3/6/01

BRIEFING PAPER ON INDUSTRIAL ECOLOGY AND EPA

Focusing on the Environment from the Point of View of Resources, Products, Industrial Systems and Eco-efficiency

EPA Industrial Ecology Workgroup
March 2001

About This Paper

This briefing paper is for people inside and outside the U.S. Environmental Protection Agency (EPA) who want to learn more about the emerging concept of Industrial Ecology and some of the opportunities to apply it at EPA. It develops several themes that were discussed at the EPA Industrial Ecology Workshop, held in November 1999 and chaired by five EPA senior career executives.

The paper was drafted by the EPA Industrial Ecology Workgroup, the interoffice team that organized the 1999 workshop (see roster in the Addendum), and has been reviewed by many of the workgroup's colleagues. It includes many quotes and references from academic, business, non-government organization (NGO) and government sources, both to give the reader a sense of what different people have had to say on this topic and to help the reader explore the topic further. The opinions and recommendations concerning possible agency policy are from the workgroup, based on the sources cited. The workgroup welcomes comments and hopes to spark an active dialogue.

The paper begins with a six-page stand-alone Introduction and Executive Summary. The main paper is organized in three parts: 1. Three Challenges to EPA As We Begin A New Century, 2. The Opportunities Presented by Industrial Ecology: A Primer, and 3. A Possible Industrial Ecology Action Strategy for EPA. There is also an appendix: "Industrial Ecology and EPA: Report on the EPA Industrial Ecology Workshop."

Abstract

Industrial Ecology (IE) is a systems approach to efficient resource use and protection of the environment. Instead of just devising improved methods of waste treatment and disposal, we look for the best opportunities to reduce waste throughout the total material cycle from virgin materials to finished products to end of product life. Instead of controlling industrial pollutants from different sources one by one at different times and with different technologies, we try to look across whole facilities, regions and even whole industries and make changes wherever in the system it is most effective to do so.

Many thoughtful observers in the research and private and public sectors are now saying that IE approaches are our best and in some cases our only opportunities to bring about further significant environmental improvement. They conclude that tinkering with the present approach is not enough. EPA's programs should seek the most effective places to improve resource efficiency and product stewardship with incentives, information and regulatory flexibility. EPA should encourage more facilities to emulate those that have voluntarily become much more resource efficient where it is already profitable. They also conclude that due to knowledge gaps and disincentives, this effort will require coordinated government action and that EPA should play a major leadership role.

Staff from around EPA have been considering this suggestion. They firmly envision that Industrial Ecology approaches should guide and supplement but not replace current regulatory programs. They have also found that there is a base of EPA activity and program ideas on which to build. This paper recommends five steps to get started, each of which can be done under current laws: (1) Familiarize key groups with the concept of IE. (2) Lay the data/information foundation for IE. (3) Ask each headquarters and regional office to make appropriate commitments to pursue IE approaches. (4) Work with other agencies of federal, state and local government, as well as foreign governments and organizations outside of government. (5) Set specific goals and expectations and measure progress.

Introduction and Executive Summary

Background

EPA's 30-year regulatory strategy has led to some dramatic reductions in air, water and land pollution. As successful as this strategy has been, there is now increasing evidence that in order to protect our progress and advance on the unfinished tasks we need to take a fresh look at our programs and build on some promising developments in the public and private sectors.

Our present environmental strategy was not designed to deal directly with issues of sustainability, growth and change in population, the economy and resource use, nor to take into account our growing understanding of the environment as a system rather than a collection of individual components, both natural and manmade. It is clear, as two scholars recently observed, that "attempting to meet the world's future consumption by simply doing 'more of the same' will accelerate ecosystem degradation and will undermine the very productivity we are striving to increase."[i] It is not even clear that doing the same thing better will help significantly.

Sensing this situation and the need for a simple but broadly applicable and visionary concept that can direct useful insight and incentives, a growing number of public and private sector stakeholders say that the emerging concept of Industrial Ecology (IE) has much to offer.

Industrial Ecology

Industrial Ecology looks at the natural environment and human activity as an ecosystem, focusing on material and energy resources and how they move and change as products and wastes. It looks at the flows of resources from extraction through manufacturing, product use, reuse and return to the environment and examines the combined effect of all these steps on the environment. (See Figure 1, "The Flow of Resources.") In this context, waste is a wasted resource. Simply put, *"Industrial Ecology is about stuff"* and *"Industrial Ecology is about systems and overcoming policy fragmentation."*

By looking at resources and products, both generally and individually, IE encourages us to look more broadly than we often have in the past for solutions to environmental problems and risks. It also yields insights and encourages changes that can benefit the economy as well as the environment. "Eco-efficiencies" (for economy and ecology) are win-win opportunities. An economy that uses materials and energy much more efficiently than we do now can also be a more profitable and productive economy. But this is unlikely to happen as fully as necessary without policy and program changes. The new government role may be to provide incentives, information, and regulatory flexibility for system changes and product stewardship more than to focus primarily on regulating "end-of-pipe" emissions from individual sources.

There are many formal definitions of Industrial Ecology, but most people who use the term would agree that:

Figure 1
The Flow of Materials

Industrial Ecology is a systems approach to efficient resource use and protection of the environment. Instead of just devising improved methods of waste treatment and disposal, we look for the best opportunities to reduce waste throughout the total material cycle from virgin materials to finished products to end of product life. Instead of controlling industrial pollutants from different sources one by one at different times and with different technologies, we try to look across whole facilities, regions and even whole industries and make changes wherever in the system it is most effective to do so.[ii]

Defined in this way, Industrial Ecology offers important insights into three major challenges facing the agency and its programs:

1. How can the U.S. achieve sustainable material and energy resource use in the face of population and economic growth? Our current programs were not designed to reach that goal and will not do so.

2. How can the U.S. take advantage of new developments in the economy and technology as we seek to achieve sustainable use of resources? During the past few years, a number of companies have begun to demonstrate that they can greatly increase the efficiency with which they use materials and energy. The "new economy," dominated by the information and service industries, has also opened up new opportunities.

3. How can the U.S. become and benefit from being an environmental policy and product leader rather than a follower in the global marketplace? How we use materials is becoming an important issue in this context.

Industrial Ecology is a broadly applicable concept because many environmental problems can be associated with one or more stages of the flows of materials or energy. The efficient use of resources at one stage often leads to environmental improvements in several stages. IE views members of industrial and consumer sectors (including large and small sources, the service sector, government facilities and operations, agriculture, land use, development and construction, etc.) as an ecosystem with system dynamics that extend beyond the individual components.

Put differently, IE draws attention to certain physical opportunities to improve the environment. Most of these opportunities are not conceptually new but until recently they have been largely neglected as we have instead focused our attention on policies and technologies to address particular issues of pollution control by facilities for the air, water and land. Looking at whole systems involving resources and products helps point the way towards the most effective places to make changes. It also draws attention to the effects of specific interventions on the whole system and helps us avoid consequences that we might otherwise overlook.

Many thoughtful observers in the research and private and public sectors are now saying that IE approaches are our best and in some cases our only opportunities to bring about significant environmental improvement and progress towards sustainable resource use in a cost-effective (and even profitable) manner. They conclude that tinkering with the present pollution control system is not enough to do the job. Instead, EPA programs should seek the most effective places at which to intervene in the flows of materials and energy and create incentives that will harness the power of private decisionmaking to improve resource use. In so doing we will encourage more people and facilities to emulate those that have already voluntarily become much more resource efficient, as they have discovered how to turn waste streams into profit streams.

These observers also conclude that because of knowledge gaps and disincentives that are the products of public policy and patterns of private ownership this effort will require coordinated government action and that EPA should play a major leadership role. Without this effort many companies will not follow the leaders and some kinds of changes that depend on regulatory reforms or industry-wide actions will never get made by any people or companies.

It is important to point out that even the strongest proponents of IE do not suggest that it should replace our current regulatory programs. IE approaches should guide and supplement our regulatory programs. A strong regulatory program will preserve a level playing field. While there is room for improvement in our current regulatory programs, they will always be needed to protect against some sources of environmental degradation and to deal with some members of the regulated community. But the pressures of population and economic growth will not allow us to make progress if we confine ourselves to this approach. We need a multipronged strategy. IE approaches can help EPA determine where to build flexibility into its regulations and they can help facilities to meet regulations more efficiently.

As a physical approach to the environment, Industrial Ecology helps us determine <u>what</u>

trends in resource use we actually want to see facilities and individuals pursue to protect the environment, rather than how we try to get them to change their behavior. Therefore, Industrial Ecology is complementary to institutional approaches, both regulatory and nonregulatory, where we have lately directed most of our environmental policy attention. EPA's recent reports, Aiming for Excellence: Actions to Encourage Stewardship and Accelerate Environmental Progress and Innovation at the Environmental Protection Agency: A Decade of Progress, and the National Academy of Public Administration's recent report, Environment.gov: Transforming Environmental Protection for the 21st Century, are among several excellent recent discussions of these efforts.[iii] IE can help guide our efforts at regulatory reform, partnerships, empowerment, incentives, better information, research and transformed agency culture and structure. It is a way of giving specific substantive direction to many of our current policy initiatives as well as new initiatives that we might develop. Indeed, each of these activities can be harnessed in an Industrial Ecology Action Strategy for EPA.

A Possible Industrial Ecology Action Strategy for EPA

If EPA decides to move in the direction of Industrial Ecology, there is a base of activity and program ideas with which to begin. We are fortunate to be able to build on some initiatives that are already starting to yield some exciting results.

Sensing the opportunities for EPA, 150 people from across EPA, other government agencies and non-government institutions gathered in November 1999 to consider how the principles of Industrial Ecology might be applied by EPA. After two days of discussion and many specific suggestions, four major themes emerged:

1. The principles of Industrial Ecology appear to offer current EPA programs and the industrial community many specific opportunities - some would say the best opportunities - to bring about significant environmental improvement and progress towards sustainable development in a cost-effective manner.

2. Industrial Ecology is consistent with EPA's recent innovation initiatives, but its full implementation would take us beyond what we are presently doing.

3. IE can be incorporated into ongoing programs and budgets.

4. EPA has many interested potential IE partners in the federal, industrial and research communities, such as those who participated in the workshop.[iv]

Several types of tools and approaches appear to offer special opportunities to EPA (see Figure 2). In each case, the agency already has some activity under way, but the current efforts would need to be greatly expanded in order to match the challenges to EPA cited above. Another characteristic of these activities is that most of them are non-regulatory, relying on the tools of incentives, information and regulatory flexibility. It also turns out that the climate program has worked with many of these approaches.

Figure 2
Sample Tools and Methods That Can Contribute to Industrial Ecology at EPA

Tool or Method	**Scale**	**Use**	**Potential EPA Role**
Material and Energy Flow Studies	Global, national, regional, company	Highlight areas for improvement and help identify the best points for intervention.	Develop data framework. Collect, exchange and manage data. Develop policy approaches drawing on this data.
Dematerialization	National, regional, company, product	Reduce the quantity of material used for a product, company, region, or nation.	Develop incentives or otherwise encourage this activity.
Eco-industrial Parks	Regional, local	Reduce waste through symbiotic materials use.	Develop incentives or otherwise encourage this activity.
Full Environmental Cost Accounting	Company, product	Internalize environmental costs which may previously have been attributed to overhead.	Develop incentives or otherwise encourage this activity. Develop model systems and collaborative efforts with other agencies.
Environmental Management Systems; energy conservation (e.g., Energy Star)	Company	Improve environmental and energy planning and performance within an organization.	Develop incentives or otherwise encourage this activity. Develop model systems that incorporate IE approaches
Performance Track, Project XL, EPA/ ECOS Agreement	Company	Encourage innovation and better environmental performance.	Specifically encourage Industrial Ecology approaches as a criterion for participation.
Life Cycle Inventory, Assessment and Design (LCA)	Product	Highlight areas for improvement. Enable material comparisons.	Collect and maintain data. Work with industry leaders and software makers to develop tools.
Design for Environment (DfE)	Product	Assist in designing products with better environmental qualities.	Work with industry leaders to develop tools.
Product Stewardship, Extended Product Responsibility (EPR), Product Takeback	Product	Reduce waste by product design and assigning product end-of-life responsibility.	Explore mechanisms. Work with states and other countries.
Regulatory Reform, Economic Incentives, Gov't. Procurement	National, company, product	Remove regulatory barriers to IE; align incentives	Review regulations and current incentives/disincentives and make changes where necessary.

The full list of activities that people have suggested that EPA undertake is too long and too detailed to begin all at once. The EPA Industrial Ecology Workgroup recommends five general steps to get started. Each of these steps can be undertaken with current authorities. There is a role for legislation, but the topic needs more study before specific legislative proposals can be recommended.

1. Familiarize key groups with the concept of Industrial Ecology and encourage them to think creatively and opportunistically about how to apply it. Top EPA managers should talk about Industrial Ecology with each other, to EPA staff and to people outside the agency. Visioning of the future, such as is being done by a working group from the EPA Office of Solid Waste and several state environmental agencies with their draft white paper, "Beyond RCRA: Prospects for Waste and Materials Management in the Year 2020," can be very useful.[v] Other programs can make similar efforts.

2. Lay the data/information and science foundation for Industrial Ecology. This step is critical and will help us set priorities. There are several efforts underway now to fill our information gaps, and more are needed, particularly in the areas of materials and energy flows and life cycle assessment of products. Interagency, international and private sector cooperation will be vital.

3. Ask each headquarters and regional office to identify a limited number of important environmental problems and make appropriate commitments to pursue Industrial Ecology approaches. There is room for much creativity. The commitments should include expanding current efforts to identify and eliminate EPA's unintentional disincentives to efficient use of resources as well as starting new initiatives that will help programs accomplish their environmental goals. Among multimedia programs, the Stewardship Track initiative has excellent potential to encourage IE approaches. Government procurement is another potentially important tool.

4. Work with other agencies of federal, state and local government, as well as foreign governments and organizations outside of government. Consider a joint initiative with other agencies interested in economic and resource efficiency, touting the direct, tangible benefits to industry. Encourage states to innovate. Seek advice from industry. This is not a job that EPA can do alone. But EPA is in an excellent position to provide a vision, analysis and a plan for how Industrial Ecology approaches can be used to improve the environment along with promoting the missions of these other agencies.

5. Set specific priorities, goals and expectations and measure progress. The commitments from HQ and regional offices should include development of appropriate indicators and progress measures, including measures of environmental results. Celebrate and reward staff for successful completion of important milestones.

This review of Industrial Ecology and EPA demonstrates that IE is entering the mainstream of thought and action in many circles outside EPA and that many of the tools and techniques that one would associate with IE are also becoming widely accepted. What remains is for IE to become part of the mainstream of EPA planning and programs.

We have only the outlines of the task ahead. We need to do much more analysis and planning to determine the best ways to apply IE principles at EPA and we need a full dialogue with all affected parties. Hopefully this paper will stimulate that process.

Part 1

Three Challenges to EPA As We Begin A New Century

Three challenges to EPA stand out as we begin a new century: 1. How can the U.S. achieve sustainable material and energy resource use in the face of population and economic growth? 2. How can the U.S. take advantage of new developments in the economy and technology as we seek to achieve sustainable use of resources? 3. How can the U.S. become and benefit from being an environmental policy and product leader rather than a follower in the global marketplace?

1.1. How can the U.S. achieve sustainable material and energy resource use in the face of population and economic growth?

While the reduction of immediate risks to human and ecological health will always be an important goal for EPA and the society at large, many people now believe that sustainable resource use should be the primary long term goal for environmental policy. In 1992, world leaders participating in the Earth Summit declared their commitment to this goal. Describing their understanding of this issue, the leaders at the Earth Summit stated in their “Agenda 21" report that “a principal cause of the continued deterioration of the global environment is the steady increase in materials production, consumption and disposal.”[vi] Since that report was published, this issue has been the subject of intense discussion. In response, governments around the world, including the U.S., have begun to acknowledge the goal of sustainable material and energy resource use and have struggled with how to address it in meaningful ways.[vii] In general, governments have had a difficult time with this task.

A few key numbers convey the general context for thinking about specific resource flows. The total material requirements of modern industrial economies have been estimated at 45-85 metric tons per person per year. Slightly less than half of this amount ends up in products and the rest is in “hidden flows” - usually not reported in economic statistics - required to produce those products.[viii] Over the next 50 years, world population is expected to grow 50%, global economic activity is expected to grow 500% and global energy and materials use is expected to grow 300%. Researchers are now beginning to understand the flows of individual resources and the different impacts they have on the environment. Looking at these general and specific analyses, the leaders of five leading research institutes in the United States, Germany, Japan, Austria and the Netherlands to state that “unless economic growth can be dramatically decoupled from resource use and waste generation, environmental pressures will increase rapidly.”[ix]

A new study by these groups, published by the World Resources Institute (WRI), also finds that “the United States is exceptional in generating larger material flows than might be expected from the size of its economy, even when hidden flows are excluded.”[x] The same appears to hold true on a *per capita* basis. With less than 5% of the world’s population, the U.S. consumes about 10% of the agricultural materials, 13% of the metals, 23% of the coal, 25% of the oil, 28% of the forest materials and 34% of the minerals.[xi]

In most cases, the materials and energy problem does not appear to be an issue of supply, at least yet. New technologies and discoveries have so far averted or delayed many of the past predictions about shortages, although it is clear that the Earth is not an unlimited source of materials. Rather, the most pressing issue we are facing now often seems to be the capacity of the Earth - the air, the water and the land - to absorb the wastes that are created by the whole life cycles of resources. Most materials that are extracted end up being redeposited into the environment, often very quickly. The WRI study found that “material outputs to the environment from economic activity in the five study countries range from 11 metric tons per person per year in Japan to 25 metric tons per person per year in the United States.” The amount triples when “hidden flows” are counted.[xii] U.S. *per capita* generation of solid waste increased 65% in the 25 years from 1970 to 1995.[xiii] Another surprising finding in the WRI study is that, measured by weight, “the atmosphere is by far the biggest dumping ground for industrial wastes,” an indication of how much energy we burn. The same study also found that the trip from extraction to disposal is quick for many materials. “One half to three quarters of annual resource inputs to industrial economies are returned to the environment as wastes within a year.”[xiv]

It is important to recognize that information about aggregate tons of many different resources is useful for setting a context and vital for understanding trends of total resources being used and introduced into the environment, but that it is not by itself detailed enough to use as a basis for many types of public policy. The WRI database contains information on 450 materials. Information about specific materials can be very useful for policymaking. For instance, information from this database about how the use of arsenic in wood preservatives has increased in the last two decades, thus creating a potential danger to the environment as the wood ages and reaches the end of its use, has raised policy interest.[xv] Further study of other flows will most likely point to additional issues which have not previously been recognized -- issues which may or may not be subject to some form of public policy and which may deserve attention.

Our current environmental system was simply not designed to deal directly with issues of change in population, the economy and resource use. Even if it worked perfectly it would not bring us to a point of sustainability. This is a major challenge which EPA shares with the nation and the world at large. The National Academy of Public Administration made a similar point in its recent report, Environment.gov: Transforming Environmental Protection for the 21st Century. While they were speaking generally and not specifically about Industrial Ecology, they stated, “[B]ecause so many of the causes of environmental harm are outside EPA’s regulatory authority, even universal compliance with existing standards will not deliver the environmental improvements Americans profess to want.”[xvi]

Reflecting on the challenges presented by resource use and disposal, the World Resources Institute has observed, “in many cases, wasteful, inefficient or short-sighted production and consumption patterns are putting at risk whole ecosystems, disrupting their normal functioning and reducing their potential productivity, now and for the future. This is perhaps the most unsustainable aspect of human economic activity today."[xvii] Robert Shapiro, former CEO of Monsanto, has concluded, "the Earth can't withstand a systematic increase of material things. If we grow by using more stuff, I'm afraid we'd better start looking for a new planet."[xviii]

1.2. How can the U.S. take advantage of new developments in the economy and technology as we seek to achieve sustainable use of resources?

During the past several years, a number of companies have discovered ways to do what was previously thought to be improbable or even impossible. By reexamining their businesses and considering the consequences and costs of the resulting flows of materials and energy, they have built new business strategies around greatly more productive use of resources, and in so doing have found ways to make more profit while significantly lightening environmental impact. Having done this mostly on the strength of visionary leadership and not direct government encouragement, they are now challenging government agencies such as EPA to develop new strategies themselves.

The story of Ray Anderson and his carpet company, Interface, Inc., has been well publicized. Interface has cut its waste by over 40% and saved millions of dollars by changing its entire corporate strategy and customer relationships, so that the company can retain ownership of its products and recycle them. By reducing the amount of new carpet it manufactures, Interface reduces many environmental problems. Recently Anderson won a major prize from the National Academy of Sciences for this work.[xix] But there are now many other examples, and whole books are being written on this subject, with hundreds of case studies of real companies and real profits. Livio DeSimone, Chair and CEO of 3M Company, and Frank Popoff, Chairman of the Dow Chemical Company, collaborating with the World Business Council for Sustainable Development, have written one of these books[xx] and businessman Paul Hawken and Amory and Hunter Lovins of the Rocky Mountain Institute have written another[xxi]. The World Business Council for Sustainable Development has also published several important reports on this subject. The most recent report is "Eco-Efficiency: Creating More Value With Less Impact" (August, 2000).[xxii]

One could not conceive of these books being written in the early days of EPA, when the environment and the economy were generally thought to be at odds with each other. Indeed, most companies are not yet at and many are not even near the stage of the companies described in these books. The leading companies are therefore giving us a sense of the opportunities at hand and the challenge we have to help more people and organizations adopt these approaches, or at least not discourage them from doing so.

Recently this movement has been boosted by some firms that have seen the business opportunities in making changes that result in lower greenhouse gas emissions. Energy efficiency and material efficiency involve the same approaches.[xxiii]

The emergence of the "new economy," dominated by the information revolution and by the expansion of the service industries, is also likely to have important consequences for the environment, in ways which are only in the process of becoming understood. The “new economy” is affecting supply chains and networks (they are becoming more global and complex), product development (products are becoming more modular and more frequently designed and tested by computer) and logistics (especially reflecting changes in retail distribution).

Broadly speaking, as information and service become more important sources of value in the economy, relative to natural resources (a major source of value in the “old economy”), natural resources can be used more efficiently and the environment can benefit. Indeed, information and service are two of the tools and strategies that companies are using to make profits and environmental progress simultaneously. Computers that route delivery trucks efficiently save time energy and money. Our challenge is to find more ways to harness this “new economy” for the environment.

At the same time, another aspect of the development of the information and service industries that is often overlooked is that even as they can promote more efficient use of resources, they use resources themselves. Computers and trucks are causing us to use more and more resources each year, both in their manufacture and use. For instance (and ironically), it is widely understood that computers have actually caused us to increase our use of paper. A related challenge is what to do with computers as they quickly become outdated. Computer engineers are now trying to design computers with components that are easier to reuse and recycle.

1.3. How can the U.S. become and benefit from being an environmental policy and product leader rather than a follower in the global marketplace?

Of the three major challenges to EPA, the one that is least understood and appreciated by the public and policymakers is the challenge posed by the global marketplace, especially the governments of our major trading partners in Europe and Japan.

In the global marketplace, how one country uses and regulates resources is important to all the others. No country stands alone when materials and products travel across borders as they move through extraction, manufacturing, use, reuse and disposal.

U.S. environmental policy has traditionally focused on regulation of individual point sources (factories and facilities), looking for ways to improve their performance, minimizing toxic releases by environmental medium (air, water, soil). Recycling is largely governed by the marketplace. In contrast, European Union (EU) countries have focused much more broadly on products, and all aspects of their design, manufacture, use and disposal. In this context, recycling is more subject to government control. Japan’s emphasis on materials and waste minimization is similar in some ways to Europe’s. Japan has recently passed a “Basic Law for Establishing the Recycling-based Society,” and a series of related laws to reduce product waste in a variety of sectors.[xxiv]

Two policy tools are being increasingly employed in Europe: product takeback and tax shifts. EU automobile manufacturers must accept their products back at the end of useful life.[xxv] Electronics manufacturers now face similar requirements, in the form of the proposed European Waste Electrical and Electronic Equipment (WEEE) Directive. Because many of the major car and electronics makers are now global operations (and not just multinational), they are responding to the EU takeback directives in ways that affect the products they sell around the world. Ford has designed a car specifically for European takeback. IBM has a strong recycling program.[xxvi] Manufacturers are uncertain what to expect in the U.S. and as a result are doing what is necessary to comply with regulations from other countries. The U.S. needs to consider what its policies should be here. A coalition of state environmental officials is currently discussing what actions they might initiate on product takeback.[xxvii]

The shift of taxes in Europe from personal income to environmental damage - emissions, energy and consumption - has been under way for a decade. It is happening slowly and with a great deal of debate, but it is happening. Gradually it is shifting the price structure in ways that favor labor and decelerate the use of materials.[xxviii] The principal venue for these discussions is currently the issue of climate and energy.

Two other international efforts are worth noting in this context. The Danish Ministry of Finance recently published an analysis of "Danish Resource Consumption" as part of its Environmental Assessment of the 2001 Government Budget, in order to highlight this issue for the public. The second is Canada's initiation of a program to promote eco-efficiency. While the program is still in its early stages, it involves several government ministries and is aimed at improving productivity and capacity, using voluntary means.[xxix]

These policy changes challenge the U.S. to be a leader rather than a follower in policies affecting resource use as we compete in the global economy. Our products must meet standards imposed by other countries or they will be banned. If our products exceed standards imposed by other countries, they can become more attractive to customers at home and abroad. If we develop better approaches to resource conservation and recycling, our approaches can become the global standard. If not, the global companies will have to follow standards set in other countries, rather than our own. From some points of view, this may not be all bad, because other countries are often stronger on resource conservation than we are, but it is hard to see why the U.S. and U.S.-based companies wouldn't benefit if we were leaders shaping policies to meet our needs rather than followers forced to go along with what others have imposed. One thing is clear, though: our current approach to resource use is not designed to bring us into line with our major trading partners and to make us as competitive or cooperative as we might be over the long run in the changing global marketplace.

Part 2

The Opportunities Presented by Industrial Ecology: A Primer

Industrial Ecology presents important opportunities for the environment, for industry and for the Environmental Protection Agency.

2.1. Opportunities for the Environment

A growing number of observers inside and outside of government believe that the way most people have thought about the physical aspects of the environment for at least the past several decades does not give us the insights we need to address the challenges we face today. Looking at technologies and waste disposal issues one by one offers certain advantages to an agency focused on regulation and enforcement. Such an approach appears to offer simplicity and certainty (although in many cases it hasn't turned out that way).

While we have made considerable progress in solving certain environmental problems using this regulatory approach, we are now at a point of diminishing returns. Moreover, our present approach does not address the large issue of efficient and sustainable use of resources. At the same time we observe that it is getting harder all the time to tighten our "end-of-pipe" emission standards without causing difficult technological, economic and political problems. The opportunities that the current economy presents us are largely occurring outside our government programs, and it is hard to see how many of our current efforts could help significant numbers of people and facilities become more resource efficient. Moreover, any discussions of take-back and tax shifts often simply do not make any sense to people who live in an "end-of-pipe" regulatory world.

We must "think outside the box" that has dominated environmental policy for the past several decades. Instead of looking at technologies and waste disposal issues one by one we need to look at them as a system.[xxx] The elements of this system can be arranged in simplified form as shown above in Figure 1, "The Flow of Resources." Many versions of Figure 1 have been developed by different analysts, some in general form (such as this one), some for specific resources of interest, some with much more detail. However, they all tell essentially the same story. For our purposes, three major points are evident from this diagram:

1. Each stage of the flow of resources can cause emissions to the air, water and/or land. In the past, EPA has addressed each of these emissions from each stage separately, usually at the "end of the pipe."

2. What happens in each individual stage affects what happens in the other stages in the system. For example, product design choices can have a powerful effect on reducing pollution at all stages - extraction, manufacturing, use and disposal. Disposal issues affect manufacturing and ultimately extraction. The system effects can be more powerful than

emission controls or pollution prevention that is focused on only one stage. The systems approach draws our attention to the best overall opportunities to reduce environmental impacts.

3. Closing loops - reuse, remanufacturing, recycling - offers major opportunities. The idea of closing loops is not new: it has been with us for centuries.[xxxi] But where the development of industrial methods has reduced the costs of many materials and where the costs of disposal have have also been low, the flow of materials has frequently been linear, from extraction to disposal. Lately we have begun to advocate more reuse, remanufacturing and recycling. As the steadily increasing volume of our wastes and as recent innovations by some of the more imaginative companies have both begun to demonstrate, we really can make improvements that are much bigger than we previously thought possible. Loops make it possible to skip whole stages - especially extraction and disposal - and the environmental impacts that come with them, although it should be noted that some environmental impacts are associated with reuse, remanufacturing and recycling.

These observations suggest a series of physical changes to flows that can affect emissions throughout the system without resorting to additional “end-of-pipe” solutions. Taken together, these physical changes would dematerialize or decouple materials/energy and the economy. These physical changes are summarized in Figure 3:

Figure 3
Physical Changes to Flows That Can Affect Emissions Throughout the System: Twelve Ways To Dematerialize or Decouple Materials/Energy and the Economy[xxxii]

Between the stages

1. Reuse the product.
2. Remanufacture the product.
3. Recycle the product or byproduct.
4. Locate/move facilities to reduce the transportation (energy use) needed between boxes; consider collocation (eco-industrial parks).

Within each stage

5. Improve extraction.
    a. Extract more useful material from the same source - reduce waste.
    b. Produce renewable resources more efficiently and use them whenever preferable.
    c. Seek ways to improve/restore the natural resource base.
6. Process materials more efficiently - reduce waste.
7. Improve product manufacture.
    a. Produce products more efficiently and make only what is actually needed by customers - reduce waste (lean manufacturing, green manufacturing).
    b. Reduce/eliminate use of harmful substances in production process.

c. Redesign the product itself (Design for Environment, green engineering).
   1. Use less material in the product - make it smaller, more concentrated.
   2. Use different materials in the product - make it more durable, easier to reuse, remanufacture, recycle, upgrade, fix (including modularizing and making replacement parts more available).
   3. Use less harmful materials.
   4. Make the product cleaner to operate and require less energy.
   5. Make the product (and parts) multipurpose - avoid the need for separate products for different purposes and have parts be interchangable.
   6. Enhance the product with service, not more material.

8. Improve use of product.
   a. Get more use from the product - share use, maintain and use it longer, use it for more different purposes.
   b. Use/operate the product in a cleaner manner and with less energy.
9. Improve methods of collection and processing to promote reuse, remanufacture, recycling.
10. Discourage use of waste disposal facilities.
11. Increase energy efficiency at each step.

<u>Beyond the stages</u>

12. Focus on solutions - the services that products are intended to provide, not the products themselves. Rethink what is really needed in the first place and seek different approaches to satisfy the need, perhaps using a different product or method altogether.

<u>Notes</u>:

1. There is overlap between the items in this list.
2. The smaller the loop the more value is retained (reuse retains the most value, followed by remanufacturing and recycling).
3. Upstream actions are usually more efficient/effective than downstream actions.
4. These steps are usually but not always less material/energy intensive compared to current practices.

The individual items on this list are not new. Although some of the technologies, especially for recycling, are being rapidly improved and industries are growing, especially for remanufacturing, most of the items on this list have been understood for a long time. The emphasis on these items in preference to “end-of-pipe” controls is somewhat new, but that is not what is most innovative. Instead, the new thought is that by viewing these items together as a system many opportunities for resource efficiencies and environmental improvement become evident. The properties of a system are different from the sum of the individual components. This way of thinking has important implications for decisionmakers in the private and public sectors.

The understanding of the flows of resources, the recognition that all environmental issues ultimately involve transformations and flows of materials and energy, and the appreciation of the physical opportunities at hand has led to the development of the field of Industrial Ecology. As suggested by the definition in the Introduction to this paper, IE seeks to understand the flows and transformations of materials and energy in the local, regional and global economies, in order to find ways that the public and private sectors can adopt policies and practices that will improve the efficiency and reduce the negative impacts of these flows and transformations. Because IE is an emerging concept, it has a variety of definitions. However, most of the definitions include several common elements:

- IE takes a systems perspective of extraction, manufacturing, use, reuse/recycling and disposal and pays special attention to the interaction of industrial and ecological systems. It can focus on specific materials (e.g. carbon [fossil fuels], nitrogen, arsenic or mercury), products and the resources they use (e.g. batteries or carpets), industries and the resources they use (e.g. autos, chemicals or agriculture) and/or geographic areas at different scales and the resources they use (e.g. New York/New Jersey Harbor, New Jersey, the U.S.A. or the globe).[xxxiii] It applies to both large point sources (e.g., factories) and small nonpoint sources (e.g., farms). It applies to both manufacturing and service industries. IE has been described by some people as a major component in the "science of sustainability."

- Because of its perspective, IE also brings a special point of view to technology and organizational/institutional issues. At the level of public policy, IE can employ both regulatory and nonregulatory tools, such as information. It is generally understood to include but be broader than the commonly understood concepts of Pollution Control, Pollution Prevention (P2), Waste Minimization, Design for the Environment, Eco-Efficiency, energy efficiency, Lean Manufacturing, Environmentally Benign Manufacturing, Sustainable Technology, Life Cycle Assessment, Materials Accounting, Industrial Symbiosis and Eco-Industrial Parks.

IE serves as both a complement to and an extension of Pollution Prevention. According to the Pollution Prevention Act of 1990, P2 is a practice which "reduces the amount of any hazardous substance, pollutant, or contaminant entering any waste stream or otherwise released into the environment (including fugitive emissions) prior to recycling, treatment, or disposal and reduces the hazards to public health and the environment associated with the release of such substances, pollutants or contaminants." Pollution Prevention commonly focuses on individual pollutants at the unit process level, whereas IE examines one or more materials in a system such as a facility, a community, a sector, or a product.

IE also encourages us to think about opportunities that are often overlooked. One set of opportunities that is frequently forgotten is the set of decisions made by individual consumers - the most basic decisions that drive the rest of the flows and transactions. Much has been written about our "materialist," "consumer" society. Only a portion of what has been said contains simple practical advice based on analysis of the full system of material flows. The Union of Concerned Scientists recently published a book on this subject. They noted that "as consumers, we make dozens of decisions every day about what to do or buy, but it is hard to know which of them, if any make a significant difference for the environment."[xxxiv] They go on to point out which consumer decisions in the areas of housing, transportation and food make the biggest difference to the full system of material flows. Work of this nature deserves more attention.[xxxv]

The importance of consumer choice has also been highlighted by advocates for green procurement by government and other large buyers. As the demand increases for products that are made in accordance with IE principles, the costs should come down, making them more accessible to other buyers. The U.S. Interagency Working Group on Industrial Ecology, Material and Energy Flows (including representatives from the Council on Environmental Quality, EPA, and the Departments of Interior, Energy, Commerce and Housing and Urban Development) bases one of its major recommendations on this idea.[xxxvi]

The field of Industrial Ecology has roots that go back many years, but the concept came to the attention of many people in 1989, with the publication of an article in Scientific American.[xxxvii] As the field of Industrial Ecology has grown there have been several important developments. The first textbook on Industrial Ecology was published in 1995.[xxxviii] Shortly afterwards, a peer reviewed journal, the Journal of Industrial Ecology was started.[xxxix] In 1997 a group of researchers from 14 institutions drafted a detailed research strategy for the new field of Industrial Ecology.[xl] On a broad scale, a major reevaluation of environmental policy at Yale University several years ago put industrial ecology as "the centerpiece of a next-generation systems-oriented environmental policy."[xli]

Another indication of the growing interest in IE is the number of professional conferences. In the last several years there have been two week-long Gordon Research Conferences on Industrial Ecology.[xlii] At the most recent Gordon Conference (June 2000) an International Society for Industrial Ecology was launched, with plans to hold its first conference in November 2001. EPA, the U.S. Geological Service, the National Science Foundation and the National Academy of Sciences have all held major conferences on Industrial Ecology in the last two years.[xliii] The U.S. Department of Energy has held discussions on the industry projects that it has initiated employing the IE approach.[xliv] Internationally, the United Nations Commission on Sustainable Development has held important discussions on what it calls "production and consumption," the Organisation for Economic Cooperation and Development (OECD) held two days of workshops on materials flow analysis in October 2000 and the North American Commission for Environmental Cooperation (U.S., Canada and Mexico, set up under the North American Free Trade Agreement - NAFTA) has started a materials flow analysis project as part of its Emerging Trends initiative.[xlv]

The general interest in this topic has fueled activity in several more specific areas, such as Life Cycle Assessment, Environmentally Benign Manufacturing, Design for the Environment, Eco-Efficiency, Lean Manufacturing, Sustainable Technology, Green Chemistry, Green Engineering and Eco-Industrial Parks, leading to a number of conferences, research projects and real-life applications. Many of the leading researchers in Industrial Ecology are university professors and are teaching the subject and related topics to their students. Several thoughtful perspectives on IE are included in Figure 4.

Figure 4
Perspectives on Industrial Ecology

"If Industrial Ecology were an art form, it would be landscape painting. Its aim is to consider the big picture and avoid narrow, partial views. Much conventional environmental analysis, by contrast, is more like portraiture, providing intimate detail on a particular subject. A typical government regulation limits the amount of chemicals a factory can release into a river; it rarely takes into account how those chemicals got there in the first place or what happens to the toxic residues that accumulate in the pollution-control devices." Reid Lifset, Yale University and Editor, Journal of Industrial Ecology[xlvi]

"Eco-efficiency is reached by the delivery of competitively-priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life cycle, to a level at least in line with the earth's estimated carrying capacity." Business Council for Sustainable Development[xlvii]

"It is important to remember that a goal of reducing materials or energy use is not seeking a sacrifice in standard of living or reduction in goods and services provided. By dramatically improving efficiency, extending the service life of materials, and reducing external costs, such as environmental damage, reduced intensity of use can improve the living standard while reducing costs." U.S. Interagency Working Group on Industrial Ecology, Material and Energy Use[xlviii]

Unfortunately, there are no formal estimates of the size of the opportunity to increase the efficiency of our resource use. The best we can do is to look at several examples that indicate the scale of the possibilities.

- In its first three and a half years of effort, Interface, Inc., the carpet maker, reduced total waste in its worldwide business by 40 percent, increased the amount of materials from its own products that it reuses and saved $67 million.[xlix]

- It has been estimated that in the construction of new cars and light trucks, three pounds of non-product materials are mobilized for every pound of materials that ends up in the product. Since the 15 million new vehicles made each year weigh at least 30 million tons, there must be at least 90 million tons of non-product output (waste), for which the companies and customers are paying. Part of this total is paint. Auto companies buy $2 billion of paint each year; about one half of this paint is wasted in the spray process and ends up being buried.[l]

- Researchers have estimated that "the amount of waste generated to make a semiconductor chip is over 100,000 times its weight; that of a laptop computer, close to 4,000 times its weight. Two quarts of gasoline and a thousand quarts of water are required to produce a quart of Florida orange juice. One ton of paper requires the use of 98 tons of various resources."[li] Much of this waste is in the "hidden flows" described earlier. (This type of number is sometimes called the "ecological rucksack" of a product.) In this context it is also important to point out that water flows are often not included in material flow analyses because the amounts can be large and often not of particular environmental interest.

- Several years ago the OECD adopted a long range goal of reducing the material intensity of the economies of member countries by a factor of ten. Using a methodology developed by the World Resources Institute, "that target can be expressed as 30 kilograms per $100 of GDP, compared to the present value of approximately 300 kilograms per $100 of GDP."[lii] This goal is not very sophisticated and in some ways is not very useful, particularly because it does not discriminate between individual materials and the impacts of their flows, but it is simple and it does grab attention.

These numbers are not comparable and they are mostly general rather than specific in their references to resource use, but they begin to give a sense of the scale of the opportunities to improve our efficiency of resource use.

2.2. Opportunities for Industry

The most impressive developments in Industrial Ecology have come from industry. The companies which have led the way find that this approach brings a variety of benefits, all of which are reflected in the bottom line: less cost, less waste, quality improvements, less regulation, better public image and less business risk. One business leader, Samuel C. Johnson, Chairman of S.C. Johnson & Son, Inc., has put it this way: "We aggressively seek out eco-efficiencies - ways of doing more with less - because it makes us more competitive when we reduce and eliminate waste and risk from our products and processes."[liii]

As companies have been trying to pursue the options suggested in Figure 3 and to use resources in ways that are radically more efficient, they have undertaken a number of activities that generally fit the list shown in Figure 5. This is a summary list based on a review of the literature and conversations with business leaders and undoubtably could be expanded.

Figure 5
What Companies/Facilities Are Doing
To Promote Greatly Increased Resource Efficiency

1. Plan for resource efficiency.
   - a. Consider what the customer needs in the first place.
   - b. Benchmark the best operations in a variety of industries.
   - c. Set ambitious "stretch" goals (e.g., DuPont: "Our goal = 0: 0 waste, 0 emissions, 0 excuses." Canberra, Australia has set a goal of zero waste to landfills.)
   - d. Integrate IE into core business processes.
   - e. Incorporate IE into strategic plans and Environmental Management Systems (EMS's).
   - f. Improve access to capital - how companies allocate capital often discourages environmental investments.

2. Manage what comes in - the supply chain.
   - a. Get better information on materials used in parts purchased; view suppliers as an extension of the company.
   - b. Set eco-efficient purchasing standards and conduct training.

3. Run the operation efficiently.
   - a. Promote principles of lean management based on quality.
   - b. Make only as much product as needed and no more, using B2B and B2C systems to help plan production runs.
   - c. Discourage waste of any type.

4. Manage what goes out - the product chain.
   - a. Design products for durability/takeback/reuse/remanufacturing/recycling.
   - b. Facilitate durability/takeback/reuse/remanufacturing/recycling by maintaining ownership and control over the product; lease products rather than selling them.

5. Measure opportunities and results.
   - a. Perform Life Cycle Assessments, integrated formal eco-efficiency assessments.
   - b. Measure for continuous environmental improvement rather than one-time accomplishments; use results for new plans.

A few leading companies are trying many of these approaches, and many companies are trying at least some of them. A thorough survey would probably show a large number of companies, at least in some industries, that are not making any serious efforts in this direction. Undoubtably, all companies could probably be doing more.[liv]

As companies consider these issues, the leaders are rethinking their basic business strategies and futures. Interface's example of leasing its carpet products rather than selling them, in order to facilitate getting them back later is being repeated in a number of other industries, among them copiers, elevators and chemicals. The same approach could be tried in more instances. Imagine, for instance, if this example were followed to a greater extent than it already is in the auto industry; durability and recyclability would certainly increase. The emerging field of nanotechnology (molecular level) also presents opportunities to create new materials with better properties. Better coatings and paints, for instance, could make many products last longer. The opportunities are not limited to companies that make things. Several of the service industries have interesting opportunities for energy conservation, particularly in the area of transportation.

Two general types of barriers stand in the way of many companies that might adopt IE approaches. The first is a knowledge gap. Many companies simply are not aware of the opportunities. The second is a series of disincentives that are the product of public policy and patterns of private ownership. Government regulations and subsidies can have unintended effects that discourage efficient resource use. Also, the fact that many companies operate at only one stage of the flow of resources often hinders them from taking actions that extend to other stages. In this connection, it is interesting to observe the activities of the U.S. Army Industrial Ecology Center, which is able to take a full systems view precisely because the Department of Defense has responsibility that extends across the entire life cycle for military products. It is also interesting to observe that certain waste collection and management companies are reshaping themselves into "resource management" companies, consulting with their clients about how they use materials and sharing in the savings on waste management that they help their clients achieve.[lv]

Reflecting further on the future, Ed Falkman, former Chairman of Waste Management International and also Chairman of the Environmental Commission of the International Chamber of Commerce and the WBCSD Working Group on Sustainable Production and Consumption, notes that "I am convinced as I look forward to the next twenty years that our destiny is to become more of a resource and materials management company."[lvi] Edgar S. Woolard, Jr., former Chairman of DuPont, observes that "During the next quarter century, the most significant net contribution to a greener world will be made by industry.... Industry has a next-century vision of integrated environmental performance. Not every company is there yet, but most are trying. Those that aren't trying won't be a problem simply because they won't be around long term."[lvii]

2.3. Opportunities for the Environmental Protection Agency

Industrial Ecology presents real opportunities to EPA. The opportunities for environmental improvement through greatly improved resource efficiency are illustrated by what the leading companies are finding that they can do. However, most companies have not (yet) adopted these practices, so there have to be many opportunities throughout the economy. <u>These opportunities challenge EPA to create conditions that will encourage companies that are ready to take positive steps on their own and to assist those companies that are not on the leading edge. At a minimum, EPA is challenged to make sure it does not inadvertently discourage greatly improved resource efficiency, especially through its regulatory programs.</u>

As mentioned earlier, because Industrial Ecology is a physical approach to the environment, it helps us determine what trends in resource use we actually want to see facilities and individuals pursue to protect the environment, rather than how we try to get them to change their behavior. Therefore, IE is complementary to institutional approaches, both regulatory and nonregulatory, on which most environmental policy attention has lately been focused. It can guide our efforts at regulatory reform, partnerships and empowerment. It is a way of giving specific substantive direction to many of our current policy initiatives as well as new initiatives that we might develop. It is also quite consistent with recent calls, such as from the National Academy of Public Administration, for EPA to employ market incentives that will help us move away from waste and emissions regulations and encourage process changes.[lviii]

Sensing the opportunities for EPA, 150 people from across EPA and from other government and non-government institutions gathered in November 1999 to consider how the principles of Industrial Ecology might be applied by EPA. After two days of discussion and many specific suggestions, four major themes emerged (see Figure 6).

Figure 6
Principal Themes from the EPA Industrial Ecology Workshop, November 16-17, 1999[lix]

1. *The principles of Industrial Ecology appear to offer current EPA programs and the industrial community many specific opportunities - some would say the best opportunities - to bring about significant environmental improvement and progress towards sustainable development in a cost-effective manner.* EPA takes pride in its multimedia efforts, but the fact remains that, with some exceptions, the agency's policies and programs are generally conceived around only a single stage of the flows of materials and energy, with little attention to the other stages. Recent work in IE challenges EPA to expand its sights, by focusing attention in an organized fashion on the full set of stages when it examines environmental problems.

2. *Industrial Ecology is consistent with EPA's current reinvention/innovation initiatives, but its full implementation would take us beyond what we are presently doing.* The concept of Industrial Ecology is not new to some parts of EPA and to some other organizations, but for many parts of EPA it is clearly a new way of looking at environmental protection. Viewed in one way, IE is traditional systems thinking applied to issues of the economy and the environment, and employed using approaches such as Design for the Environment and life cycle analysis. However, EPA statutes do not typically encourage the agency to think in these terms.

3. *IE can be incorporated into ongoing programs and budgets.* Industrial Ecology is a means to an end and not an end in itself. It is not a prescription or specific set of endpoints. Nor is it the basis of a new program or a new budget item. Rather, it is an approach - a way of thinking. For this reason, modest institutional culture change at EPA is really the key to success. Having made this point, it is also important to note that although many of the actions

recommended at the workshop are not regulatory, IE can significantly augment our current regulatory program.

4. *EPA has many interested potential IE partners in the federal, industrial and research communities, such as those who participated in the workshop.* There are also many individuals in state and local government and non-governmental organizations who are ready to be partners and more can be brought along. Communication among all these groups is critical.

Ideally, EPA's challenge would be to focus solely on finding the most efficient and effective places to intervene in the flows of materials and energy and then to use its own regulatory authorities and convince other government agencies to use their various authorities to encourage greater resource efficiency. However, though, EPA's challenge is bigger, because there are places where our regulations actually appear to get in the way of efficient resource use. These instances are inadvertent but real. Best available control technology approaches, for example, simply were not designed with resource efficiency in mind.

We need to understand this subject better, but no systematic studies seem to have been done. Many knowledgeable observers believe that all of EPA's major programs are implicated and that some of the most important examples may occur due to RCRA regulations. Some analysis of this type has been done concerning barriers to pollution prevention and technology innovation. One such analysis, by the Environmental Law Institute, included five case studies with some interesting conclusions. In each case an examination of the flow of materials shows that current regulations are impeding opportunities to improve resource efficiency, reduce environmental impacts and save money. For instance, in a case involving iron and steel, the study shows that RCRA regulations make the disposal of spent acids cheaper than recycling.[lx]

Another recent report for EPA on Lean Manufacturing sheds additional light on changes in industrial practice and the issues these changes pose for the current regulatory system. Lean Manufacturing is manufacturing with very low waste. By thinking about the scale of production and the flexibility and reliability of machines, and focusing on a continuous flow of production, low inventories and minimum shipping costs, a growing number of companies are showing that it is frequently possible to cut waste dramatically and avoid many environmental impacts that we currently accept. However, the case studies in this report show that the regulatory system has not kept pace with these changes in the manufacturing system and can unintentionally become an impediment to efficiency.[lxi]

Two important recent documents support changing the emphasis of environmental programs in directions consistent with the principles of Industrial Ecology. A draft white paper by a working group from the EPA Office of Solid Waste and several state environmental agencies, "Beyond RCRA: Prospects for Waste and Materials Management in the Year 2020" (previously cited), suggests that we need to think strongly about materials management as we consider the future of government environmental programs. The second document is the "Draft OECD Environmental Strategy for the First Decade of the 21st Century." The document notes that “ecosystems are finite and vulnerable, their capacity as sinks and sources is limited and efficient use of natural resources must guarantee their conservation.” Objective 2 in the Strategy is “Decoupling environmental pressures from growth in economic sectors.” The objective is accompanied by a full set of possible policies and measures for OECD member nations to consider.[lxii]

Reflecting on these opportunities, a new report from the Center for Global Business Research at the University of North Carolina observes,

> Many large corporations are adopting pollution prevention and eco-efficiency (P2/E2) practices that offer the potential for the private sector to move beyond regulatory requirements to reduce or eliminate pollution at the source rather than merely controlling emissions. The federal and state governments can play a crucial role in identifying P2/E2 practices that work well in the private sector, reinforcing through incentives and regulatory relief those companies that adopt beyond-compliance environmental management systems, and helping to disseminate best practices within industries and to small and medium-sized businesses.[lxiii]

Part 3

A Possible Industrial Ecology Action Strategy for EPA

If EPA decides to move in the direction of Industrial Ecology, there is a base of activity and program ideas with which to begin. EPA currently has a number of activities underway that move the agency in directions suggested by Industrial Ecology. Some of these activities are already starting to yield some exciting results. Beyond these activities, there are many other specific activities that people have suggested EPA could undertake to make the principles of Industrial Ecology an important part of its strategy for 2001 and beyond. Some of these ideas have been laid out in detail already, and others are waiting to be developed further. Having a sense of what is on this list gives us an idea of how to get started on a process that will have to evolve over time.

3.1. Current EPA Activities

Without having consciously planned it, EPA has some projects underway that together form the nucleus of an Industrial Ecology effort. This fact was noticed in 1998 by a group of four EPA staff from three offices who came together and created an *ad hoc* EPA Industrial Ecology Workgroup. The initial task that the group undertook was to catalogue significant ongoing projects at EPA that related to Industrial Ecology. This initial list had information concerning 30 projects in just four HQ offices (OSW, OPPT, OP and ORD) and one regional office (Region 2). Figure 2 earlier in this paper is an updated sampling of tools and approaches on which EPA is working now.

Most of these projects were not originally designed as industrial ecology projects *per se*, but simply as useful contributions to environmental protection. Nor were very many of these projects designed with most of the other projects in mind. Still, it is interesting to see that the projects on this list cover much of the industrial ecology spectrum, from large scale issues (regional, national and international issues), to industry issues, to product issues. The list includes projects in the areas of pollution prevention, Design for the Environment, information, sustainable development, "place-based" analyses, waste reduction, energy conservation, Green Chemistry, Life Cycle Analysis and Eco-Industrial Parks. As mentioned earlier, another characteristic of these activities is that most of them are non-regulatory, relying on the tools of incentives, information and regulatory flexibility. It also turns out that the climate program has worked with many of these approaches. The significance of the list is that the projects provide an excellent starting point for future EPA Industrial Ecology efforts. While the ideas of Industrial Ecology certainly do not dominate EPA policymaking, they are also not completely new to the Agency.

The EPA Industrial Ecology Workgroup is now composed of nine people from five headquarters offices and one regional office (see Addendum). It has met nearly every week since 1998 to compare notes and work on several joint projects. It organized the previously mentioned EPA Industrial Ecology Workshop in November 1999, it has sponsored about a dozen seminars on Industrial Ecology for EPA staff and it has arranged speakers for several high-level EPA meetings and conferences. This paper is an effort from the group to bring further focus to the opportunities presented by Industrial Ecology. The specific recommendations and the ideas for getting started that are presented below are a direct product of the process started by this group.

3.2. Specific Recommendations

There are many specific actions that EPA can undertake to follow a path suggested by the principles of Industrial Ecology. For instance, the participants at the EPA Industrial Ecology Workshop in November 1999 generated scores of recommendations to EPA. The workshop report (Appendix 1) lists all these recommendations and groups them into four general recommendations:

1. Assemble and disseminate the information that is needed to support Industrial Ecology approaches.
2. Devise appropriate incentives and other program measures.
3. Answer key questions through focused research.
4. Support necessary organizational culture change.

The workshop participants did not attempt to prioritize the list. The EPA Industrial Ecology Workgroup has subsequently developed its own "top ten" list (see Figure 7), considering the following factors: feasibility, potential impact, dollar costs, people costs, time required, and whether any work is already underway (to minimize startup issues). In this process, the work group combined some of the recommendations, split some others apart and made other minor adjustments. The workgroup did not attempt to create a priority order within the "top ten."

Figure 7
"Top Ten" Industrial Ecology Recommendations for EPA
(As chosen by the EPA Industrial Ecology Workgroup from the recommendations offered at the EPA Industrial Ecology Workshop, November 1999. The numbers in parentheses refer to the recommendations in the workshop report appended to this paper.)

1. Work more intensively with other Federal agencies to promote Industrial Ecology approaches, particularly on information, policy, procurement, taxes, subsidies and sectors. (1.3, 1.7, 2.3, 2.5, 2.6, 3.1, 4.2)

2. Use National Environmental Performance Partnership System (NEPPS) agreements to partner with state environmental agencies: leverage resources, try different ideas. (2.5)

3. Encourage the EPA Science Advisory Board to consider Industrial Ecology issues in their reviews (the SAB Environmental Engineering Committee has taken the lead). (4.2)

4. Help lead international discussions on Industrial Ecology, especially on information and policy. Learn from other countries and do joint research. (1.4)

5. Develop and implement a strategy to gain support of private sector partners. Help firms set targets and share best practices. Recognize leaders (2.4, 2.8)

6. Provide opportunities for government/academic/industry interactions to develop Industrial Ecology innovations, methods, etc. (1.8, 2.8, 2.10, 4.2, 4.3)

7. Apply Industrial Ecology approaches to some significant and high visibility EPA issues, looking for most cost-effective points in the flow of materials for EPA to be involved. (2.1, 2.3, 3.2, 3.3)

8. Increase strategic efforts to apply principles of Industrial Ecology through EPA's industry and sector-oriented programs such as Design for the Environment (DfE), Pollution Prevention (P2), Energy Star, Green Chemistry, Extended Product Responsibility (EPR), Environmental Management Systems (EMS), Project XL, state innovation projects and Performance Track. (2.10)

9. Examine whether our regulations encourage recycling or disposal of resources and make appropriate changes. Support multi-facility regulations based on materials exchanges and on-going eco-industrial development activities (Brownfields, etc.). (2.2, 2.3, 3.1, 3.2)

10. Expand internal EPA communication and training on Industrial Ecology. Help EPA people think "outside the box" about Industrial Ecology approaches, roles, goals. Develop an EPA Industrial Ecology plan and build it into the EPA strategic plan and other GPRA activities, including the development of outcome measures. Follow through with efforts such as "RCRA Vision," and expand the idea to other parts of the agency. (2.10, 4.1, 4.2, 4.3)

Examining the detailed recommendations, there are several points worth observing:

- The recommendations developed at EPA are basically in line with the recommendations from the U.S. Interagency Task Force on Industrial Ecology, Material and Energy Flow[lxiv] and the World Business Council on Sustainable Development.[lxv]

- At every step there is an important role for information and analysis. IE approaches must be information based. Without the proper information base we will not know where our best opportunities lie and we will not be able to measure our progress later. In our analytical work we need to be on continuous lookout for the best places for government intervention, whether by EPA or another agency. In particular, when reviewing our regulatory and non-regulatory programs that affect one stage of material flows, we need to think about the other (earlier and later) stages.

- IE should be applied in appropriate ways in all our programs to help them accomplish their environmental goals. There is an obvious connection with our waste programs, and there are already discussions about how it ought to evolve into a materials and waste program. IE applies just as strongly, if not more so, to the air program, as the air receives more tons of waste than the land or the water. The numbers of tons may be smaller for some other programs, such as pesticides, but the insights are just as useful. Real progress will require real effort. There is a lesson to be drawn from the Pollution Prevention Program: because our efforts have been relatively small, P2 has not become the driving force in environmental protection that it could be.

- There is much to be learned from working with other countries, many of which have tried some approaches that we haven't and may be ahead of us. The European experiences with takeback and green taxes are two areas where we should pay special attention.

- There is a role for legislation, but the question needs more study before specific proposals can be recommended. The general areas of opportunity are defining a national interest in Industrial Ecology and material flows and making it easier to encourage innovation. Another possible topic for legislation that has been mentioned is setting national goals (e.g., the Factor 10 goal set by the OECD). While formal, binding targets are often fraught with difficulty, informal, flexible targets, if carefully drafted, can be very useful. These are hard topics to treat in legislation. Meanwhile, much can be done with current legislative authorities.

- It is important to point out that even the strongest proponents of IE do not suggest that it should replace our current regulatory programs. A strong regulatory program will preserve a level playing field. While there is room for improvement in our current regulatory programs, they will always be needed to protect against some sources of environmental degradation and to deal with some members of the regulated community. But the growing pressures of population and economy will not allow us to make progress if we confine ourselves to this approach. What we need is a multipronged strategy.

- One should not look to Industrial Ecology for guidance on all issues. At best, Industrial Ecology provides only partial guidance on some important issues.

- Staff need to be given opportunities to see the advantages of the IE approach to help them meet their goals and objectives, see how others have used it, see how it is compatible with existing programs, see that it is not too complicated and then to develop the actual plans that they will use to implement IE strategies. Finally they should be rewarded for significant successes. This is an important and long process.

- Top EPA management needs to be visionary and get people inside and outside the agency to rethink their approaches to environmental protection, but they do not need to reorganize the agency or seek budget increases.

Reflecting on the opportunities presented by Industrial Ecology, the previously mentioned report of the Yale University project that put IE as the centerpiece of the next generation of environmental policy had some interesting observations:

> Industrial ecology is not a panacea for environmental policy. Many of the difficulties in environmental policymaking are challenges of governance, knowledge, values, and cost that transcend questions of analytical framework. But with a process of incremental advances building on past advances and on a systems-based understanding of the problems we face, we may be able to create an environmental management system founded in industrial ecology that wins the confidence of policy revolutionaries and conservatives, as well as those in the vast middle ground. As the number of successfully implemented practices grows, they will begin to replace the current system, both informally and formally, through regulation and legislation. Industrial ecology offers an analytic framework for the accumulation of such practices which, when stitched together, can become the fabric of a new environmental policy needed in a world where the interactions between nature and human society daily become more complex. As those practices are given the status of public policy, we can shed our frayed air-water-waste coat and be on a new path to a sustainable America.[lxvi]

3.3. Getting Started

The list of activities to undertake is too long and too detailed to begin all at once. As mentioned earlier in this paper, the EPA Industrial Ecology Workgroup recommends five general steps to get started:

1. Familiarize key groups with the concept of Industrial Ecology and encourage them to think creatively and opportunistically about how to apply it. Top EPA managers should talk about Industrial Ecology with each other, to EPA staff and to people outside the agency. Talks by outside experts to HQ and regional staff can be very useful at this stage, as can other forms of formal and informal discussion and training. Visioning of the future, such as is being done by a working group from the EPA Office of Solid Waste and several state environmental agencies with their draft white paper, “Beyond RCRA: Prospects for Waste and Materials Management in the Year 2020,” can be very useful. Other programs can make similar efforts. It is very important that EPA staff and people outside the agency see top EPA managers talking about the subject and expressing their interest in it. This will legitimize the subject and get people thinking creatively. EPA’s Reinvention Action Council has had two initial (and well received) discussions of material flows and Industrial Ecology and should continue its discussions.

2. Lay the data/information and science foundation for Industrial Ecology. This step is critical and will help us set priorities. It applies at the level of the economy (material and energy flows), sectors (uses of chemicals/energy and products produced), firms (analysis of supply chains and TRI-type data) and products (Life Cycle Assessment and

environmental profiles of products). In this connection, it is interesting to note a comment in the new material flows report from the World Resources Institute: "The total quantities of outflows remain a mystery to most regulators and to the economic actors who produce them."[lxvii] There are several efforts underway now to fill our information gaps, and more are needed. Interagency, international and private sector cooperation will be vital.

3. Ask each headquarters and regional office to identify a limited number of important environmental problems and make appropriate commitments to pursue industrial ecology approaches. A wide range of options, both regulatory and non-regulatory, long and short term, have already been identified and there is room for much creativity. In some cases the offices are already engaged in promising initiatives which can be expanded. The commitments should include expanding current efforts to identify and eliminate EPA's unintentional disincentives to efficient use of resources as well as starting new initiatives that will help programs accomplish their environmental goals. Among multimedia programs, the Stewardship Track initiative has excellent potential to encourage IE approaches. Government procurement is another potentially important tool.

4. Work with other agencies of federal, state and local government, as well as foreign governments and organizations outside of government. Within the federal government we need to work especially with the U.S. Geological Survey, the Departments of Energy, Commerce, Agriculture and Defense, and the Council on Environmental Quality. Consider a joint initiative with other agencies interested in economic and resource efficiency, touting the direct tangible benefits to industry. Encourage states to innovate. Seek advice from industry. This is not a job that EPA can do alone. In many cases these other government agencies can do more using their authorities than we can by using our authorities alone. But EPA is in an excellent position to provide a vision, analysis and a plan for how Industrial Ecology approaches can be used to improve the environment along with promoting the missions of these other agencies.

5. Set specific priorities, goals and expectations and measure progress. Engage senior managers in a strategic discussion of goals and necessary data and how to integrate IE into GPRA planning. The commitments from HQ and regional offices should include development of appropriate indicators and progress measures, including measures of environmental results. Internal goals will have to focus initially on projects and should seek some early successes. One of the projects should be to consider an external goal, such as the Factor 10 goal set by the OECD (although, perhaps not this particular goal). Celebrate and reward staff for successful completion of important milestones.

3.4. Looking Ahead

This review of Industrial Ecology and EPA demonstrates that IE is entering the mainstream of thought and action in many circles outside EPA and that many of the tools and techniques that one would associate with IE are also becoming widely accepted. What remains is for IE to become part of the mainstream of EPA planning and programs.

Industrial Ecology offers EPA the major part of a needed organizing concept or approach for 2001 and beyond. It could direct fresh attention and useful insight to the most important challenges facing the agency and its mission. It is simple yet visionary, has broad applicability and appeal and builds on significant recent developments in the public and private sectors. It holds out the opportunity of helping us accomplish critical environmental and economic goals that we could not reach with our present approaches, and it can also inform and employ many of the institutional initiatives we are currently pursuing.

The shift to Industrial Ecology approaches at the agency and program level can accelerate immediately but will likely take some number of years to have the full impact that it can have. The change will be significant, but it will have to be progressive. Meanwhile, the agency needs to maintain a strong regulatory presence in its “traditional” mold, especially as many companies will be followers rather than leaders in finding ways to reduce materials use and costs.

We have only the outlines of the task ahead. We need to do much more analysis and planning to determine the best ways to apply IE principles at EPA and we need a full dialogue with all affected parties. Hopefully this paper will stimulate that process.

Footnotes

i. Emily Matthews and Allen Hammond, Critical Consumption Trends and Implications: Degrading Earth's Ecosystems, World Resources Institute (Washington, DC, 1999), p. 9.

ii. This definition is based on the remarks of one the speakers at the EPA Industrial Ecology Workshop. See "Industrial Ecology and EPA: Report on the EPA Industrial Ecology Workshop, November 16-17, 1999," EPA, February 7, 2000, p. 1. (The workshop report is Appendix 1 to this paper.) Another widely referenced definition, from the Journal of Industrial Ecology, is "Industrial Ecology is a rapidly growing field that systematically examines local, regional and global uses and flows of material and energy in products, processes, industrial sectors, and economies. It focuses on the potential role of industry in reducing the environmental burdens throughout the product life cycle from the extraction of raw materials, to the production of goods, to the use of those goods and to the management of the resulting wastes." See the workshop report for more detail on definitions of Industrial Ecology.

iii. U.S. Environmental Protection Agency, Aiming for Excellence: Actions to Encourage Stewardship and Accelerate Environmental Progress, 1999; U.S. Environmental Protection Agency, Innovations at the Environmental Protection Agency: A Decade of Progress, 2000; and National Academy of Public Administration (NAPA), Environment.gov: Transforming Environmental Protection for the 21st Century, Washington, DC, 2000. See also EPA Science Advisory Board, Toward Integrated Environmental Decisionmaking, Washington, DC, 2000; Reason Public Policy Institute, et al., Managing for Results at the U.S. Environmental Protection Agency: Bipartisan Observations and Recommendations on Improving the Management and Performance of the U.S. Environmental Protection Agency, Alexandria, VA, 2001; Five Winds International, Emmitsburg Plan for Fostering the Rational Integration of Human and Environmental Considerations Into Public and Private Decision-Making Processes, prepared for the American Chemistry Council, West Chester, PA, 2001; and J. Clarence Davies and Jan Mazurek, Pollution Control in the United States: Evaluating the System, Resources for the Future, Washington, DC, 1998.

iv. "Report on the EPA Industrial Ecology Workshop," pp. 2-3.

v. U.S. Environmental Protection Agency, Office of Solid Waste, and the EPA-State RCRA Vision Workgroup, "Beyond RCRA: Prospects for Waste and Materials Management in the Year 2020," draft white paper, October 2000.

vi. United Nations, Report of the Conference on Environment and Development (Agenda 21), 1992, quoted in U.S. Interagency Working Group on Industrial Ecology, Material and Energy Flow, Industrial Ecology: Material and Energy Flows in the United States, 2000, p. 12. The agencies participating in this "Interagency Report" include CEQ, EPA, DOE, DOI (including USGS), DOC and HUD. The Interagency Working Group also published a shorter and more widely distributed version of their report under the title Materials, 1999.

vii. See, for instance, The National Commission on the Environment, Choosing a Sustainable Future, Island Press, Washington, DC, 1993; and The President's Council on Sustainable Development, Towards a Sustainable America, (Washington, DC, 1999).

viii. World Resources Institute, Resource Flows: The Material Basis of Industrial Economies, (Washington, DC, 1997), pp. 1-2. [WRI's involvement in this study, as well as the Weight of Nations and Critical Consumption Trends and Implications, cited in this paper, was principally supported by the U.S. Environmental Protection Agency.]

ix. World Resources Institute, The Weight of Nations: Material Outflows from Industrial Economies, Washington, DC, 2000, p. v.

x. WRI, Weight of Nations, p. 14.

xi. Interagency report, p. 19, and Michael Brower and Warren Leon, The Consumer's Guide to Effective Environmental Choices, Three Rivers Press, New York, 1999, p. 5.

xii. WRI, Weight of Nations, p. xi.

xiii. National Strategy on Environmental Technology, 1995, quoted in Interagency report, p. 5.

xiv. WRI, Weight of Nations, p. xi.

xv. WRI, Weight of Nations, p. 119.

xvi. NAPA, p. 60.

xvii. Matthews and Hammond, Critical Consumption Trends and Implications, p. 9.

xviii. Quoted in Interagency report, p. 14.

xix. See Ray C. Anderson, Mid-Course Correction - Toward a Sustainable Enterprise: The Interface Model, Peregrinzilla Press (Atlanta, 1998). The prize that Anderson won is the 2001 George and Cynthia Mitchell International Prize for Sustainable Development. The selection committee for the $100,000 prize was administered by the National Academy of Sciences. The announcement was made on January 16, 2001 (see www.nas.edu).

xx. Livio D. DeSimone and Frank Popoff, with the World Business Council for Sustainable Development, Eco-Efficiency: The Business Link to Sustainable Development, MIT Press (Cambridge, MA, 1997).

xxi. Paul Hawken, Amory Lovins and Hunter Lovins, Natural Capitalism: Creating the Next

Industrial Revolution, Little, Brown and Company (Boston, 1999). See also, Amory Lovins, Hunter Lovins and Paul Hawken, "A Road Map for Natural Capitalism," Harvard Business Review, May/June 1999, pp. 143-158.

xxii. World Business Council for Sustainable Development (WBCSD), Eco-Efficiency: Creating More Value With Less Impact (2000). See also WBCSD, Eco-Efficient Leadership for Improved Economic and Environmental Performance (1996), and WBCSD, Sustainable Production and Consumption: A Business Perspective (1996). All are available at www.wbcsd.ch/publications.

xxiii. William Drozdiak, "U.S. Firms Become 'Green' Advocates," The Washington Post, November 24, 2000, p. E1.

xxiv. David Allen, "A Strategic Vision for Environmentally Benign Manufacturing," viewgraphs for talks at the Workshop on Environmentally Benign Manufacturing, National Science Foundation (NSF), Arlington, VA, July 13, 2000, pp. 31-42; and Cynthia Murphy, "Geographic Overview," also in NSF, pp. 17-30. See also Braden R. Allenby, Industrial Ecology: Policy Framework and Implementation, Prentice Hall (Upper Saddle River, NJ, 1999), p. 210. Japan Environment Agency, "The Challenge to Establish the Recycling-based Society," 2000; and Law No. 110 of 2000, "The Basic Law for Establishing the Recyling-based Society."

xxv. "Directive 2000/53/EC of the European Parliament and of the Council, 18 September 2000, on end-of-life vehicles," Official Journal of the European Communities, 21.10.2000, L269/35-42.

xxvi. Murphy, p. 22.

xxvii. For more information, see (1) www.epa.gov/epr, (2) Garth Hickle, "Whose Responsibility?" The Environmental Forum, July/August 2000, pp. 21-27, and (3) "States' Plan Aims to Boost Product Stewardship, Take-Back Effort," Inside EPA, Vol. 21, No. 45, November 10, 2000, p. 1.

xxviii. Murphy, p. 23; see also, Willem Vermeend and Jacob van der Vaart, Greening Taxes: The Dutch Model, Kluwer (Deventer, 1998); and Organisation for Economic Cooperation and Development, Environmental Taxes and Green Tax Reform, 1997.

xxix. Denmark: Danish Ministry of Finance, "Danish Resource Consumption," Strategic Environmental Assessment of the 2001 Government Budget, pp. 49-68, August 2000. Canada: Speech by Jerry Beausoleil, Director General, Strategic Policy Branch, Industry Canada, "Eco-Efficiency: A New Canadian Priority," December 12, 2000.

xxx. For a good discussion of this systems approach, see Allenby (1999).

xxxi. See Pierre Desrochers, "Market Processes and the Closing of "Industrial Loops: A Historical Reappraisal," Journal of Industrial Ecology, Vol. 4, No. 1, Winter 2000, pp. 29-43.

xxxii. Various lists of this type have been developed by different groups. For instance, the WBCSD has identified 7 elements of eco-efficiency: "1. Reduce the material intensity of goods and services. 2. Reduce the energy intensity of goods and services. 3. Reduce toxic dispersion. 4. Enhance material recyclability. 5. Maximize sustainable use of renewable resources. 6. Extend product durability. 7. Increase the service intensity of goods and services." Dow Chemical has developed what they call a "6-point eco-efficiency compass: 1. Dematerialize. 2. Increase energy efficiency. 3. Eliminate negative environmental impacts. 4. Close the loop. 5. Borrow from natural cycles. 6. Extend service, enhance function." See WBCSD, Eco-Efficient Leadership for Improved Economic and Environmental Performance, pp. 6 & 10.

xxxiii. See, for instance: *Carbon:* R. Socolow, C. Andrews, F. Berkhout, V. Thomas (editors), Industrial Ecology and Global Change, Cambridge University Press, 1994; *Nitrogen/Agriculture:* Ann P. Kinzig and Robert H. Socolow, "Human Impacts on the Nitrogen Cycle," Physics Today, November 1994, pp. 24-31; *Mercury:* Byron Swift, "A Better, Cheaper Way to Regulate Mercury," Environment Reporter, Bureau of National Affairs, Inc., Washington, DC, Vol. 29, No. 34, 1/1/99, pp. 1721-1729; *Carpets:* Anderson, previously cited; *Autos:* Thomas E. Graedel and Braden R. Allenby, Industrial Ecology and the Automobile, Prentice Hall, Upper Saddle River, NJ, 1998; *Autos and Lead:* Robert Socolow and Valerie Thomas, "The Industrial Ecology of Lead and Electric Vehicles," Journal of Industrial Ecology, Vol. 1, No. 1, 1997, pp. 13-36; *NY/NJ Harbor:* New York Academy of Sciences, Industrial Ecology and the Environment: Applications to the New York Harbor, 1998; *New Jersey:* "Mercury in New Jersey," presentation by Michael Aucott, PhD., New Jersey Department of Environmental Protection, 2000;

xxxiv. Brower and Leon, p. viii.

xxxv. A good collection of some of the more scholarly writings on this subject is Laura Westra and Patricia H. Werhane, The Business of Consumption: Environmental Ethics and the Global Economy, Rowman and Littlefield Publishers, Inc., Lanham, MD, 1998. Two other useful discussions of the consumption issue are Gary Gardner and Payal Sampat, Mind Over Matter: Recasting the Role of Materials In Our Lives, Worldwatch Institute, Worldwatch Paper 144, Washington, DC, 1998; and National Research Council, Environmentally Significant Consumption: Research Directions, National Academy Press, Washington, DC, 1997.

xxxvi. See Interagency report, especially Recommendation 4 on page 80: "The Federal Government's behavior should continue to be modified with respect to procurement, use of buildings, transportation, etc., to harmonize better with the concepts of industrial ecology."

xxxvii. R.A. Frosch and N.Gallopoulos, "Strategies for Manufacturing," Scientific American, 1989, 261(3), pp. 144-152.

xxxviii. T.E. Graedel and B.R. Allenby, Industrial Ecology, Prentice Hall, Englewood Cliffs, NJ, 1995.

xxxix. *Journal of Industrial Ecology*, published quarterly by the MIT Press, Cambridge, MA, since 1997.

xl. Iddo K. Wernick and Jesse H. Ausubel, "Industrial Ecology: Some Directions for Research," May 1997, http://phe.rockefeller.edu . See also the report from the National Research Council (1997), cited above.

xli. Marion R. Chertow and Daniel C. Esty, editors, *Thinking Ecologically: The Next Generation of Environmental Policy*, Yale University Press, New Haven, 1997, p. 9.

xlii. See www.grc.uri.edu

xliii. Conference reports: (1) EPA: "Report on the EPA Industrial Ecology Workshop," previously cited; (2) USGS: *Material and Energy Flows in the Earth Science Century: A Summary of a Workshop Held by the USGS in November 1998*, USGS Circular 1194, 2000 (http://greenwood.cr.usgs.gov/pub/circulars/c1194); (3) NSF: "Linking Industrial Ecology to Public Policy: Report of a Workshop," 1998 (http://policy.rutgers.edu:8080/IE/); (4) NAS: Workshop on Material Flows Accounting of Natural Resources, Products and Residues in the United States, January 26-27, 1998 (no report published, but workshop papers availablae from NAS and EPA staff).

xliv. See www.oit.doe.gov/mining/materials

xlv. UN: see www.un.org/esa/sustdev ; Preliminary reports from the OECD workshops are now available from EPA staff. NACEC reports are forthcoming.

xlvi. Reid Lifset, "Full Accounting," *The Sciences*, New York Academy of Sciences, May/June 2000, p. 34.

xlvii. BCSD, 1993, quoted in *Sustainable Production and Consumption: A Business Perspective*, World Business Council for Sustainable Development, 1996, p. 11.

xlviii. Interagency report, p. 36.

xlix. Anderson, p. 11.

l. Estimate by John Sparks, U.S. EPA

li. Hawken, Lovins and Lovins, p. 50.

lii. WRI, *Resource Flows*, p. 2.

liii. Quoted in DeSimone and Popoff, p. ix.

liv. See (1) Jacquelyn A. Ottman, "Five Strategies for Business Reinvention: The Development of Sustainable Products and Services," Corporate Environmental Strategy, Vol. 5, No. 5, Autumn, 1998, pp. 81-89; and (2) William McDonough and Michael Braungart, "The NEXT Industrial Revolution," The Atlantic Monthly, October 1998.

lv. For a good discussion of barriers, see "The Ottawa Statement on Product and Supply Chain-Focused Policies and Tools for Sustainable Development," prepared for Environment Canada by Five Winds International, 2000. For information about the U.S. Army Industrial Ecology Center, see www.pica.army.mil/iec/. For information about new initiatives by waste collection and management companies, see Paul Ligon, et al., "Waste Service Providers Become Resource Managers," Biocycle Magazine, April 2000; and Paul Ligon and Tom Votta, "Strategic Contracting Increases Waste Prevention and Materials Recycling," Resource Recycling, March 2001.

lvi. Quoted in DeSimone and Popoff, p. xv.

lvii. Quoted in WBCSD, Eco-efficient Leadership, p. 13

lviii. NAPA (2000)

lix. "Report on the EPA Industrial Ecology Workshop," pp. 2-3.

lx. Byron Swift, "How Environmental Laws Can Discourage Pollution Prevention: Case Studies of Barriers to Innovation," April 2000, paper based on research described in Barriers to Environmental Technology Innovation and Use, (Washington, DC: Environmental Law Institute, January 1998). The five cases can be summarized as follows: *Iron and steel:* RCRA emphasizes "cradle to grave" for hazardous waste, rather than "cradle to cradle" recycling, encouraging waste rather than reuse. (The regulations make disposal of spent acids cheaper than recycling.) *Incinerators:* Current regulations focus on limiting emissions from waste incinerators. The study suggests that restricting intentional uses of mercury in products and industrial processes would be a far more efficient and effective means to reducing mercury in the environment than regulating. *Baking:* A "percentage rate reduction" standard for ethanol emissions requires most bakers to adopt a single technology selected by government regulators, instead of allowing them to choose other technologies that use less energy, eliminate the use of toxic metals and cost less. *Dry cleaning:* Current regulations focus only on control technologies reduction of emissions of perchloroethylene and don't encourage innovative technologies that could simply eliminate the use of this hazardous solvent. *Electric power generation:* Technology standards focus only on different categories of plants and discourage more efficient resource use.

lxi. Ross & Associates Environmental Consulting, Ltd., "Pursuing Perfection: Case Studies Examining Lean Manufacturing Strategies, Pollution Prevention, and Environmental Regulatory Management Implications," report prepared for U.S. EPA under Contract #68-W50012, August 20, 2000.

lxii. "Draft OECD Environmental Strategy for the First Decade of the 21st Century," ENV/EPOC (2000) 13, October 2000.

lxiii. Dennis A. Rondinelli, Director, Center for Global Business Research, University of North Carolina at Chapel Hill, Rethinking U.S. Environmental Protection Policy: Management Challenges for A New Administration, published by the PricewaterhouseCoopers Endowment for the Business of Government, Arlington, VA, 2000, p. 5.

lxiv. The Interagency Working Group's recommendations were as follows: 1. Maintain Federal efforts to collect and publish critical data on materials and energy. 2. Expand analysis of available data for specific materials and sectors. 3. Government Agencies should examine data and information programs with a view to present information in easily usable forms. 4. The Federal Government's behavior should be modified with respect to procurement, use of buildings, transportation, etc. to harmonize better with the concepts of industrial ecology. 5. Incentives to encourage behavior improving efficiencies and reducing environmental impacts of materials and energy flows need to be developed. Interagency Report, pp. 79-80.

lxv. WBCSD, Sustainable Production and Consumption, p. 28.

lxvi. Chertow and Esty, Chapter 1: "Industrial Ecology: Overcoming Policy Fragmentation," by Charles W. Powers and Marian R. Chertow, pp. 32-33.

lxvii. WRI, Weight of Nations, p. 32.

Addendum

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