely and reliable, and available to companies on demand.

## The Earth Science Century

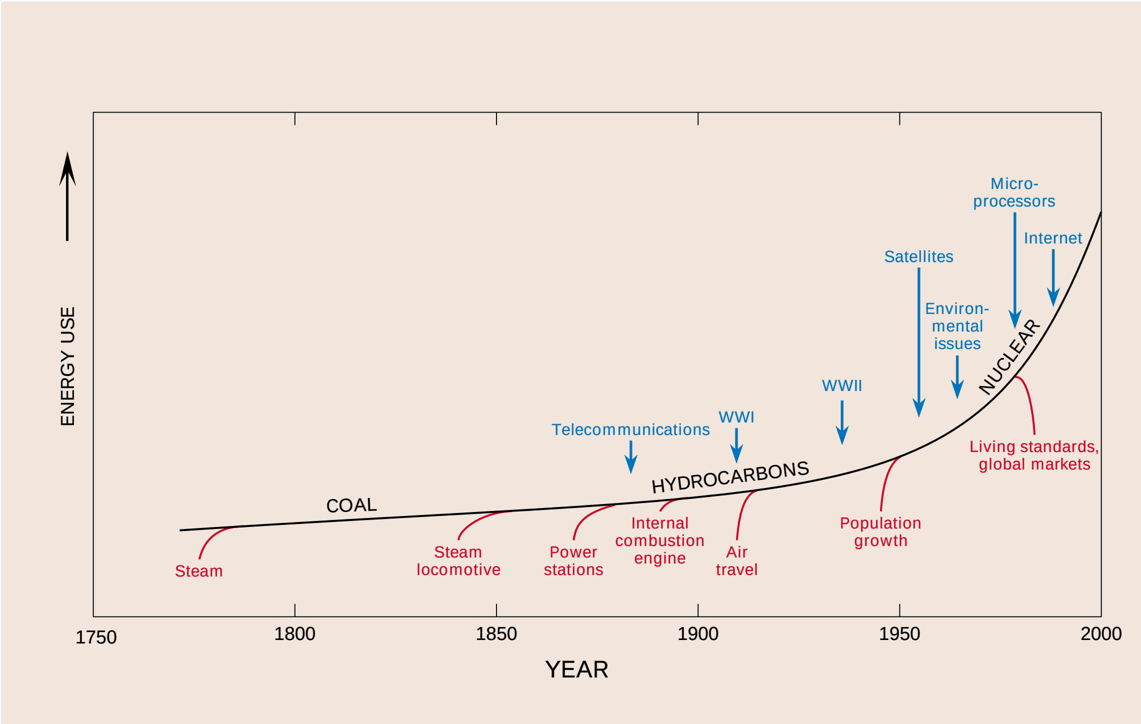
Steven Bohlen, Associate Chief Geologist for Science, USGS, introduced the Earth Science Century. As we move into the next century, we see humankind becoming more and more of a dominant geological force, primarily with respect to the surficial processes of the Earth. Growing numbers of people and expanding development of the places they must live also increase their vulnerability to geologic hazards. A larger population will need additional resources, and will need to obtain these without compromising environmental quality. Finally, human health will be a major concern with respect to the ways in which humanity imposes itself on the surface of the Earth.

The essentials of the Earth Science Century are (1) a priority emphasis on the surface of the Earth as a coherent air, water, and land system; (2) unification of geologic, biological, and ecological sciences within a social science context; and (3) new and higher levels of collaboration of practitioners within the earth science community. Areas ripe for advance include understanding the Earth in real time, the structure and function of ecosystems, forward modeling of complex systems, the connectedness of seemingly unconnected processes, the implications of surface processes for the origin of life and extinctions, and understanding the surface and near surface of the Earth.

From Bohlen's perspective, the stage is set for the 21st century to be the century of the earth sciences, in much the same way the 20th century has been the century of physics. Evidence of the latter is manifest in many ways from the tradition of having a physicist as the Presidential Science Advisor and head of the Office of Science and Technology Policy (with apologies to Frank Press as a notable exception) to the funding of large, expensive, national-scale physics experiments. The emergence of the earth sciences will not follow the physics paradigm, but there is no question that the stage has been set for the strong emergence of the earth sciences. Humankind has emerged in the past few decades as a powerful and, in some respects, a dominant geologic force on the planet. The need for, and reliance upon, natural resources, the concern for environmental quality, the concern for human health that in many cases may have a basis on geologic phenomena, and the rising concern for the health of the planet all point toward the potential emergence of the earth sciences. Indeed, the earth sciences should play a role in shaping the most important debate of the next century—what will be the global population, the standard of living, and the state of environmental health. To be sure, this debate will not be decided in some grand forum, but rather by thousands of decisions made around




Current Eco-Industrial Park (EIP) sites in the United States. "PCSD Demo" refers to sites initiated through the President's Council on Sustainable Development. Modified from the presentation at the workshop by Edward Cohen-Rosenthal, Work and Environment Initiative, Cornell University.




Schematic representation of energy use, showing "modifiers" (above the curve) and "drivers" (below the curve) over the past 250 years. Modified from Cook, 1997, p. 10.

the world by those who might not even realize that they were engaged in the debate or that they influenced it. In many ways, the debate has begun. Bohlen argued, for example, that one manifestation of the debate is this country's current struggle with health care, and deciding how to best provide it and how to pay for it. Bohlen summarized these issues by saying that the earth sciences need to provide the understanding that will allow people to enjoy, rather than endure, the 21st century. For the next century to be the century of earth science, three fundamental changes must occur within the earth science community: (1) there must be priority emphasis on the surface of the planet as a coherent air-water-human-earth system; (2) the geologic, biological, and ecological sciences (to which he refers as the earth sciences with apologies to colleagues in the biological and atmospheric sciences who often do not see themselves in such a shorthand phrase) must become unified; and (3) the earth science community must cease its small-minded, internally competitive ways; work much more cooperatively; and embrace a larger, more holistic vision for the science. Success in the latter area might be defined by priority setting and the integration of research and mutually supportive efforts on the part of those conducting earth science research funded by the Department of Agriculture, Department of Defense, Department of Energy, Environmental Protection Agency, National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration, State Surveys and Departments of Natural Resources, and the USGS and other Department of the Interior agencies. If significant progress can be made in these three areas, then rapid progress will occur in several areas of research that Bohlen believes represent important opportunities for the earth sciences. Success in these areas will define the role of the earth sciences in the next century.

- Understanding the Earth in real time. Advances in land-, sea-, and space-based sensors of all types combined with precision geographic positioning systems (GPS) will allow us to monitor the Earth in real time. For example, global networks of seismometers, magnetic observatories, hydroacoustic sensors, GPS receivers, along with constellations of satellite sensors spanning a wide range of the electromagnetic spectrum afford the opportunity to gain a comprehensive understanding of the Earth at many scales of time and distance. Together, these allow insightful monitoring of all kinds of key indicators of the Earth's condition and dynamics. In addition, these capabilities will likely lead to major advances in specific areas. For example, knowledge of the strain regions of the Earth's crust will lead to significant advances in understanding of earthquake cycles and the nature of seismic hazards in the United States and around the globe. Closer interaction can also be expected among scientists in using the information from various aspects of this global system along with data derived from classified sources. From this will certainly come a more comprehensive understanding of the air-water-human-earth system. The ability to monitor the Earth in real time presents a major opportunity for the USGS, as integrators of classified and unclassified data (data management and new product development), interpreters of the data (research) and verifiers of the remotely sensed data (ground truth from geologic studies and fieldwork). This real-time capability should benefit the pursuit of each of seven science goals, providing the opportunity for advances in hazards mitigation and disaster response, natural resources assessments, understanding regional climate variability, the design of insightful monitoring of ecosystems, flora changes, and soil moisture conditions, to name but a few examples.

- The structure and function of ecosystems. This area is ripe for major advance as a consequence of an ability to more comprehensively monitor the Earth, and because so little is known about the structure and function of ecosystems. The ability of people to enjoy the next century may depend heavily on advances in this area. To date, the United States has not taken a very systematic approach in understanding ecosystem structure and function. Well-publicized efforts to deal with a frog, fish, or owl here and there exemplify the difficulty of dealing with ecosystems as systems defined by geology and climate. The emphasis on specific threatened or endangered species may have had the unintended effect of slowing progress in gaining a more comprehensive understanding of the interactions of the biologic, geologic, and climatic processes shaping ecosystems and driving the dynamics of which endangered species are but one manifestation. To a large degree, the USGS is well positioned to lead in this area, but to do so, it will have to come to terms with the different cultures of biology and geology and set priorities for the time and length scale of integrated studies. Bohlen is among those who view the addition of the National Biological Survey (NBS) to the USGS as one of the greatest opportunities to achieve full scientific integration.
- Forward modeling of complex systems using artificial intelligence and other advanced computing techniques. One of the activities that is a proper responsibility of government is the reduction of risk. One key element in risk reduction is the ability to model phenomena and to make useful forecasts. The initial work in decision support systems is a beginning, to do for the air-water-human-earth system what advanced atmospheric models are doing for weather forecasting. However, this is just a beginning. Unless there is access through partnerships to the most advanced computing facilities and expertise, investigators will not be able to develop the kind of four-dimensional models necessary for useful forecasting of disasters, resource discovery potential and environmental impact of use, ecosystem modification (such as changes in flora and fauna) as a consequence of climate variation, and the migration of contaminants through fractured rock.
- The connection of seemingly unconnected processes. By virtue of enhanced global monitoring capabilities, scientists are discovering surprising connections between phenomena that are not intuitively connected. Perhaps the best example is the apparent relationship between certain frequency modes of the free oscillations of the Earth and changes in atmospheric pressure. At the moment, such a connection is simply an empirical fact, and no one knows how or why atmospheric pressure changes should correlate so strongly with free oscillations. Similarly, other seemingly unconnected processes are suspected to influence each other over a range of length and time scales. Following from the example just given, understanding processes that explain the connection of extremes of physical conditions (air and earth) might be the most important for building a comprehensive understanding of the air-water-human-earth system. The most likely connections may be discovered in pursuit of USGS Science Strategy goals (p. **38**, this volume). Within the Science Strategy, there are goals for climate variability, ecosystem structure and function, links between human health and geologic processes, and geologic controls on ground water and hazardous waste solution. More specifically, there is the expectation to discover connections between all forms of life and basic geologic processes, which brings us to the next area where rapid advance is likely.
- Origin of life, processes of extinctions, and consequences for surface processes. Here, Bohlen referred not to such processes as the role of meteoric impacts on life, but rather a far more subtle, but no less influential effect that the origin and destruction of life has on geologic processes at or near the surface of the Earth. Life exists almost everywhere at or near the Earth's surface. Bacteria have been found in the most extreme environments and in the most confined spaces, such as in the tiny fractures of deep-seated rocks. The role of life in modifying the surface and near surface is an area of research worthy of our most creative attention. Everything from the role of so-called biotapes (bacterial colonies) in reducing the viscosity of oil for enhanced recovery, to various bioremediation efforts using metabolizing bacteria for contaminant cleanup, to the potential use of bacteria for mining points to the remarkable role of life in moderating or catalyzing processes basic to our enjoyment of the next century. Owing to the relatively recent discovery of life in extreme places and conditions, there seems little doubt that researchers shall learn much in the coming years about the role of life in surface and near-surface Earth processes. This work will be important to advancement in the areas of energy and mineral resources, ecosystem structure and function, links between human health and geologic processes, and geologic controls on ground water and hazardous waste isolation. We should not be at all surprised if research into the role of life in surface and near-surface Earth processes has significant impact on efforts addressing all of the goals.
- Finally, but certainly not least, an area considered to be ripe for advance is the overall understanding of the surface and near surface of the Earth. All USGS Science Strategy goals direct us toward the surface of the Earth. Just as 40 years of concentration on the workings of the solid Earth have yielded a rich understanding of the core-mantle-crust system, 40 years of effort will do the same with respect to the surface and near surface of the Earth and the air-water-human-earth system.

By directing ourselves toward the Earth's surface, we recognize that such a change marks a very significant departure in the course of the USGS, and the earth sciences as a whole. Unfortunately this period of new challenge is coming in a time of flat or decreasing budgets, a public debate about the value of government and government-sponsored science, and a global society seemingly obsessed with the near term. These factors, contrasted with the rich array of new tools and technologies at our disposal, and a stunning number of exciting recent discoveries in the earth sciences, make it hard to know whether these are good times or bad. Certainly the negative influences cause us as a community to fall back on baser instincts of self-preservation, focusing inwardly in a bunker mentality and squabbling among ourselves. Now is not the time for inward focus and internal competition, however. The vision outlined in this section can only be achieved by bold initiatives brought forward collectively by Federal and State agencies, the academic community, and the private sector engaged in earth science, each with its own mission, in a mutually supportive way. Given our history, this will be no small achievement, but there should be plenty of success to go around. We need not be destructively competitive in pursuit of broader objectives. Each of us has a role in achieving this broader vision. Just as the debate about the future of the planet will be resolved by the collection of many seemingly unrelated decisions, so will the earth, biological, and ecological sciences be unified and directed toward the issues noted herein, by the actions that all of us take in reaching out, seeking fruitful collaborations, and cooperatively forging into new areas.

## Geology for a Changing World

In his remarks in the previous section, Steven Bohlen referred several times to the Science Strategy for the Geologic Division of the USGS, 2000–2010. The following paragraphs, based on excerpts from that strategy, show part of the vision of the USGS with respect to research in and related to materials and energy flows.

- The USGS is building its scientific strategy to meet the needs of the Earth Science Century. One goal of this strategy is to advance the understanding of the Nation s energy and mineral resources in a global geologic, economic, and environmental context. The United States is among the world’s leading producers of energy and mineral resources, and the Nation’s economic security depends on maintaining adequate supplies from various domestic and global sources. The Nation constantly faces decisions involving the supply and utilization of raw materials, substitution of one resource for another, and the environmental consequences of resource development. With respect to materials and energy flows, the USGS maintains a unique role within the Federal Government and the private sector in comprehensive assessments of energy and mineral resources.
- Future scientific challenges for the USGS involve (1) anticipating new and changing resource demands, such as the shift from coal and oil to natural gas, and technology-driven substitutions, such as the potential shift from lead to other metals in batteries; (2) developing new principles and concepts to increase scientific understanding of critical, high-value resources that are expected to have increased future demand; (3) formulating and (or) improving science-based assessment methods (including total-cost assessments); and (4) conducting global assessments of resources having substantial economic importance, such as oil and strategically important mineral commodities. The products from these activities include national, issue-specific, and total-cost assessments of the Nation’s petroleum, coal, and selected metallic and industrial mineral resources; geologic, geophysical, and geochemical maps, surveys, and syntheses of carefully selected geographic areas in support of resource assessments; quantitative global assessments of oil and gas resources and selected high-value mineral resources; and integrated life-cycle products of selected energy and mineral commodities.
- Human population growth and economic development are strong forces that drive land-use decisions and have the potential to alter the distribution, structure, function, and health of ecosystems. In the face of human modifications to ecosystems, resource managers must develop and implement ecosystem management strategies that conserve biological diversity, restore degraded habitats, facilitate sustainable plant and animal harvests, control invasive species, and maintain water quality. The USGS will assist ecosystem managers by providing the essential scientific information needed to make wise land-use decisions.
- USGS geologists will work with biologists, ecologists, hydrologists, and chemists to characterize the geologic framework and hydrologic cycle of ecosystems and to identify the geologic and geochemical processes critical to ecosystem structure, function, and restoration. The temporal focus will be on time scales of agricultural, industrial, and urban development to provide the scientific understanding necessary for management of ecosystem health, sustainability, and restoration.
- USGS geoscience studies of ecosystems will be concentrated in rapidly urbanizing areas, coastal zones, public lands, and other regions of national importance or interest such as the Florida Everglades, the Mojave Desert, the North Slope of Alaska, the Rocky Mountain Front Range Urban Corridor, and the Chesapeake Bay region (p. **43**, this volume). The products from these activities will include maps of surficial and shallow-subsurface lithologic, mechanical, and geochemical properties of ecological significance for selected ecosystems, models of geologic and geochemical processes that affect ecosystem functions, geochemical baselines of metals and other contaminants, rates of faunal and floral change during recent geologic history determined from paleontological and geochemical studies, and assessments of fundamental geologic fluxes that affect ecosystem dynamics.
- That some aspects of human health can be affected by geologic materials and processes is widely recognized. Once released, toxic substances can be circulated and concentrated by geologic processes through a range of sensitive environments and are commonly incorporated into food chains, increasing the risks to human health. USGS studies in cooperation with health experts have already contributed to the understanding of these effects and demonstrate the need for expanded research efforts in this area. For example,

USGS scientists were among the first to recognize that not all mineralogical forms of asbestos lead to increased incidences of cancer in humans, and USGS scientists are currently helping to understand the origin of acidic volcanic fog in Hawaii. Earth science research can also identify how geologic processes transport and store substances that are toxic to humans, including both naturally occurring materials and those produced by human activities. Better understanding of these processes can lead to development of improved strategies for pollution prevention, mitigation, and remediation.

- The products from this work will include lay-oriented and publicly accessible summaries of the geology, geochemistry, and health effects of selected potentially toxic elements, mineral phases, and organic compounds; nationally consistent, regional-scale environmental geology and geochemistry databases and maps; integrated geologic, geochemical, and biological assessments of regions where contaminated sediments may accumulate; and national and (or) regional, geology-based health assessments.

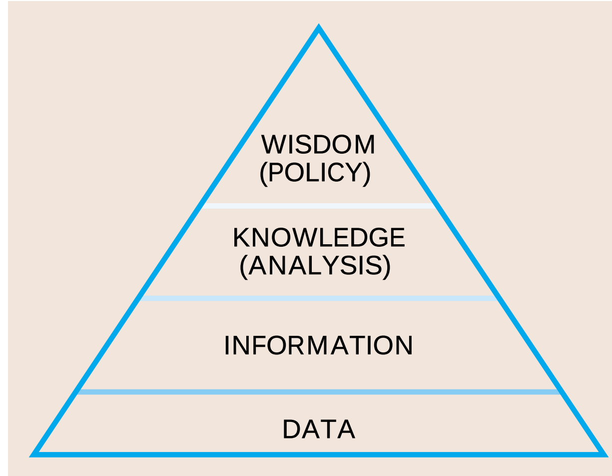
## Responding to the Challenges: The Work of Breakout Groups

The workshop participants split into four groups to provide reaction and additional points of view to complement the questions posed in the opening days' plenary sessions. Participants set out to answer the following set of questions, to add new information based upon their learning and interactions with others over the course of the workshop, and to answer additional questions posed by breakout group leaders. All groups were tasked with exploring the same set of questions in an attempt to discover a variety of independent processes towards answering the questions, and to reveal a variety of answers to the questions.

- What are the major issues in materials and energy flows from a policy perspective?
- What are the major issues in materials and energy flows from a corporate perspective?
- What is the status of research on materials and energy flows by and among universities, industry, and governments?
- What contribution could the USGS make to materials and energy flows issues?

The participants also elected to use part of the breakout sessions to review and comment on the draft statement of the Board on Earth Sciences and Natural Resources, National Research Council (NRC), that evolved from the 1998 NRC Workshop on Material Flows Accounting of Natural Resources, Products, and Residues in the United States (p. **28**, this volume).

A group led by Virginia Burkett, Chief, Forest Ecology Branch, National Wetlands Research Center, USGS developed answers based on the construct of a pyramid. The base of the pyramid is data, upon which information is built. The information leads upward to knowledge coming from the analysis of information, and wisdom in the form of policy based on knowledge caps the pyramid.




Data-information-knowledge (analysis)—wisdom (policy) pyramid, from the presentation by the workshop breakout group led by Virginia Burkett.

From a policy perspective, the group recommended developing credible and reliable indicators in order to foster responsible stewardship, reduce entropy, and reverse adverse impacts on human health and ecosystems. The major policy objective, couched in the form of a question, should be "How can we ensure sustainability?" Investigators should define policy in a way that does not interfere with market goals, considering how to handle the probability of increased competition for resources, and how to maintain access to resources as they become more scarce. There must be open pathways to multi-use, high-efficiency systems through combining incentives and removing barriers. For example, society must create markets for recycled and reused materials such as paper, buildings, roads, and oil. Additionally, the Federal Government should leverage its market position. The group recommended reducing impasses to public confidence and regulatory inefficiencies, mainly through making policy based on objective evaluation. They also recommended conserving resource values embedded in urban areas as a policy objective.

From a corporate perspective, the group recommended making comprehensive information available to the corporate sector. The risk to investors could be reduced through government's attending to due process (fairness), decreasing uncertainties, and using one-stop permitting. Governments should attempt to maximize access to resources for both small- and large-scale users of materials and energy flows information. The group noted that public land use and environmental policies have made it difficult to access domestic resources, for example, oil on the Outer Continental Shelf. The government is in a good position to promote networking among eco-industrial units in order to share and integrate proprietary or confidential information. Agencies can promote the ability to share resources, particularly in the arena of hazardous/regulated materials where many barriers limit information exchange. The government has opportunities to consider mass balance audits or assessments to maximize profits. Finally, it should consider the appropriate roles for market forces. Where should the government dominate or intervene? How does the government value or account for negative externalities?

With respect to the status of research on materials and energy flows, very little attention has been placed on applied science. The status of such research was uncertain to group members. Present approaches provide only rough ideas of trends, and input/output models seem to be the major tools currently in use. Researchers need models from the supply chain, for example, Year 2000 (Y2K) models, such as those advocated by John A. Koskinen, Chairman of the President's Council on the Year 2000 Conversion; critical infrastructure models; and life cycle analysis (LCA) models. The group noted that the EPA has made tremendous strides in trend analysis in its work on Superfund, STORET (the EPA's STOrage and RETrieval database used for water quality data storage for the Nation), and the National Pollutant Discharge Elimination System (NPDES).

With respect to potential USGS contributions, the group recommended that the USGS function as an integrator of information from ecological, biological, and corporate disciplines. The USGS should capitalize on scientific synergy, and the important separation it maintains from the regulatory sector. The USGS has a major role with respect to developing, maintaining, and consolidating databases. First, the USGS needs to integrate databases internally. These need to be under a high level of quality control, and easily accessible. The USGS has a major role in involving data users in determining which questions the data are designed to answer; however, this role must be augmented by more aggressive partnering and networking with other agencies. The USGS can work with the National Academy of Sciences (NAS) to help coordinate multi-agency, multidisciplinary work in materials and energy flows. There is a USGS role for providing data on the end uses of materials, and providing an historical data bank with ready access and analysis features. Within its data structure, however, the USGS use of the data is primary. The USGS data must support research on such key processes as ecosystem structure and function, and urban systems, and provide knowledge to decisionmakers. This is to attend to the National Research Council recommendations presented by Craig M. Schiffries (p. **28**, this volume), and to the requirements of law such as the Paperwork Reduction Act of 1995. The group also called for integrating, streamlining, and simplifying the USGS publications systems to facilitate public access to its information, and to reduce the "data smog" in order to foster wisdom.

A group led by John H. DeYoung, Jr., Chief Scientist, Minerals Information Team, USGS, found that considerable overlap occurred in public policy, corporate, and sustainability issues. The group thought that among these, time scales and priorities assigned to each issue would shift. For example, sustainability could require a longer-term perspective than treatment of a corporate issue. Likewise, corporate prioritization of a social issue would most likely be lower than public policy prioritization of the same issue. In evaluating issues, the group also agreed to look both upstream at supplies and downstream at wastes within the materials flow cycle.

The group posed 11 questions for identifying policy issues:

- How does the United States ensure reliable sources of energy and materials in the face of international economic, political, and military unrest?
- What are the adverse toxic impacts in materials and energy flows processes?
- How can materials and energy flows be managed to promote community stability?
- How can policy tools, such as incentives like tax breaks and disincentives like fines, be most effectively integrated for comprehensive management of materials and energy flows?
- How can manufacturing standards be developed and put in place, for example, in automobile designs, to promote greater pollution prevention and recycling? What are the implications of national design standards for international trade?
- How can educational programs on implications of using resources be improved?
- What is the current role of data collection on policy formulation? What is the role of models in policy formulation? How can data collection and modeling be more useful to policy makers?
- How do import and export policies affect public health? For example, what are the human health consequences of exporting to other countries pesticides banned in the United States?
- In an era of limited budgets, how can governments make the shift from reacting to problems once they become serious to identifying them before they become serious? How can governments take initiative rather than acting after the fact?
- How can leveraging of government resources be increased to promote greater interagency cooperation?
- How can the USGS and other producers of large databases ensure adequate feedback from users of databases and models so that timely adjustments can be made in research and data collection, and reporting processes?

The group posed two questions about identifying corporate issues:

- In terms of materials and energy flows, what is the appropriate planning horizon for corporations? How do these horizons vary from sector to sector? For example, the forest industry tends to have a long-term perspective on planning, given the time it takes trees to grow.
- How can corporations release reports on company programs and environmental status most effectively to build creditable working relationships with the public?

The group posed four questions on sustainability issues:

- What is the appropriate time horizon for promoting sustainability at the community level, the national level, and the international level? Is the time horizon the same for renewable and nonrenewable resources?
- How can the processes of changing tastes, preferences, and behaviors be used to promote sustainability?
- How can the government monitor the success or failure of the programs it implements? What is the role for models in this arena?
- Should the government monitor recycling of construction material? How can the government do such monitoring?
- Should the Federal Government collect data in the United States on exploration for non-fuel minerals?

Finally, the group posed 12 questions on research issues:

- In developing research programs, how can agencies determine what the extent of data coverage should be and what data quality standards should be met?
- How can the coverage issues of collecting data statistically or by measuring the whole population be addressed to ensure that the coverage is both adequate and practical?
- How can data collection be targeted effectively? Can models be used to target emerging or potential problems?
- Is voluntary data reporting by industry as effective as or more effective than mandatory reporting?
- How can modeling be used more effectively in sensitivity analysis to identify research areas?
- Given limited funding, how should priorities be set for data collection for materials and energy flows? Should decisions be based on highest volume, highest value, highest toxicity, or scarcest supply?
- How can the impact of one community's use of materials and energy on another community be measured? How can researchers measure the impacts of imports and exports? How do energy and materials move through the import-export system?
- How can agencies and interagency groups avoid engaging in studies that are so complex and expensive that they cannot be finished? How can these groups avoid creating a product that is not worth the investment?
- How can various data sources be merged? These data sources include regular data series and data from ad hoc studies in the USGS, and data from other Federal agencies, State, local, and international sources.
- How often should data be collected in series? How can data collected in different years be compared?
- Should the government collect data on the quality as well as the quantity of materials flows? For example, should the USGS be looking at the contents of coal, or how much cadmium is associated with the use of zinc?
- Should production data be expanded to include information on the amount of overburden moved to extract ore and metal? What is the volumetric footprint, both in terms of the environmental impacts of excavation, and the energy requirements to manipulate the overburden?

A group led by David Berry, Interagency Working Group on Industrial Ecology, Material and Energy Flows, and W. David Menzie, Chief, International Minerals Section, Minerals Information Team, USGS, offered the following points:

Major issues in materials and energy flows and sustainability from a policy perspective include:

- Identifying where markets work well and where they do not work well. Investigators should concentrate on the latter.
- Examining where government policies do or do not support sustainability from a national perspective. These include tax, fiscal, and land-use policies.
- The broad problem of identifying and responding to materials flows issues globally.
- The need for information on natural flows and processes in order to evaluate the significance of anthropogenic flows.

Major issues from a corporate perspective include:

- Consistency of government policies.
- Availability of data.

The group treated the status of research in terms of challenges to research.

- The challenge of funding demands prioritization of effort.
- The issues surrounding materials and energy flows and sustainability need to be more clearly recognized. Building the recognition requires new levels of networking because of the interdisciplinary nature of the issues. Positive examples in this regard include the Integrated Assessment Program among the U.S. Department of Energy, the Environmental Protection Agency, and the National Science Foundation.
- The scope and size of the interest in these issues might be determined by a search of the World Wide Web.

Contributions by the USGS might include:

- Providing additional perspectives both on spatial distribution of flows and on products.
- Analyzing information on international trade for global assessments of materials and energy flows.
- Performing case studies.
- Performing input/output analyses.

With respect to sustainability, the group focused on:

- Equity issues, such as issues in environmental justice.
- Understanding and assessing resource endowments.
- Transferring best practices to the developing world.

A group led by William M. Brown, Minerals and Materials Analysis, Minerals Information Team, USGS, focused on reviewing the Draft Statement of Task provided by Craig M. Schiffries of the National Research Council (p. **28**, this volume). The group made the following points:

For the National Research Council draft, the issue statements should be revised to be clearer and tighter.

With respect to identifying the extent to which materials flows and reservoirs can be characterized to one significant digit:

- For what reasons is the decision needed?
- What is the extent to which this work needs to be done?
- Is one significant digit sufficient?
- Specify that researchers should be estimating the magnitude of error.

With respect to identifying information of highest priority for use by government agencies, the private sector, the research community, and the public:

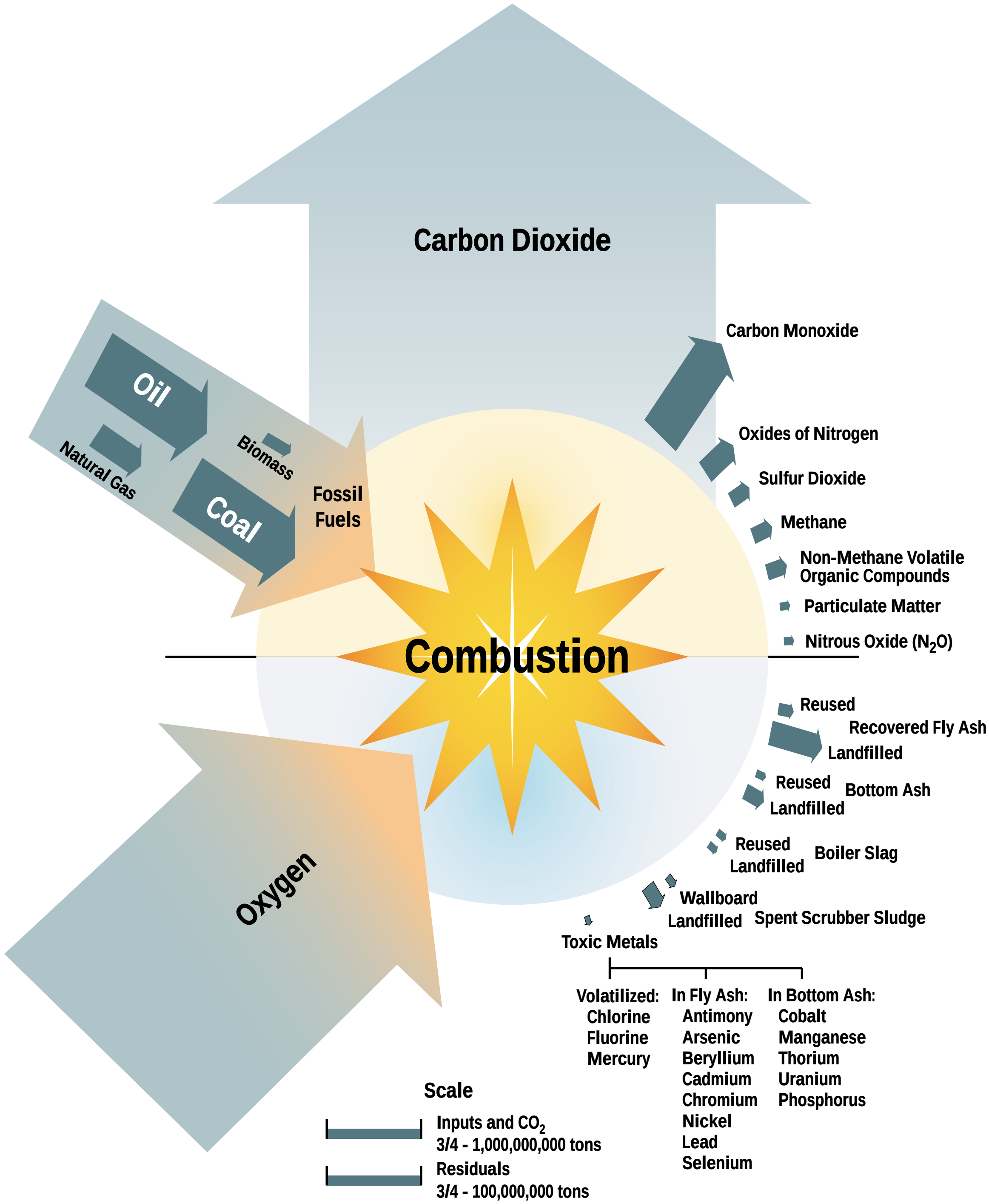
- Could information be earmarked as to whether or not it is confidential (proprietary)?
- Specify how to prioritize.
- Build a list of examples or case studies around this issue, and state them in the task document.
- Summarize the institutional and regulatory constraints with respect to the issues in order to see what might be needed to overcome these constraints.

With respect to integrating existing data and developing new data for making informed private and social decisions, including cost aspects:

- Rewrite this issue statement to make it more specific.
- Provide an estimate of how much is this activity going to cost.

With respect to standardizing accounting procedures, especially the terms, definitions, and formats of data:

- Where would standardization be most useful?




Combustion flows and residuals. Modified from the Interagency Working Group on Industrial Ecology, Material and Energy flows, 1998, p. 10.

With respect to identifying opportunities to close materials loops, especially in cases where leakages present significant environmental impacts:

- Investigators need to incorporate the idea that materials flow is dynamic as opposed to the static point of view represented by annual data.
- Researchers should provide examples of modeling frameworks.

The group also asked the following questions and made the following points with respect to the set of issues questions posed for all breakout groups:

- What are the major environmental problems globally, and how can these problems be prioritized?
- How does a local entity or activity fit into the global perspective of environmental problems?

- There is a need for data at the local, national, and global levels that interconnect local activities with a global perspective.
- Materials and energy flows and their relations to sustainability constitute the basis for a new emerging science. This science is dependent upon the resources, economic, and other databases produced by the USGS and several other government agencies.
- The quality of databases needs to be improved to account for materials in imports, consistency of reporting, and methods for collecting more metadata.
- Data reporting that has heretofore been proprietary needs to be supplied for universal access, whether voluntary or mandatory.
- The USGS needs to continue to evolve its activities from a focus on data collection to comprehensive data analysis.

The breakout groups compiled their results and reported these in the Thursday morning, November 5 plenary session. The breakout groups also submitted their reviews of the NRC document to Craig M. Schiffries (p. **28**, this volume).

## Research Activities and Opportunities within the USGS

### The Chesapeake Bay Ecosystem

Scott Phillips, Principal Investigator for the Chesapeake Bay Ecosystem Program, USGS, presented relations between nutrients and materials and energy flows in the Chesapeake Bay ecosystem. The ecosystem of Chesapeake Bay has been adversely affected by a combination of nutrient enrichment, toxic substances, sediment influx, and overharvesting shellfish and finfish. Excessive nutrient inputs have caused eutrophication and periods of hypoxia (dissolved-oxygen concentrations lower than 1.0 milligram per liter), which in turn have killed or stressed living resources in many areas of the bay. Algal blooms from high nutrient inputs and sediment loads also decrease water clarity, which is largely responsible for the decline of submerged aquatic vegetation (SAV). Submerged aquatic vegetation, one of the most important components of the ecosystem, provides critical habitat for shellfish and finfish and food for waterfowl. Finally, fish health is threatened by toxic dinoflagellates, whose increase may be related to adjacent land-use practices.

In 1987, the Chesapeake Bay Program (CBP), a multiagency restoration effort, established a goal to reduce controllable nutrient loads into the estuary 40 percent by the year 2000. The goal was based on the results of a computer model that indicated that a 40-percent reduction in nutrient loads would eliminate hypoxia in the mainstem of the bay. The nutrient-load reduction is expected to decrease the severity of algal blooms in the tributaries and encourage the regrowth of SAV. However, resource managers are concerned that the bay and watershed will respond more slowly to the nutrient-reduction measures than was previously anticipated. Therefore, scientific information on lag times between nutrient inputs and water-quality and living-resource response is needed to assess the effectiveness of nutrient-reduction strategies. Analysis of long-term biological, chemical, and hydrogeologic records integrated with new collected information can help managers gain a perspective on the bounds of inherent variability of the ecosystem and its effect on restoration goals. The USGS, through its Ecosystem Program, collects and interprets scientific information to help resource managers determine the success of management strategies and the response of the ecosystem to nutrient reduction.

The USGS Chesapeake Bay Ecosystem Program, which began in May 1996, is a 5-year effort to provide relevant information on nutrient and sediment conditions. It is also investigating the response times and the factors affecting nutrient and sediment dynamics and selected living resources. This information was used for the evaluation of nutrient-reduction strategies in 1997 and will be used for the final assessment in the year 2000. Nutrient and sediment data for the entire watershed will be used to document and further understand conditions in the watershed. The program attempts to clarify the principal factors affecting nutrient and sediment transport and their relation to the changes in the sources of these constituents in selected hydrogeomorphic regions (HGMR’s) of the watershed. HGMR’s are areas of unique physiography and rock type that may have characteristic water-quality and biological response to natural variability and changes in nutrient inputs. The USGS is relating surface and subsurface characteristics to water quality and living-resource response over several temporal scales through studies in selected watersheds, and river and estuary reaches within HGMR’s.

The Ecosystem Program prepares or enhances detailed spatial coverages of the bay watershed for land characteristics (topography, hydrography, drainage divides, physiography, land cover, and soil), subsurface characteristics (geology and lithochemistry), and estuarine characteristics (bathymetry and shoreline changes). A new satellite-image mosaic of the watershed has been prepared using data developed by ongoing efforts of the USGS and other agency programs. Additionally, a temporal land-use change study is designed to show the influence that agricultural, urban, and forest land-use change over the past 200 years has had on nutrient and sediment input into the Patuxent River Basin and on water quality and living resources. Information on nutrient inputs is being compiled as part of this effort. Data-management tools will be developed to provide access to and interpret the information compiled and generated under the program. Within USGS, the multidisciplinary program is working with mapping specialists to obtain detailed characteristics of more localized areas through production of Digital Orthophoto Quadrangles.

One program element is to further define the factors that affect the sources, sinks, transport, and residence time of nutrients and sediments in major areas that drain into the Chesapeake Bay. The river basins in the watershed have been identified as the major source of nutrients and sediments to the estuary. The success of the nutrient- and sediment-reduction practices implemented in the watershed will depend on an improved understanding of the factors affecting input and transport of nutrients and sediments.

The Ecosystem Program provides information about the occurrence, trends, and transport of nutrients and sediments in the watershed, and it updates an existing USGS database. Initial information on nutrient and sediment budgets will be compiled from existing studies. Information on nutrient and sediment retention and transport will be collected via field efforts in selected watersheds in different HGMR's and the Susquehanna River reservoir system. Statistical analysis and regression modeling will be used to assess the relation of water-quality response to nutrient inputs and surface and subsurface characteristics of the watershed. The Ecosystem Program will be coordinating with several other USGS efforts including the River Input project, the National Water Quality Assessment (NAWQA) Program, the National Research Program (NRP), and district offices to obtain and interpret data on nutrient occurrence, trends, and loads.

Another program element is to quantify the nutrient load entering Chesapeake Bay from ground water and identify the effect of residence time of nutrients in the ground-water system on water-quality response in the rivers and the bay. Assessment of the residence time of nutrients in the ground-water system helps managers to understand the lag time between nutrient-reduction actions and water-quality response. A better understanding of the factors controlling nutrient movement and concentration will help resource managers more effectively target the placement of nutrient-reduction measures.

The Ecosystem Program is documenting the quantity of ground water and associated nitrogen loads entering the bay and the residence time of nitrogen in the ground-water system. Hydrograph-separation techniques will be used to determine the amount of ground-water discharge to rivers entering the bay. Water samples have been collected from springs and wells to document ground-water ages and chemistry. These data and the information on subsurface characteristics will help to clarify the factors affecting traveltime and nutrient concentration in the different HGMR's. Statistical analysis will be conducted to determine the strongest influences on nutrient movement and concentration. Studies in more localized areas will be conducted to confirm the results of the statistical analysis. Within USGS, information on discharge of ground water to the bay will be collected through coordination of the USGS Delmarva study unit of the National Water Quality Assessment (NAWQA) Program and evaluation of geologic properties through a coordinated effort with the National Cooperative Geologic Mapping Program.

Another program element has as its goal to improve the understanding of the hydrologic, geologic, and water-quality factors affecting selected living resources and their associated habitat in the rivers, tidal tributaries, and estuary. Understanding the response of living resources and associated habitat to water-quality improvements is one of the primary objectives of the nutrient-reduction goal and tributary strategies. In the tidal system, SAV is expected to respond favorably to improved water clarity and quality. Additionally, understanding the link between land use, nutrients, and fish health is needed in the bay system.

The Ecosystem Program is documenting the response of SAV in areas of selected tidal rivers where the habitat requirements for SAV have been meet, but SAV has not yet returned to the system. At selected sites in the tidal portion of the Potomac River, USGS will transplant SAV to evaluate the factors affecting its response, and then will use this information to update SAV habitat requirements. Data collected in the nontidal portion of the watershed will be used to study the occurrence and change of algal and other selected biological communities due to changes in water quality and other environmental conditions. Within USGS, biological resources specialists will also be participating in study efforts to identify the causes of fish lesions and fish kills and their relation to land use, nutrients, and fish health.

The program also is studying the history and evolution of the Chesapeake Bay ecosystem and its response to changes in sedimentation, salinity, and nutrient loading during the past several decades and centuries. Investigating the depositional history of the bay will help describe the condition of the bay's ecosystem prior to human development and improve knowledge of present conditions. Understanding the influence of climatic cycles on freshwater flow, and fluctuations in the bay's hydrology will lead to understanding nutrients, dissolved oxygen, salinity, sedimentation rates, and biodiversity. The understanding will help determine the extremes of natural fluctuations and their relation to restoration goals.

The Ecosystem Program is part of a multiagency effort to carry out an integrated coring, sedimentological, environmental, and ecological investigation of the bay's ecosystem. The USGS will examine the response of biological resources to natural and anthropogenic changes at several time scales, including the last five decades, when nutrient inputs have greatly increased into the bay, and the past four centuries, during which populations have increased. Sediment cores collected from the bay show historical trends in habitats, nutrients, salinity, and sedimentation from age dates, paleoecological proxies (pollen, diatoms, ostracodes, foraminiferal ecology), sedimentary geochemical indicators, and chemical analyses of major nutrients. The USGS compares these biological and chemical data to historical records on rainfall, river inflow to the bay, land-use changes, and nutrient inputs to evaluate the causes of changes in the sediment, as represented by the cores. Coordination within the USGS includes working with the Climate Change and Marine and Coastal Geology Programs.

The program also has elements comprising information dissemination and outreach. There is a continuing need to translate scientific information into usable results to better manage and restore the bay and its watershed. The USGS is working closely with the Communications Subcommittee of the Bay Program and the Alliance for the Chesapeake Bay to relay scientific results to State and local government resource managers in the bay watershed, program managers in the USGS and the Department of the Interior, scientists, the media, and the general public. The USGS disseminates information through a series of mechanisms including a Home Page on the World Wide Web, fact sheets and reports, press releases and media events, pilot projects with Tributary Strategy Teams, and presentations to agencies and scientists at selected meetings and conferences.

## Merging Economic Modeling with Energy and Minerals Programs

Gene Whitney, Chief Scientist, Central Energy Resources Team, USGS, examined the concept of merging economic modeling with Energy Resources, Mineral Resources, and other USGS programs. He reviewed the traditional role of the USGS in energy research. This role is to study processes that produce fossil fuels, and study the geological habitat in which energy deposits form and occur. The USGS estimates (or assesses) the amount of undiscovered energy resources (oil, natural gas, and coal) in the Nation and the world. Finally, the USGS conducts topical environmental and economic studies relevant to energy resource development and use. He noted, however, that this traditional role is mainly oriented to a small part of the materials flow cycle for these resources. In an example of the materials flow for oil, the USGS is mainly involved with the supply part of the cycle, and has little involvement with conversion, use, and emissions that account for other major parts of the cycle. Whitney noted that the environmental impact of resource use might outweigh supply issues within the materials flow cycle.

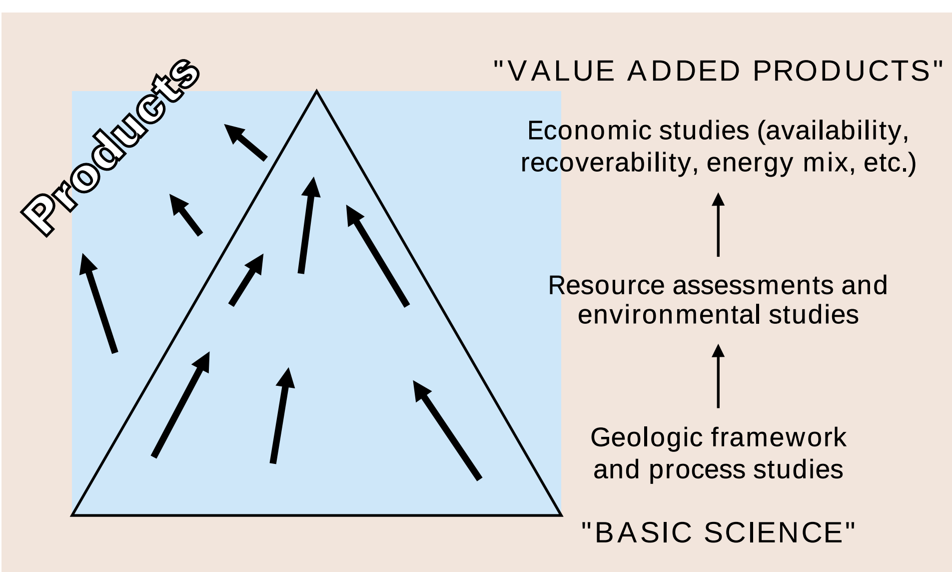
In addition to economics and technology, availability of energy resources is commonly a function of cultural or political factors. For example, international agreements preclude significant energy development in Antarctica. Political decisions about preserving the Alaska National Wildlife Refuge and the Kaiparowits Plateau in the United States limit energy development possibilities in those areas. Cultural priorities such as dwellings, power lines, wildlife habitat, floodplains, and cemeteries are sometimes negotiable, but nonetheless restrict resource availability. Additionally, there is a problem of competing development, as in the case of coexisting resources in oil fields and coalmines.

There are issues of technical recoverability and economic recoverability of resources. Even if a resource is technically recoverable, its remote location, a lack of infrastructure, or the quality of the resource may constrain its recoverability. Additionally, the environmental impacts of resource extraction might be too severe to allow extraction to occur or expand. Currently, the relation of carbon dioxide emission to potential global warming is an important issue. Unlike recycling of minerals, metals, and other materials, "recycling" of fossil fuel combustion waste is a relatively new concept. Whereas fossil fuel supply issues are important, the atmospheric effects of combustion may drive society more quickly to alternative energy sources. Thus, it is important to compare the systems impacts of fossil fuels to the systems impacts of alternative energy sources. For example, a move to cadmium-tellurium photovoltaic cells would quickly consume all cadmium worldwide. The question becomes one of how to place economic values on atmospheric and climatic issues, and use the values to assess economic recoverability and use of fossil fuel resources.

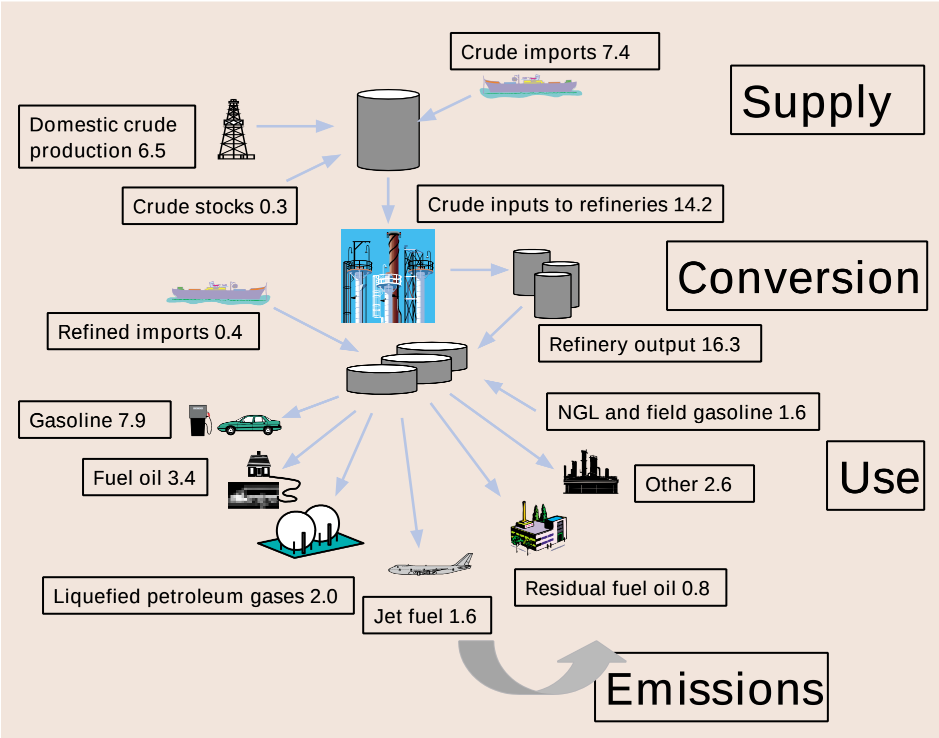
The USGS has philosophic, strategic, and product-enhancement rationales for developing energy economic modeling. Philosophically, geologic commodities are essential economic commodities. Strategically, there is a need for first-approximation models for setting commodity and regional priorities in national and global energy supply studies. Finally, from a product-enhancement point of view, geologic information is more usable if researchers understand geologic, technological, and economic constraints on resource development. Thus, the USGS would do well to encourage economics as a "second language." The agency could conduct simple strategic modeling internally for identifying priority commodities and regions. It could provide critical geologic data for economic analysts, including quantity, quality, and environmental impact of development and use of resources. In addition, the USGS could build partnerships by collaborating with the experts on large-scale, long-term models, such as the National Energy Modeling System and models used by universities and industry.

## Water as a Material: Water Use in the United States, 1950–1995

Wayne B. Solley, Chief, Branch of Water Use and Information, USGS, examined water use in the United States. Many existing sources of water are being stressed by withdrawals from aquifers and diversions from rivers and reservoirs to meet the needs of homes, cities, farms, and industries. Increasing requirements to leave water in the streams and rivers to meet environmental, human, and recreational needs further complicate the matter.




Energy science pyramid. Modified from the presentation at the workshop by Gene Whitney, USGS.



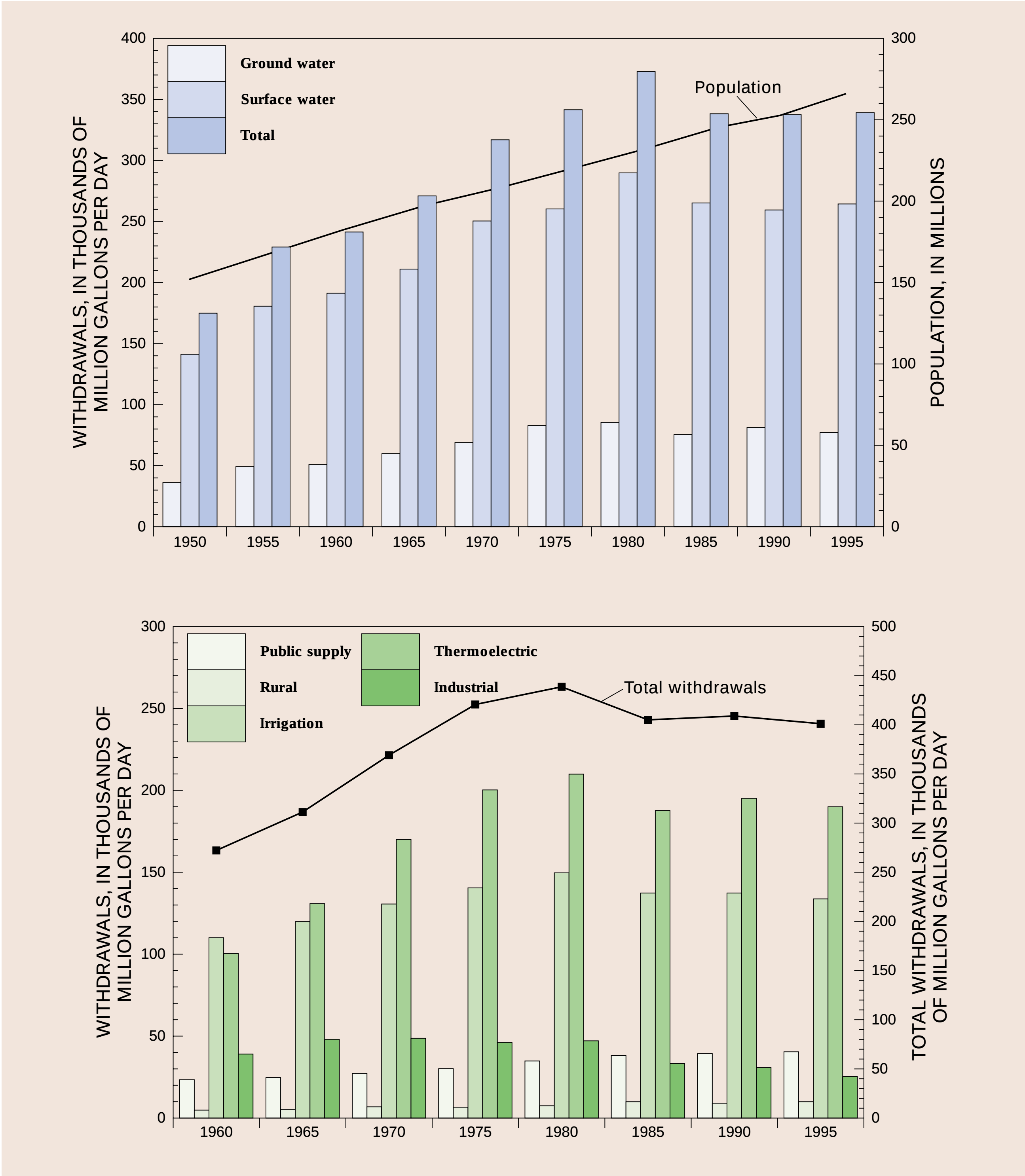

Materials flow for oil. Modified from the Department of Energy, Energy Information Administration (DOE/EIA), and presented at the workshop by Gene Whitney, USGS. NGL, natural gas liquids.

Traditionally, water management in the United States has focused on manipulating the country's supplies of freshwater to meet the needs of users. Many large dams were built during the early 20th century to increase the supply of freshwater for any given time. This era of building large dams to meet water demands in the United States has passed. As we approach the 21st century, the finite water supply and established infrastructure require that demand be managed effectively within the available sustainable supply. Quantitative assessments derived from national water-use compilations, such as those performed since 1950 by the USGS, can be used to evaluate the impacts of population growth and the effectiveness of alternative water-management policies, regulations, and conservation activities. As the focus on water management is increasingly on the river basin or watershed, commonly spanning multiple States, the national water-data compilation also can be used to develop and evaluate trends in water use, to plan for more effective uses of the Nation's water resources, and to make projections of future demands.

In a little-noticed but potentially historic environmental turnabout, water use in the United States declined by about 10 percent from 1980 to 1995. The withdrawal of fresh and saline water during 1995 is estimated to have been 402,000 million gallons per day (Mgal/d) for all offstream uses—2 percent less than the 1990 estimate. The 1995 withdrawal estimate is nearly 10 percent less than the 1980 estimate, which is the peak year for water use documented in the 5-year compilation series that the USGS began in 1950. This decline in water withdrawals occurred even though population increased 16 percent from 1980 to 1995, and implies that people are finding ways to use water more efficiently. The decline in water use runs contrary to the conventional belief that water use rises with economic and population growth.

Total surface-water withdrawals in 1995 were about the same as during 1990, while ground-water withdrawals were about 4 percent less than during 1990. Saline-water withdrawals were about 12 percent less in 1995 than in 1990. The use of reclaimed wastewater was about 36 percent greater in 1995 than in 1990. Offstream water-use categories are classified by the USGS as public supply, domestic, commercial, irrigation, livestock, industrial, mining, and thermoelectric power. The two largest water-use categories continue to be thermoelectric power and irrigation. In 1995, the most water was withdrawn for thermoelectric power cooling, whereas the most freshwater was withdrawn for irrigation. The estimate of total (fresh, saline) self-supplied withdrawals for "other" industrial uses during 1995 is about 3 percent less than during 1990. Industrial withdrawals declined from 1980 to 1995 after remaining about the same for the years reported from 1965 to 1980. In fact, self-supplied withdrawals for "other" industrial use during 1995 are the lowest since records began in 1950. Water for hydroelectric power generation, the only instream use compiled by the USGS, is estimated to have been about 4 percent less than the 1990 estimate.

Total freshwater consumptive use is estimated to have been about 6 percent more during 1995 than in 1990. Consumptive use by irrigation accounts for the largest part of total consumptive use. Freshwater consumptive use in the East (water-resources regions east of and including the Mississippi regions) is about 12 percent of freshwater withdrawn in the East and accounts for only 20 percent of the Nation's consumptive use. By comparison, freshwater consumptive use in the West is about 47 percent of freshwater withdrawals. The higher consumptive use in the West is attributable to the 90 percent of water withdrawn for irrigation that occurs in the West.




Trends in fresh ground- and surface-water withdrawals, 1950-95, and trends in water withdrawals (fresh and saline) by water-use category and total (fresh and saline) withdrawals, 1960-95, from U.S. Geological Survey, 1998a, p. 65.

The USGS has systematically tracked water use in the United States since 1950, and has noted some significant trends:

- Most of the increases in water use from 1950 to 1980 were the result of expansion of irrigation systems and increases in energy development.
- The development of center-pivot irrigation systems and the availability of plentiful and inexpensive ground-water resources supported the expansion of irrigation systems.
- Higher energy prices in the 1970's, and large drawdown in ground-water levels in some areas increased the cost of irrigation water. In the 1980's, improved application techniques, increased competition for water, and a down-turn in the farm economy reduced demands for irrigation water.
- The transition from water-supply management to water-demand management encouraged more efficient use of water.

• New technologies in the industrial sector that require less water, improved plant efficiencies, increased water recycling, higher energy prices, and changes in the laws and regulations to reduce the discharge of pollutants resulted in decreased water use and less water being returned to the natural system after use.
• The enhanced awareness by the general public of water resources and active conservation programs in many States has contributed to reduced water demands.

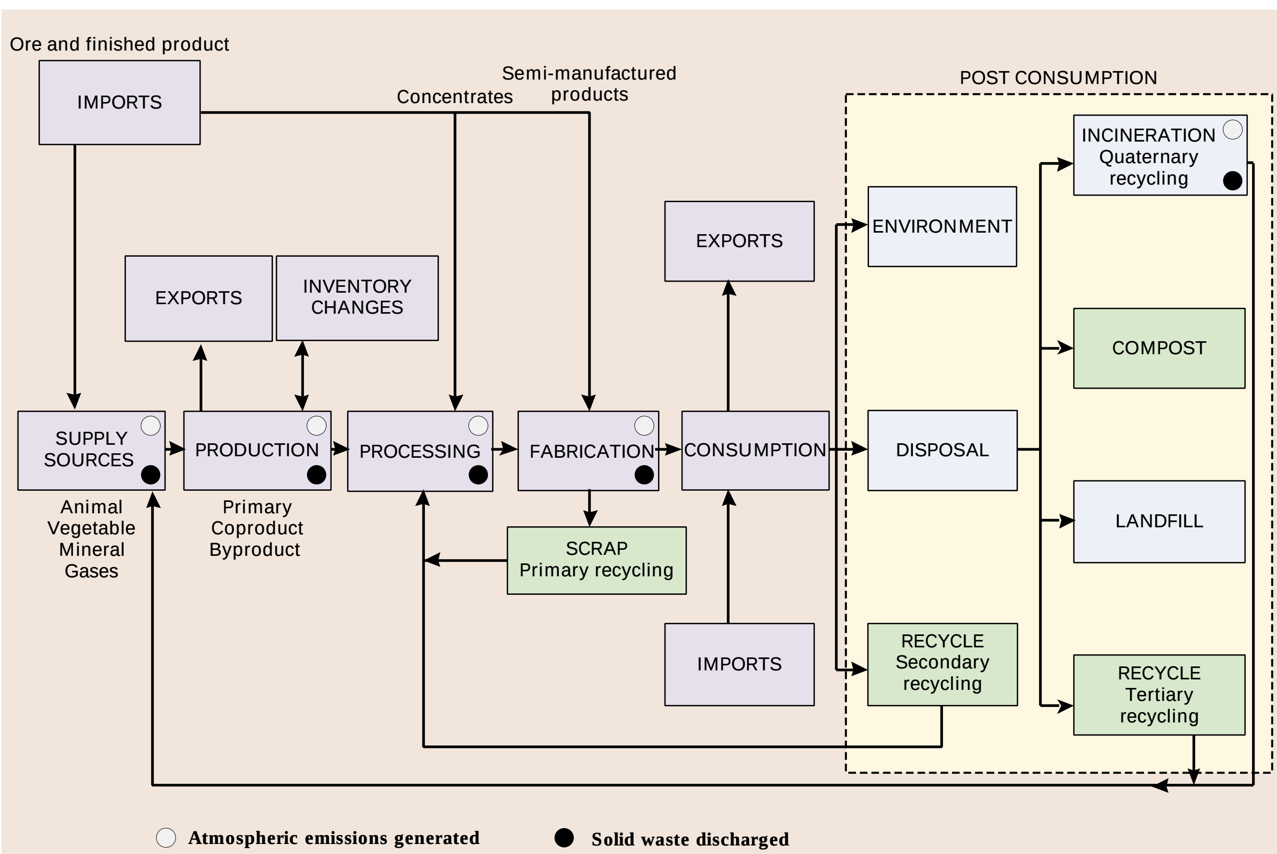
Projections of future water use are beyond the scope of Solley's reporting, although the trends established over the past 45 years from these national compilations provide some basis for estimating future water demands. Water withdrawals for public supply and domestic uses seem likely to continue to increase as population increases. Higher water prices and active water conservation programs, however, may reduce the per-capita use rates. With increased competition for water for instream uses, such as river-based recreation, esthetic enjoyment, fish and wildlife habitat, and hydroelectric power, along with higher municipal uses, irrigators will have increasing difficulty competing economically for available water supplies. Thus, a leveling in the rate of agricultural water use combined with growing population and urbanization suggests that, for the foreseeable future, new balances will have to be struck in water use between rural and urban areas, especially in the Western United States. It seems likely that, for the foreseeable future, industrial water use and use per unit of production will continue to decline in most sectors, although probably not as sharply as in the recent past.

Regardless of which projection proves correct, the United States needs to devote major attention to water-management problems to ensure that maximum benefits will be obtained from use of the Nation's water resources. This has become more evident because, in addition to the need for an adequate water supply, water-quality conditions need to be suitable if supply and demand are to be kept in balance.

## Global Implications of Minerals and Materials Analysis in the USGS

David (Dave) Menzie, Chief, International Minerals Section, Minerals Information Team, USGS, briefly reviewed the history of sustainability concepts. In 1972, the book "The limits to growth" used dynamic systems modeling to explore the relationships among population, agriculture, industry, pollution, and natural resources in a search for global equilibrium. The modeling predicted resource exhaustion. However, the intervening years have proven that resources were more abundant than the modeling assumed, and people turned to other concerns. In the late 1980's, concerns arose that although resources might be abundant, the effects of pollution that attended industrialization would limit human welfare. In 1987, the Brundtland Commission (p. **26–27**, this volume) enunciated a goal of sustainable development, and scientists began to examine new strategies for minimizing pollution.

An outgrowth of the new strategies is the field of industrial ecology (p. **11**, this volume) that derives from the observation




Generalized commodity flow cycle. Modified from Kostick (1996).

that in nature, webs that connect organisms to each other are the mechanisms by which equilibrium is maintained in ecosystems. Industrial ecology uses ecological models as analogs for developing sustainable industrial systems that minimize or reuse harmful industrial wastes. Some strategies for lessening wastes include zero emissions, materials substitution, dematerialization (including decarbonization), industrial symbiosis, and economic reconceptualization. The methods of studying material use include materials flow and balance analysis, life cycle analysis, indicators of sustainability, material dynamics, and international comparisons. Wernick and Ausubel (1997) explain both the strategies and methods.

Some ways in which the USGS contributes to materials analysis include providing production and consumption data; conducting materials flow studies; developing methods for estimating total consumption (including materials embodied in total consumption); identifying locations of wallboard plants and power plants with Flue-Gas Desulfurization (FGD) units (p. **15**, this volume); and investigating the use of quarry fines as soil amendments. The chart of consumption of raw materials in the United States over the course of the 20th century (p. **10**, this volume) represents USGS production and consumption data. USGS materials flow studies for Fiscal Year 1999 include construction materials, aluminum, chromium, cobalt, lead, manganese, mercury, selenium, sulfur, tantalum, tin, vanadium, and zinc. The USGS plans to conduct materials flow studies in Fiscal Year 2000 for antimony, beryllium, cadmium, copper, gold, iron and steel, molybdenum, nickel, platinum, silver, tellurium, and tungsten.

Additionally, the USGS is interested in patterns of mineral production and consumption in developing countries that will play key roles in whether societies can become self-sustaining. One example of the situation is population growth rate compared with Gross Domestic Product (GDP) per capita. Using this comparison, many countries with the highest rates of population growth are also seen to be the countries with the least GDP per capita. Menzie also compared Japan, Republic of Korea, and the United States over the period 1965–95 with respect to several population and consumption trends. The rates of population growth are approximately the same for Japan and the United States; however, the population growth in the Republic of Korea accelerated rapidly in the late 1960's, and continues to outpace that of the United States and Japan. Correspondingly, the rate of aluminum consumption per capita in the Republic of Korea is rapidly approaching that of the United States and Japan as we move into the 21st century, and the per-capita consumption of cement in the Republic of Korea accelerated past that of the United States and Japan in the mid-1980's. By 1995, per-capita consumption of copper in the Republic of Korea exceeded that of the United States and Japan, whereas the Republic of Korea's consumption of salt remained well below that of the other two countries.

Menzie noted that the per-capita consumption of cement in People's Republic of China (PRC) and Indonesia, while rising modestly between 1965 and 1990, has accelerated greatly in the 1990's. Similarly, copper consumption per capita rose by a factor of three in PRC between 1990 and 1995, and by a factor of two in Indonesia during the same period. These trends are highly significant when viewed in the context of development aspirations for populous countries. Currently, PRC, India, the United States, and Indonesia are the world's four most populous countries. However, the GDP per capita in the United States exceeds $25,000 whereas the GDP per capita in the other three countries ranges from about $2,000 to $4,000. As these three countries seek to increase their GDP, the implications for demands for materials become enormous. For example, the trends in copper demand and consumption in PRC have global significance. Copper use is a clear adjunct to modern development, inasmuch as copper would be used throughout societal infrastructure for plumbing, electricity, communications, transportation, and other common applications. In 1975, the world as a whole consumed 7.0 million tons of copper. In 1995, the world as a whole consumed 10.5 million tons of copper. Based on PRC's population, rate of consumption, and development aspirations, the expected demand for copper in PRC alone in 2015 is in the range of 7.5 to 15.8 million tons. This figure implies doubling the world's copper production over the course of less than two decades.

Some implications for what the USGS is discovering from its analyses are these:

- Economic activities in developing countries will account for an increasing share of global materials flows;
- Increasing consumption by developing countries will result in significant increases in environmental residuals and significant changes in supply patterns;
- Developing countries will produce an increasing share of environmental residuals, including those that are purposely or accidentally exported via air and water; and
- Materials flows analysis by individual mineral commodity explains reasons for and consequences of change, which is not possible if data are aggregated by physical quantity or value.

## Urban Dynamics and Resources Demand in the Eastern United States

Gilpin R. (Rob) Robinson, Research Scientist, Eastern Mineral Resources Team, USGS, described the spatial dynamics of the Baltimore-Washington corridor, and trends and issues for materials flow in the region. The dominant mineral resources used in the United States comprise the construction resources of stone, sand and gravel, cement, and clay. These resources were 52.5 percent of all mine production of nonfuel minerals and coal in the United States in 1995. Aggregate (stone, sand and gravel) mining is most intensive in the Eastern United States, with New Hampshire, Connecticut, Rhode Island, Massachusetts, New Jersey, Pennsylvania, Maryland, Virginia, Ohio, and Indiana reporting 1,500 to 5,000 tons per square mile mined during 1995.

Robinson illustrated mid-Atlantic aggregate production using Washington, D.C., and vicinity, extending northward into Pennsylvania; westward into Virginia, and eastward and southward into Maryland and Virginia. County-level aggregate production in this region for 1995 ranged from 0 to 12,500 t per square mile. The demand is particularly heavy in many counties because of urbanization, growing transportation networks, and intensified use of land. The trends create issues of shifts in intensity of land use and economic activity, shifts in resource needs and availability, rates of change of demand, quality of life, and resource management and use.

The resource management issues are of primary interest to the USGS, and include lack of public awareness of processes needed to meet demand, concentrating and consolidating the industry, sterilizing the resource and minimizing waste, and mismatches between markets and management units. The research response to these issues is encapsulated in a Mid-Atlantic Geology and Infrastructure Case Study. The response focuses on urban and high growth areas, regional analysis, resource characterization and assessment, decision-support tools, and facilitating regional interaction and integration. The study is identifying geologic sources of high-quality aggregate resources. It is documenting for the past 35 years the producers of aggregate, amounts of production, aggregate users, aggregate consumption, and aggregate recycling and disposition. Part of the work is to develop and calibrate a regional aggregates-demand forecasting tool, and to analyze land-management planning with respect to aggregates.

Urban dynamics are measured by resource needs, infrastructure changes, and rates of change. For the Baltimore, Md.–Washington, D.C., Region Study, USGS objectives are to develop an intrinsic growth-rate model for urbanizing areas. The model will be calibrated in terms of the infrastructure elements of roads, people, and housing units. The USGS will develop resource demand forecasting models for natural aggregates and cement, and estimate the spatial and temporal resource requirements needed for infrastructure elements. The model is based on spatial data for 1792–1992, and uses this information to make projections to 2025, 2050, and beyond. The results are directed towards resource conservation and availability strategies—which include managing resources at a larger scale, coordinating market activity, changing perceptions of social costs, increasing local benefits, and expanding resource supplies from existing sites.

# Directions and Opportunities for Research in Materials and Energy Flows

Martha S. "Marty" Power, Program Scientist, Mineral Resources Program, USGS, voiced her appreciation for the crosscutting nature of most of the earlier workshop discussions. She noted that the USGS is in a position, by the work that it does, to play a key role in materials and energy flows studies. One of the issues the USGS needs to consider is how to present the information it already has, and the vast amount of work that it is already doing. She stressed the importance of the role of the USGS in data compilation, data analysis, and the formulation of analytical and economic models. Nonetheless, the USGS is being pressured for more of everything with respect to materials and energy flows—more data, more models, more participation, using more resources, and more dissemination of information that is integrated across disciplines and across agencies.

The issues about the future directions for the USGS make for a large order of business for the panel. Power acknowledged that many participants have definite ideas about the USGS role, and she invited questions, comments, and friendly disagreements among the audience and the panel after the panel members made their presentations.

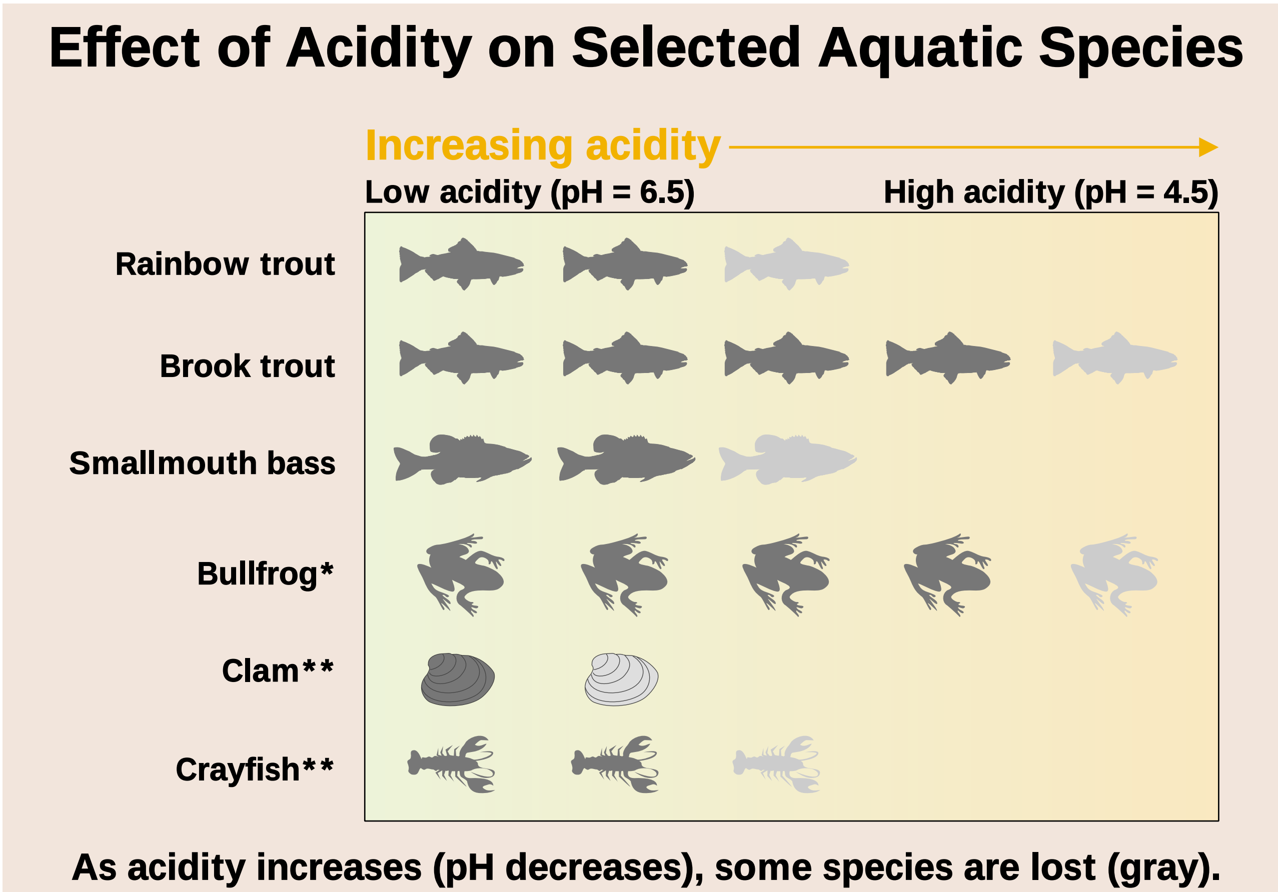
## An Ecosystem Focus for Materials and Energy Flows

Susan Haseltine, Deputy Chief Biologist for Science, USGS, discussed an ecosystem focus for materials flow. She noted that many speakers remarked about the USGS having the technical expertise, credibility, and track record to make significant advances in materials flow science. She advocated incorporating ecosystem services into analysis of materials flow and sustainable development. Biological scientists are accustomed to looking at work of this type with a systems focus, and are valuable contributors in considering the ecosystem wealth that must be maintained in order to maintain economic and materials systems of wealth. If researchers do not consider those basic ecosystem functions, they will be doing society a disservice in the long term to hopes of achieving sustainability of any kind of wealth. She was encouraged by a new mission statement of the Geological Society of America (GSA) with its emphasis on sustainability, and the challenge to consider all earth systems, including the living renewable systems, when thinking about sustainability. Thus, there is a real emphasis on ecosystem function and the process it brings to sustainability.

Haseltine discussed the ecosystem focus in terms of structure and function, multiple impacts, nonlinear responses, and multiple scales, times, and places. In an example, she described how the destruction or disturbance of even a small tract of land critical to a migratory bird population could impact an entire continental species.

Important research topics for ecosystems are hidden flows, remote effects of consumption, leakages in the materials flow stream, and proposing solutions to leakage problems. Haseltine observed that hidden materials flows could be either positive or negative. For example, islands created from dredge spoils—the results of hidden materials flows resulting from dredging waterways—have become productive habitats for migratory waterfowl. For hidden flows with respect to areas of mining, information is needed on biological indicators to assess impacts of acid mine drainage on the ecosystems of receiving streams. She illustrated impacts of acidity on selected aquatic species, showing the loss of species and the resulting alterations of the biological communities with incremental increases in acidity. The impacts of valley fills on aquatic habitat also need to be assessed. Target levels of pollution reduction need to be determined to achieve stream restoration and return to a healthy ecosystem. Additionally, the USGS is often asked to provide information on the impacts of removing overburden (for example, from coal seams in mining operations) on the ecosystems that will be displaced by the activity.

With respect to measuring the remote effects of consumption, for example, nitrogen deposition in high mountain lakes is a problem west of the Colorado Front Range Urban




Effect of acidity on selected aquatic species. Presented at the workshop by Susan Haseltine, USGS. *, embryonic life stage; **, selected species.

Corridor. Dissipated emissions are altering these high mountain lakes as an unintended consequence of urban activities. The lakes of the Colorado Front Range receive higher deposition rates of nitrogen from the atmosphere than the rest of the State. Spring and summer nitrogen comes primarily from urban and agricultural areas of the eastern plains, whereas winter nitrogen comes from western industrial sources, and urban, industrial, and agricultural sources immediately east of the Colorado Front Range.

The USGS is attempting to solve some of the problems using new technology. For example, USGS biologists are experimenting with a carbon dioxide ($CO_2$) system that is smaller and less expensive than any other remediation measure for acid mine drainage. This system is self-sustaining on the landscape, and treats sufficient acid mine drainage to allow significant recovery of downstream waterways. Haseltine suggested that similar treatment processes might be in order to combat the zebra mussel problem. Zebra mussels are discharged into waterways from the bilge water in tankers, and proliferate rapidly with harmful effects to powerplant outflows and wastewater treatment plants. Losses to the economy because of the presence of zebra mussels are estimated at $30–$60 billion per year. Researchers are now looking to use a $CO_2$ system in tankers to treat the problem at its source.

Haseltine mentioned that biologists are seeking to collaborate with other USGS scientists and any other partners on a variety of ecosystem management problems. She suggested that the solutions to leakage problems involve rethinking landscape scale effects (continental effects) of various land uses, finding new and better indicators of ecosystem stress, looking more closely at interactions between and among ecosystems, and focusing on the scale and time of ecosystem change.

She showed an illustration of an Alaskan brown bear, and concluded with the goal that we will have a functioning Earth and its systems and processes so that we will always have this brown bear in Alaska for our children to enjoy. She cautioned participants to remember that any sustainability that does not consider the functioning of these systems is shortsighted, and hoped that she had stimulated interest in partnerships with BRD.

A participant asked about how researchers place value on ecosystem services. For example, do they value ecosystem services in terms of dollars, or some other units?

Haseltine replied that the USGS/BRD has a unit at their Ft. Collins, Colo., Research Center that is struggling with this very issue. Although several methodologies are available, no consensus exists among their practitioners about how to measure the value of ecosystem services. Some communities of investigators reject the entire notion of valuing ecosystems in terms of dollars. Haseltine suggested that investigators should concentrate on those functions and services that are needed for continued sustainability, and that do have a dollar value associated with them. For example, cleaning water and cycling nutrients can be valued in dollar terms.

## Spatial Aspects of Materials and Energy Flows

David Kirtland, Global Change Program Manager, USGS, noted that at the outset of his agreement to participate as a panelist, he was not particularly familiar with the concepts of materials flows, industrial metabolism, or industrial ecology. He did not initially see how the activities with which he was most familiar could contribute directly to such work. So he went to the website the organizers had set up and checked the library for background materials. He used this new information along with what he learned from the first 2-1/2 days of the meeting and this panel session to build his understanding. Given what was learned about industrial ecology in the plenary sessions, what might be the roles of the USGS? As participants discussed in the breakout sessions earlier, however, that is not an easily answered question.

Kirtland reflected upon programs at USGS with which he was most familiar: the National Mapping Program and the Global Change Research Program. The National Mapping Program is focused on ensuring the availability of geospatial data describing the Earth's land surface. Part of that responsibility includes producing what is known as framework data. These include geographic data about the land surface such as hydrography, transportation, elevation, digital orthoimagery, governmental units, cadastral, and geodetic control. These data along with digital raster graphics of USGS quadrangles, thematic data such as land cover/use, and land remote-sensing data are referenced by the Interagency Working Group on Industrial Ecology, Material and Energy Flows in their list of important resources for materials flow research. The National Mapping Program also focuses on documenting change in land cover and understanding why that change occurred. The USGS is just beginning to build a capability for doing analysis of land surface change and decision support systems for translating that analysis into meaningful information for decision makers. Changes in the flow of materials across the landscape may manifest in changes in the surface—new roads and pipelines, new development, and altered land uses.

An initiative being considered for FY2001 focuses on monitoring changes in the land surface, which could provide a database of great use in materials flows research. The U.S. landscape changes continuously. Typically these changes are subtle and predictable in the short term. Yet on longer time scales they are difficult, if not impossible, to predict and may manifest significant changes affecting the cover of the land.

The base data produced by the National Mapping Program are important to the USGS Front Range Infrastructure Resources Project (FRIRP) mentioned by Acting Director Tom Casadevall in his opening remarks for this workshop. The goal is to provide the public and decision makers with objective information about the location and characteristics of land, natural aggregate, water, and energy resources that are vital to sustaining the population of the urban corridor of the Rocky Mountain Front Range of Colorado. To accomplish this, the USGS is developing an integrated spatial database, conducting land surface analysis, and contributing to the development of a group decision support system capability. Historical land-use data are being compiled to investigate the rate at which infrastructure resources have been preempted by alternative and often conflicting uses. Forecasts of future land use, produced using simulations of areas likely to experience development, will be made to investigate the effects of development on infrastructure resources. These data for the 45-quadrangle study area will be integrated with geologic and hydrologic data in a Geographic Information System (GIS) and used in infrastructure resource studies. For example, mapping the sand and gravel deposits will provide information critical to understanding the interplay between mudpit waste sites/evaporation ponds and possible movement of produced waters. Various chemical databases will also assist in mapping water quality of the produced waters. The GIS will be integrated with a modeling complex that allows for what-if analysis. A land-use decision support tool known as Smart Places, developed by the Consortium for International Earth Science Information Network (CIESIN), is being applied to the FRIRP to assist resource managers in producing a range of alternative scenarios and evaluating their consequences.

The Front Range Infrastructure Resources Project is but one of countless projects that demonstrate the utility of understanding the "where" of materials flow, that is, where materials are located; where they move to; and how they are transformed en route. GIS provides a useful framework for integrating information, driving models, and communicating output. Today, statistical routines and modeling capabilities are being incorporated directly in leading GIS's. The Smart Places software, for example, is an application written in ESRI's scripting language Avenue, that acts as a higher-level entry to the ArcView product.

The presentation mode of USGS information is another aspect of work that could assist materials flow research. Cutler J. Cleveland (p. **20**, this volume) called for more than descriptive databases for material flows research, emphasizing modeling and analysis instead. The electronic National Atlas of the United States, currently under development, will provide an excellent resource where scientists and the public can view, analyze, and access data and information that could be used to inform about materials flows around the Nation. The Atlas highlights the "where" by allowing the user to explore the spatial dimensions of phenomena. It is being designed to serve the interests and needs of a diverse populace in many ways: as an essential reference; a framework for information discovery; an education instrument; a research aid; and a source of accurate and reliable scientific information. It will contribute to a better understanding of the environmental, resource, demographic, economic, social, political, and historic dimensions of the Nation. It could be used to communicate the importance of materials flows and sustainability by portraying them through maps.

Another capability of potential use to materials flow applications research is image mapping. Aerial photos that have been processed to be map-like are available through Microsoft® as a result of a Cooperative Research and Development Agreement (CRADA). These high-resolution images of the Earth are available for many areas in the Nation and are used in many GIS applications, including vegetation and timber management, routing of roads, pipelines, powerlines, and other facilities, habitat analyses, environmental impact assessments, facility management, and ground-water and watershed analyses.

Shifting to Global Change research, Kirtland noted that frequent references to climate change and global warming during the workshop were made from the standpoint of energy flows. Carbon accounting is a major research activity of the interagency U.S. Global Change Research Program. Balancing the carbon budget, which was referred to in this workshop as the single largest dissipative flow in the energy system (p. **13**, this volume), is an important objective. Craig M. Schiffries (p. **28**, this volume) referred to a scientific paper that suggests that North America is a net carbon sink. The USGS is engaged in a project that is investigating the role of erosion and sedimentation in sequestering carbon. One of the hypotheses is that significant amounts of carbon are being sequestered in sediments deposited primarily as alluvium and colluvium and in reservoirs. Ninety percent of the material eroded from the landscape remains in these deposits, never making it to the ocean. As long as carbon generation and turnover occur on hillslopes, the potential for these components of the terrestrial system to sequester carbon could be significant. The Kyoto Conference of the Parties (COP3) and Buenos Aires Conference of the Parties (COP4) have thrust carbon into the limelight. An understanding of carbon sources, sinks, and fluxes will be crucial to any international agreements requiring carbon accounting. Carbon research initiatives are a likely outgrowth of this attention. PRC's use of high-sulfur bituminous coal for example, unchecked, would render almost any effort to curb carbon emissions ineffective. Various regulatory mechanisms for reducing the growth in carbon emissions, like the Initiative on Joint Implementation, could have significant impacts on energy materials flows.

Another focus area of the Global Change Program of potential interest to materials flows and sustainability is the National Assessment of the Potential Consequences of Climate Variability and Change for the United States. The United States Global Change Research Program (USGCRP) Act of 1990 charges involved agencies to conduct an assessment of the impacts of global change at least every 4 years. The USGCRP community is responding with its first assessment focused on climate impacts. A key feature of this activity is its engagement of interested citizens as stakeholders. The impacts are being investigated at regional and sectoral levels. In addressing the issue four fundamental questions are being asked: (1) What are the key environmental stresses occurring in the region or confronting a sector? (2) Will a change in climate lessen or worsen these stresses or introduce new ones? (3) What data and research are needed to answer new questions identified by the assessment? and (4) How might current coping mechanisms be emphasized or modified or new mechanisms identified to move us towards a greater capability to cope if climate changes are realized? The idea behind considering ways to enhance coping mechanisms is to best position humankind to handle the kinds of surprises that we may see under a changing climate. Society's use of materials is certainly one source of stress on the current systems. In the Southwest, for example, rapid growth and development and the commensurate flow of materials will certainly be affected by changes in climate or its variability. The USGS is conducting regional assessments in the Southwest, the Great Basin/Rocky Mountains, and Alaska, as well as a sectoral assessment of climate effects on water resources within the United States.

In listening over the course of the workshop, Kirtland developed a list of thoughts, issues, and questions:

- It would be useful to present many of the graphics that participants have seen during the workshop in a spatial context; that is, researchers should map at all scales the flows, transformations, and uses of specific materials.
- Researchers should consider the vulnerability of the infrastructures of industrial ecosystems to natural hazards. Recent news reports (November 4, 1998) estimated that up to 75 percent of the infrastructure in Nicaragua has been damaged or destroyed by Hurricane Mitch (Oct. 27 through Nov. 1, 1998). With these kinds of consequences, the effects on developing societies with respect to materials flows must be staggering.
- Researchers should consider the importance of understanding the myriad interactions in industrial ecosystems to best position society for the realization of a sustainable future.
- How does the miniaturization of technology resulting from high design/low materials products affect the recoverability/reusability of materials? Whereas participants have talked about dematerialization as a good thing (p. **21**, this volume), does dematerialization occur to a great degree as a result of miniaturization? (See, for example, Richards and Pearson, 1998.)
- How will the flow and transformation of materials change under climate and other global changes?
- How do the flow and transformation of materials affect the landscape?
- How do the flow and transformation of materials affect human health? If all tires were recycled, the breeding grounds for disease carrying mosquitoes could be reduced, and this might improve overall human health.
- Researchers seeking improvements in industrial ecosystems must take care to minimize the probability that they succumb to what Wernick and others (1996) have referred to as "Revenge theory," which describes the unintended and often ironic consequences of human actions.

In summary, Kirtland was struck with the importance of and need for education and communication in industrial ecology and sustainability. He indicated that the USGS is well positioned to be a leader in both these fields.

A participant made a brief presentation advocating the need to view materials and energy flows as a systems problem. He supported the support idea of spatial aspects, as well as temporal and sectoral aspects of the materials flow problem. However, he emphasized that the important connection is that materials flows and energy flows are not separate. Almost every materials flow and transformation involves the use of energy. This is true in a physical sense from extraction, through transportation, beneficiation processes, manufacturing, recycling processes, and reuse processes that materials flow addresses. Investigators need always to link materials and energy flows, because when one is affected, an effect on the other is likely. Once society lays down an infrastructure of roads and facilities, it moves down the path to certain future development, and structures the way it is going to use energy in transportation systems from then on. It also works the other way. If for some reason society winds up having to use much less energy, as seems to be a possibility in the case of energy shortages or lack of a place to put the combustion products, then it is going to have to change the layout of the transportation infrastructure spatially. That will have an effect on where the materials come from and where they wind up on the landscape. Therefore, this is really a systems problem. Researchers have to treat the materials and energy flows together, not separately, and they have to treat them spatially as well as temporally.

Kirtland observed that reports of the President's Council on Environmental Quality (CEQ) frequently presented abundant information on materials and energy flows. However, the reports were difficult to read because the information was presented in graphical and tabular format, and not in a spatial format that would be easier to interpret. Perhaps a closer look at spatially oriented presentation could help show the interconnections of materials and energy flows.

## Water: The Largest Materials Flow

Dennis J. Sulam, Regional Staff Hydrologist, Northeast Region, USGS, Water Resources Division (WRD) described how the WRD's structure across the United States positions it for work in materials and energy flows. The WRD is geographically dispersed in each State throughout the Nation, and possesses multidisciplinary talent within all of its principal offices. Issues of State, regional, and national importance can be readily addressed based on that organizational structure. Additionally, the WRD maintains contracts with a large number of partners; for example, the WRD had approximately 1,200 partnerships throughout the Nation in 1997.

Ongoing WRD activities of interest here include studies of nutrients, the transport and fate of certain metals, water quality in paved and unpaved areas, the effects of sewer systems on water resources, forest harvesting, calcium depletion, nitrogen cycling, and the geochemistry of mercury. Additionally, many spinoffs to the National Water Quality Assessment (NAWQA) occur, particularly with respect to nutrient evaluation, and WRD maintains a large program in monitoring and evaluating abandoned mine lands.

Potential studies of consequence to the discussions here involve work and initiatives being developed for the Great Lakes region. WRD is seeking to add its expertise to the USGS Geologic Division Urban Dynamics Study there, and is pursuing a coastal zone initiative around the Great Lakes that could result in projects similar to those now being carried out for the Chesapeake Bay Ecosystem (p. **43**, this volume). On the West Coast, the WRD is developing a study on dredge spoils recycling.

WRD has the expertise and interest nationally to undertake many activities related to materials and energy flows, and would be more than welcome to address issues in multidisciplinary and interdivisional partnerships.

Virginia Burkett asked whether USGS researchers are adequately considering water as a factor in these discussions about materials flow research.

Sulam responded that, looking at the process and the scope of materials and energy flow activities, WRD is indeed involved, but not very formally. That is, WRD has not formalized the concepts of materials and energy flows within its programs.

Eric Rodenburg commented that water is indeed a huge materials flow and literally swamps all other materials flows. Also, the USGS does an excellent job of characterizing those flows in North America. Water is considered in international groups to be a materials flow, and researchers certainly do not want to overlook water among the flows on which the international community is focusing.

Sulam noted that water considered as a commodity would be a major factor in these programs.

## Environmental Geochemistry and Earth System Services

Geoff Plumlee, Chief Scientist, Central Mineral Resources Team, USGS, reflected on materials and energy flows from the perspective of an environmental geochemist. He used his own background as a metaphor for how the USGS Mineral Resources Program (MRP) has evolved. He began his career by studying how mineral deposits form, then became involved in the environmental aspects of mineral resources as they became key issues 10–15 years ago. He worked at becoming an environmental geochemist, but after this meeting, he considers himself a "leakage specialist" because he deals with leakage of metals from the materials flow cycle into the environment. He noted how the MRP has also changed its focus from mineral resources assessments and how mineral deposits form to how minerals are dispersed into the environment and the consequent environmental impacts. He noted the fortunate addition of the Minerals Information Team, comprising people and resources from the former U.S. Bureau of Mines (p. **10**, this volume), to the USGS, providing better tools for looking at materials flow.

Plumlee quoted from the Science Strategy of the Geologic Division, USGS (p. **38**, this volume): One goal defining future thrusts in traditional areas of national leadership for the Geologic Division is studies of the Nation's natural resources to advance the understanding of the Nation's energy and mineral resources in a global geologic, economic, and environmental context. He noted that materials flow plays a key role within that goal.

Plumlee referred to what he had heard earlier from the EPA (David Rejeski, p. **22**, this volume) regarding widely dispersed but numerous sources of copper from automobile brake linings, and silver from dentists offices and photographic laboratories. If researchers think about individual households throughout the country, what role do "Ozzie and Harriet" play in materials flow and materials life cycles? Whereas economic necessity forces General Motors Corporation and other companies (p. **24**, this volume) to engage in more and more recycling, average households in the United States do not have the economic awareness to participate in recycling, and they are not regulated to the extent of businesses and industries. Perhaps our scientists need to analyze the many materials that go down the house drain, out with the trash, up the chimney, and down the storm drain. The potential cumulative impacts of individual households on materials flow cycles could be great. How much nitrate comes off lawns? Given the huge spread of urban areas exhibited by Rob Robinson (p. **49**, this volume), and Scott Phillips (p. **43–44**, this volume) what is the actual nitrogen contribution? What is the contribution of trace metals from cleaners, and the clay content of magazines that people send to the dumpster?

Natural disasters also play a major role with respect to materials flow. Massive hidden flows associated with landslides, floods, and volcanic eruptions are great earthmoving agents. Natural hazards are an important component of Earth system services and disservices, which is an analog to ecosystem services described earlier by Susan Haseltine (p. **50**, this volume). Major differences exist between developing and developed countries in this regard. A flood in Honduras provides a huge disservice in terms of economic disruption, whereas an earthquake in California becomes a major boon to construction. In either case, massive amounts of materials must be removed from affected areas after a natural disaster, and other materials must be moved to rebuild the damaged infrastructure.

Investigators need to carefully track and quantify sources of materials. For example, scientists need to apply materials forensics to situations like that surrounding the San Francisco Bay, Calif., where the dominant sources of copper reaching the bay reputedly are the brake pads of automobiles. Researchers need to explore the amounts of materials concentrated in the biomass, for example, metals in humans, animals, and plants. If we totaled all the metal in humans throughout the world, what would be the fraction in human bodies of the total availability of a metal or metals?

Plumlee noted that Steve Bohlen (p. **38**, this volume) had alluded to the fact that the USGS clearly cannot do it all. This field represents a huge, complex series of issues that are all interlinked. In this case, researchers need to envision how to make simplifying assumptions, focus on key issues, and select the highest priority issues for study, because the overall problem is apparently too great to be handled by a single organization.

Plumlee saw after participating in the workshop that materials flow is everywhere. He spoke to the example of nitrogen reaching the Gulf of Mexico from the apparent source of fertilizers in the Mississippi River Valley in the central United States. Investigators should be looking at sources of atmospheric nitrogen, and factoring in a materials flow analysis at the front end of a carbon budget analysis. Researchers should be studying leakage components of materials flow with respect to human health. They should engage in materials forensics, looking carefully for the sources of materials and linking materials flow, for example, with geochemical tracers such as stable radiogenic isotopes. For example, researchers can use sulfur isotopes for tracking sources of sulfur, and lead isotopes for tracking sources of lead and associated metals and the geochemical processes that may be affecting their distribution.

Researchers have to understand and anticipate what is going on in the world around us in order to help understand where we are heading as a Nation. Materials flow clearly is a key link that helps researchers wrap together resources, climate, and environment, and helps them to anticipate future trends in resource use. This is a big role for the USGS, particularly in looking at the trends for different commodities such as those discussed by Dave Menzie (p. **48**, this volume). The USGS also needs to think about where it is heading scientifically as well, and where and when to focus attention on a particular problem. For example, what will be the impacts of development in PRC on $CO_2$ emissions from cement production and coal burning? What trace materials might go into the atmosphere? Researchers also need to consider water as a commodity, particularly using examples from other countries where water is in short supply.

## Why What We Do is Important: Reaching and Exceeding the Workshop Goals

Harvey L. (Lee) Case, Theme Coordinator, Natural Resources, USGS, summarized the workshop. He revealed from his perspective that it was an absolutely outstanding workshop. His evaluation was based on looking back at what the organizers intended to do when they started the course of the workshop. They put together the proposal to sell the workshop as a good idea. Now, we ask ourselves after it is completed whether or not they really did what they said they would do. In reviewing the announcement for the workshop, there are some phrases that tell us what was intended.

This workshop brought together principals from the USGS, other Federal agencies, industry, academia, and international organizations to discuss roles of the USGS in materials and energy flows research. The participants identified problems and explored partnerships by:

- Examining the importance of materials and energy flows in United States and global economies
- Reviewing national goals and policies that are based on materials and energy flows and sustainability precepts
- Envisioning integrated approaches to materials and energy flows research

The plenary sessions provided:

- Background and tutorial on materials and energy flows, sustainability, industrial ecology, and related topics
- Alternative views on the roles of participants in materials and energy flows research
- Potential directions and opportunities for research in materials and energy flows

The breakout sessions provided:

- A forum for individuals across all divisions of the USGS, other Federal agencies, private companies, universities, and disciplines to express their thinking on concepts of materials and energy flows, sustainability, industrial ecology, and related subjects
- Deliberations on the various roles of industry, academia, and government in materials and energy flow research
- Reviews of current research directions and future research agendas
- Identification of roles and opportunities for the USGS in materials and energy flows research

Participants here met, reached, and, in most cases, exceeded each of these goals. In that regard, Case acknowledged that what the participants were doing here is important, and it is also important for them to recognize that. It is okay for the speakers and audience to tell themselves that. The earlier comments about outreach, and this workshop as an example of outreach, are absolutely on the mark.

For the future, each participant has a responsibility to let others know what materials flow is all about, and why it is important. The challenge is not to let fade the energy, the enthusiasm, and the synergy that was felt over the past few days. Each participant must commit to follow-up, even if that is to make only one phone call to another person to talk about the experience here. If this is done, the effort becomes even more of a success.

Case thanked all participants for their energy, their time, and their active engagement in making the workshop a success.

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# Appendix 1. Workshop Announcement and Agenda

## Science, Sustainability, and Natural Resources Stewardship—The USGS and Research on Materials and Energy Flows

## A National Workshop, November 3-5, 1998

USGS National Center
12201 Sunrise Valley Drive
Reston, Va.

### Announcement

The U.S. Geological Survey (USGS) provides information on the use and flow of materials in the U.S. and world economies. The USGS also seeks to identify areas where adverse impacts of these flows could be minimized through enhanced efficiencies, such as materials recycling, reducing wastes at the source of extraction, and creative waste management.

Materials flow research can provide insights into how the use of materials affects society, the economy, and the environment from extraction through production, consumption, disposition, and losses or dissipation to the environment. It also seeks to define the relation of materials flow to energy inputs. Identifying these patterns provides a framework for identifying future materials and energy requirements, and for understanding long-term issues of resource supply and waste management. The approach also aims to inform policy makers and the public on issues related to materials and energy flows, as well as the effects of consumer decisions.

Understanding the entire system of materials and energy flows and related trends can help society better manage the use of natural resources and protect the environment. It also can motivate societies to increase economic efficiencies and improve the life span of the products they design, thereby encouraging technological innovation. In this context, universities, private-sector institutions, and all levels of government are focusing on new roles in comprehensively researching environmental systems. The emerging field of Industrial Ecology provides insights for assessing these roles.

Industrial Ecology studies the flows of materials and energy for industrial and consumer activities and their effect on the environment, as well as the economic, political, regulatory, and social factors that influence the transformations of resources. Practitioners in the field seek to organize thinking about the massive, systematic transformations of materials and energy in modern economies, and provide a framework within which to improve knowledge and decisions about materials and energy use, waste reduction, and pollution prevention.

The sustainability of the human population and our life-support system depends upon an extraordinarily complex interplay of factors affecting the availability and use of water, air, soils, land, energy, and minerals. Comprehending this interplay will require new ways of documenting, surveying, monitoring, modeling, and understanding Earth systems as a whole. The USGS, with its broad geoscientific expertise in biology, cartography, geology, hydrology, and information systems, is an agency well suited to provide leadership in many of these tasks.

This workshop brings together principals from the USGS, other Federal agencies, industry, academia, and international organizations to discuss roles of the USGS in materials and energy flows research. The participants will identify problems and explore partnerships by (1) examining the importance of materials and energy flows in United States and global economies; (2) reviewing national goals and policies that are based on materials and energy flows and sustainability precepts, and (3) envisioning integrated approaches to materials and energy flows research.

Plenary Session Presentations: The goals of these presentations are to provide (1) background and tutorial on materials and energy flows, sustainability, industrial ecology, and related topics; (2) alternative views on the roles of participants in materials and energy flows research; (3) potential directions and opportunities for research in materials and energy flows.

Breakout Sessions: The goals of the breakout sessions are to (1) provide a forum for individuals across all divisions of the USGS, other Federal agencies, private companies, universities, and disciplines to express their thinking on concepts of materials and energy flows, sustainability, industrial ecology, and related subjects; (2) deliberate on the various roles of industry, academia, and government in materials and energy flow research, (3) review current research directions and future research agendas, and (4) identify roles and opportunities for the USGS in materials and energy flows research.

Facilitation and Reporting: Recorders will compile the proceedings of the plenary sessions. Facilitators will help guide the breakout sessions, and compile the results for reporting back to the plenary audience. A writing team will compile all plenary and breakout session results and other contributions, and prepare a summary report.

Displays: There will be several poster displays in the vicinity of the auditorium to provide additional information about USGS activities in materials and energy flows, and to serve as catalysts for informal discussion and interaction. Participants are invited to bring display materials, and should advise the workshop coordinators about their intentions to have a display and about their setup needs.

## Agenda

### Tuesday, November 3, 1998—Plenary Session

7:30–8:30 ***Registration***

8:30 ***Welcome and Introductions***
Katherine F. Lins, Eastern Regional Director, USGS

8:40 ***Opening Remarks and Presentation of Speakers***
Thomas J. Casadevall, Acting Director, USGS

9:15–11:30 **Background and Tutorial on Materials and Energy Flows, Sustainability, Industrial Ecology, and related topics**

9:15 ***Introduction to Industrial Ecology***

Robert H. Socolow, Director of the Center for Energy and Environmental Studies, Princeton University

9:45 ***Concepts of Materials and Energy Flows***

Iddo K. Wernick, Columbia Earth Institute, Columbia University

10:15 **Break**

10:45 ***Central Role of Earth Science Concepts and Importance of Ecological Footprints in Understanding Sustainability***

A.R. "Pete" Palmer, Chairman, Critical Issues Committee, Geological Society of America

11:15 **Audience Reaction/Question and Answer Session—** Facilitator

11:30 1:00 **Lunch**

1:00–2:00 **Plenary Session—Background and Tutorial on Materials and Energy Flows, Sustainability, Industrial Ecology, and related topics**

***Overview and presentation of speakers***

Kathleen M. Johnson, Acting Program Coordinator, Mineral Resources Program, USGS

1:00 ***The Role of Federal Science in Materials and Energy Flows Research***

Mark Schaefer, U.S. Department of the Interior, Office of Policy and Analysis, Water and Science

1:30 ***Sustainability and Materials Flow Issues in USGS Ecosystem Studies***

Sarah Gerould, Program Coordinator, Integrated Natural Resource Science Program INATURES, USGS

2:00 ***Nitrogen in the Upper Mississippi Valley, Water Quality, and Hypoxia in the Gulf of Mexico: A Materials Flow Example***

Donald Scavia, Senior Scientist, National Ocean Service, National Oceanic and Atmospheric Administration

2:30–3:00 **Break**

3:00–4:30 **Plenary Session—What are the major issues in materials and energy flows?**

3:00 ***From a research perspective?***

Cutler J. Cleveland, Center for Energy & Environmental Studies and Department of Geography, Boston University

3:30 ***From a policy perspective?***

David Rejeski, U.S. Executive Office of the Council on Environmental Quality

4:00 ***From a corporate perspective?***

Dean A. Drake, Manager, Regulatory Systems, Public Policy Center, General Motors Corporation

7:00–9:00 **Joint Reception with participants of the *USGS Workshop on Enhancing Integrated Science,* Sheraton Reston Hotel, 11810 Sunrise Valley Drive, Reston, Va.**

## Wednesday, November 4, 1998—Plenary Session

8:00 ***The Council on Environmental Quality (CEQ) Interagency Workgroup on Industrial Ecology, Materials and Energy Flows***

David Berry, Interagency Working Group on Industrial Ecology, Material and Energy Flows, and Theodore Heintz, Office of Policy Analysis, U.S. Department of the Interior

8:30 ***National Research Council Workshop on Material Flows Accounting of Natural Resources, Products, and Residues in the United States, January 1998***

Craig M. Schiffries, Director, Commission on Geosciences, Environment, and Resources, National Research Council

9:00 ***Federal Committee on Environment and Natural Resources (CENR) FY2000 Initiative on "Integrated Science for Sustainable Ecosystems"***

Dennis B. Fenn, Chief Biologist, USGS

9:30 **Break**

10:00 ***The U.S. Environmental Protection Agency and Materials and Energy Flows***

Derry Allen, Office of Policy, Planning, and Evaluation, U.S. EPA

10:30 ***Materials Flow in Industrialized Nations—A Framework for Physical Accounting***

Eric Rodenburg, World Resources Institute

11:00 ***International Perspective—The Wealth of Nations***

Kirk Hamilton, Environment Department, The World Bank

11:30–1:00 **Lunch**

1:00–2:00 **Plenary Session**

1:00 ***Applying Industrial Ecology: Linking Materials and Energy Flows to Economic Development Strategy***

Edward Cohen-Rosenthal, Director, Work and Environment Initiative, Cornell University Center for the Environment

1:30 ***Issues in Materials and Energy Flows in the Earth Science Century***

Steven R. Bohlen, Associate Chief Geologist for Science, USGS

2:30–4:30 **Breakout Sessions**

Breakout groups will provide reaction and additional points of view to complement questions posed in the Tuesday and Wednesday plenary sessions.

- What are the major issues in materials and energy flows from a policy perspective?
- What are the major issues in materials and energy flows from a corporate perspective?
- What is the status of research on materials and energy flows by and among universities, industry, and governments?
- What contribution could the USGS make to materials and energy flow issues?

(Additional questions will be posed by breakout group leaders at the Workshop.)

## Thursday, November 5, 1998—Plenary Session

8:00–9:00 ***Reports of the Breakout Groups***

Reporters & Facilitators

9:00–11:30 **Research activities and opportunities—Integrated science and interdivisional opportunities in the USGS**

9:00 ***The Relation between Nutrients and Materials and Energy Flows in the Chesapeake Bay System***

Scott W. Phillips, Principal Investigator, Chesapeake Bay Ecosystem Program, USGS

9:30 **Break**

10:00 ***Merging Economic Modeling with Energy, Minerals, and Other Research Programs***

Gene Whitney, Chief Scientist, Central Energy Resources Team, USGS

10:30 ***The Role of Water in Materials and Energy Flow Processes, and as a Material***

Wayne B. Solley, Chief, Branch of Water Use Information, USGS

11:00 ***Minerals and Materials Analysis in the USGS***

W. David Menzie, Chief, International Minerals Section, Minerals Information Team, USGS

11:30–1:00 **Lunch**

1:00–3:30 Plenary Session

1:00 ***Baltimore-Washington Regional Spatial Dynamics: Human Impact Animation***

Gilpin R. “Rob” Robinson, Jr., Eastern Mineral Resources Team, USGS

1:30–3:30 **Panel Discussion—Potential directions and opportunities for research in materials and energy flows**

***Moderators:*** Lee Case, Resource Theme Coordinator, USGS, and Marty Power, Program Scientist, Mineral Resources Program, USGS

***Panelists:*** Susan D. Haseltine, Deputy Chief Biologist, Science, USGS/BRD; David A. Kirtland, Global Change Program, USGS/NMD; Dennis J. Sulam, Regional Staff Hydrologist, Northeast Region, USGS/WRD; Geoffrey S. Plumlee, Chief Scientist, Central Mineral Resources Team, USGS/GD

***Suggested panel topics:*** Hidden flows; Efficiency improvements; Redesign of materials and various materials and energy flows processes; Materials and energy flows across political boundaries; Leakages in the materials flow stream & consequences thereof; Remote effects of consumption; Adequacy of assumptions about sources and drivers of materials and energy flows; Analyzing proposed solutions: recycling, remanufacturing, redesigning, and rethinking; future directions for the USGS; other topics.

3:30–4:00 **Summary and Closing**

***Summary statements***

William M. Brown, USGS

***Closing remarks***

Lee Case, Resource Theme Coordinator, USGS

**Steering Committee:**

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William M. Brown, USGS, Geologic Division, Minerals Information Team

Virginia Burkett, USGS, Biological Resources Division, National Wetlands Research Center

Thomas M. Gunther, U.S. Department of the Interior/ Assistant Secretary—Water and Science

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Workshop Web Page URL:
**http://minerals.cr.usgs.gov/misc/mit/workshop-1.htm**

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