THE POLICY IMPLICATIONS OF INDUSTRIAL ECOLOGY

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Summary

The existing conceptualization of environmental issues, which essentially treats them as “overhead” for both society and private firms, is obsolete. If a sustainable economy, integrating economic and environmental efficiency, is to be achieved, a new way of thinking about environment and economic activity must be developed. This article presents an intellectual framework, based on industrial ecology, which represents this synthesis. The goal is achieving a sustainable economy through the process of continued economic, cultural, and technological evolution. Appropriate policies include those that stimulate the development of knowledge necessary to understand sustainability, protect natural systems (biosphere, atmosphere, water, and soil), promote the development and use of sustainable energy systems, encourage the conservative use of materials, and utilize the free market system to satisfy human needs and wants with ever increasing environmental and economic efficiency. These policies must be robust enough to be beneficial in spite of our limited current knowledge and capabilities, and adaptive enough to evolve as we learn more about the environmental consequences of human activities.

1. Introduction

Industrial ecology is the objective, multidisciplinary field which studies the science and technology of industrial and economic systems and their linkages with fundamental natural systems. In the broader sense, it can incorporate, as well, the normative disciplines of anthropology, law, management, and social sciences, in order to objectively understand and define appropriate societal actions to achieve sustainable development. In the narrower sense, industrial ecology can be thought of as the science of sustainability.

The following treatment spans the broader scope, starting from a discussion of some global ecological issues and the implications of various responses to these issues, through a brief description of the scope and methods of industrial ecology, leading to principles and specific implementation suggestions for policies which should move us in the direction of sustainability.

2. Stewardship of the Earth

2.1 Sustainability within a Closed System

Earth is a physically closed and energetically open system. Sun light enters the system, and heat is lost into space, but otherwise our planet does not exchange resources to any appreciable extent with the rest of the universe. The enclosed human, animal, plant, and micro-organic inhabitants need to live in harmony with each other, satisfying their own and each other's needs, without fouling the environment or using everything up such that future inhabitants are left wanting. Fortunately, the living systems and the environments in which they live can adapt to many perturbations, repairing and refreshing themselves when disturbed, and modifying their functional needs through adaptation and evolution, as required. Unfortunately, these recovery responses have limits and can break down if the perturbation is too great. Currently, the pressures on natural systems generated by population growth and economic expansion are powerful and accelerating. Willing or not, humanity is thrust into the critical role of stewardship over the resources needed for its own future and over many of Earth's treasures.

2.2 Industrial Revolution and Global Perturbations

The Industrial Revolution was a critical point in the evolution of our species. Prior to it, while there is evidence that local environmental degradation played a role in the decline of local civilizations, habitats, and species, the impact of human activity taken as a whole was simply not of sufficient scale to cause global problems. The technologies of the Industrial Revolution and the accompanying agricultural revolution, however, essentially created a condition of temporarily unlimited resources for the human species, which, as is the general rule in population biology, resulted in exponential population growth. Predictably, concomitant environmental impacts, which could have been assimilated by natural systems at low levels of population and economic activity, have caused increasingly significant perturbations of those systems.

2.3 Master Equation

The relationship between human activities and the environment is captured in, and critical policy concepts highlighted by, the so-called master equation:

$$\text{Environmental Impact} = \text{Population} \times \frac{\text{Wealth}}{\text{Person}} \times \frac{\text{Environmental Impact}}{\text{Unit Wealth}}$$

According to consensus scientific assessments, the overall environmental impact of human activity is exceeding responsible levels. The question is, which of the factors of the master equation is accessible and what can we do to control our impact to levels that our environment can accommodate?

2.4 Population and Wealth

It is apparent that controlling the first term of the master equation, population growth, will be a complex and lengthy process, and that the eventual leveling-off point could be as high as ten billion. Fortunately, there is increasing evidence that population growth rates decline with a higher standard of living. As regards the second term, it is obvious that most people are not willing to reduce their wealth, or desire for more wealth, voluntarily, and that people in developing countries want to become as well off as those of more fortunate nations.Quality of life" is probably a more appropriate measure for this term, but wealth is easier to measure and, for most people at any rate, is roughly equivalent to quality of life anyway. However desirable, any shift to a less materialistic quality of life measure for most people, and for society as a whole, is certainly well in the future. Accordingly, it must be concluded that, even if the level of environmental impact is already unacceptable, growth in population and wealth are strongly positive, and will continue to increase their pressures on the environment, at least in the short term.

2.5 Technology's Role

The obvious conclusion from the above perspective is that, especially in the short term, every effort must be made to reduce the value of the third term of the master equation, if continued- even accelerated- growth in environmental impact is to be avoided. Importantly, the third term is a technology term. It says that, as a society, we must figure out how to produce increasing quality of life at much reduced environmental impact per unit of wealth. Restating this conclusion as a policy imperative:

> A fundamental goal of environmental and technological policy must be to encourage the rapid evolution, and diffusion throughout the global economy, of environmentally appropriate technology and technological systems.

3. Emergence of Ecological Perspectives

3.1 Environmental Paradigm of the 1960s to the 1980s

In the always informative light of hindsight, it is apparent that the end of the 1980s marked the beginning of a fundamental shift in the way environmental issues were conceptualized by both society and private firms. The prevailing paradigm was one that dealt with environmental concerns localized in both time and space: individual landfills, specific waterways, the airsheds over major metropolitan areas. The focus was on individual substances: particular pesticides, lead, polychlorinated biphenyls (PCBs). Policy endpoints were ad hoc and limited; most programs were driven by risk assessments that focused almost exclusively on acute human toxicity or carcinogenicity. Not only regulatory methodologies and tools but also research in environmental science was heavily biased in similar directions, predominantly reductionist (limit specific impacts of individual substances) and with a strong anthropocentric bias.

3.2 Need to Move Beyond the Symptomatic Approach

We now are beginning to appreciate that, while such activities reflected our knowledge at the time, and still have value, they are by themselves inadequate. They treat the symptoms — local environmental perturbations or hazards — rather than the disease — an unsustainable global economy. Virtually all significant regional and global environmental impacts are inherent characteristics of the operation of our current globalized economic system. They are direct products of the use of technology — the automobile and associated infrastructure, energy production and use patterns based on fossil fuel resources, consumer reliance on throwaway articles and packaging — which had their genesis during the Industrial Revolution, and which, by and large, have been created with no concern for environmental impact. Problems such as global warming, soil degradation and erosion, loss and degradation of fresh water resources, ozone depletion, and loss of biodiversity do not simply reflect bad management of emissions and residues. They represent widespread dysfunctional economic choices, particularly in the selection and use of technology. The assumptions of the Industrial Revolution — unlimited resources for population and economic growth — are not appropriate for an increasingly environmentally constrained world.

3.3 Complex Systems Treatment of the Economy and Nature

While local hazards must be controlled, such action must be seen as an adjunct to the most important policy endpoint: the achievement of, or at least the closer approach towards, a sustainable economy on the scale of decades to centuries. The focus cannot only be local, but also must be regional and global, including impacts that are only manifested over long time periods, or after significant lag times. The approach cannot at heart be reductionist; it must be systems-based, comprehensive, and recognize that many perturbations of concern manifest themselves only as emergent characteristics of complex systems — in this case, the economy and the supporting natural systems.

3.4 Integration of Scientific, Technological, Environmental, and Economic Considerations

Over time, there have been differences in approach to environmental management. Table One summarizes these. In the past, resources were used and waste materials dumped outside of the work or community sites. The present controls reflect a much increased awareness of subtle dangers, but still treat our environment as open and reducible, not closed and integrated. Our task for the future is not remediation or improved emission controls; it is the re-engineering of the Industrial Revolution.

The need to integrate technology, science, and environmental considerations throughout the economy becomes the responsibility of all of us: academics, policy makers, industrial leaders, environmental activists, citizens. Despite all the rhetoric and expenditures, society has really been treating environment (when treated at all) as overhead, conceptually trivial and irrelevant to its primary economic activities once the proper control equipment or regulation is in place.

If we are truly serious about mitigating anthropogenic perturbation of fundamental natural systems, we can no longer afford the luxury of such naiveté.

Time Frame	Primary Activity	Focus of Activity	Endpoint	Relation of Environment to Economic Activity	Underlying Conceptual Model
Past	Remediation	Individual site, medium, or substance	Reduce local anthropocentric risk	Overhead	Command and control in simple systems
Present / Past Focus	Compliance	Individual site, medium, or substance	Reduce local anthropocentric risk	Overhead	Command and control in simple systems
Present / Future Focus	Industrial ecology; Design for Environment	Materials, products, services, and operations over life cycle	Global sustainability	Strategic and integral	Guided evolution of complex systems

Table 1: Reference Time Frames for Management of Technology and Environment

4. Ecological Approaches

It is instructive to compare the industrial ecology approach to other common approaches frequently taken in thinking about the interactions among industry, environment, and society. Table 2 summarizes these.

Approach	Effect on Technology	Implications
Continuation of Current Trends	Ad hoc adoption of specific mandates (e.g. Emission controls); little effect on overall trends	Unmanaged population crash; economic, technological, and cultural disruption
Radical Ecology	Return to low technology	Unmanaged population crash; economic, technological, and cultural disruption
Deep Ecology	Appropriate technology; "low tech" whenever possible	Lower population; substantial retrenchment of economic, technological, and cultural status
Industrial Ecology	Reliance on technological evolution within environmental constraints; biased to environmentally preferable technology	Moderately higher population; substantial adjustments to economic, technological, and cultural status

Table 2: Ecological Options for Technology-Society Interactions

4.1 Continuation of Current Trends: Unsustainable Growth

Continuation of current trends is obviously fundamentally flawed; not so obviously, it is also a high-cost choice. A continuation of exponential growth can be followed only in the short term; it will bring extreme and highly visible environmental damage, followed by the imposition of substantial remediation and resource recovery costs on future generations and global systems generally. Continually escalating materials flows and rapid growth in capital stock, energy, and resource consumption simply cannot be maintained. The most likely outcome of the continuation of the status quo is, ironically, similar to that resulting from radical ecology (discussed below): a dramatic degradation of the quality of life and eventual reduction in human population, with ongoing political, economic, and social disruption.

4.2 Radical Ecology: Severe Contraction

Radical ecology refers to a return to pre-industrial, low- (even anti-) technology pastoralism. It rejects the use of modern agriculture, electronics, medicine, transportation, energy production, and other technological systems. This concept is mentioned in order to emphasize the connection between the level of technology and the supportable population. A radical ecological approach most probably could not support current population levels, much less those of the future; a drastic population collapse would occur. In addition, the pre-Industrial Revolution agrarianism is not recoverable without enormous remedial cost and, by the way, significant technological and biological effort, and would not be publicly supported.

4.3 Deep Ecology: Managed Contraction

Deep ecology represents a strategy that intends to integrate environmental values into the culture, but views technology with suspicion, in part because of the recognized impact of technology on environmental perturbations. Technology is seen as something to be controlled, not exploited, to be part of the problem rather than a component of the solution. Proponents advocate a return to low technology options, which, in all probability, would only support a lower level of human population (a reduced carrying capacity for our species). This reduction might be managed well enough, however, to produce a gradual and controlled transition. While possible, this option would require fundamental cultural change and may well be unattainable because the majority of the world's people will not want diminished material wealth.

4.4 Industrial Ecology: Potentially Sustainable Development

Industrial ecology, in contrast, recognizes the need for continued technological evolution, and sees the development of environmentally appropriate technologies as a critical component of the transition to a more sustainable world. Given that the global technology state and the level of human population are inextricably linked, if the goal is to maintain current population levels (or even to allow for population growth), evolving appropriate technology is a crucial requirement.

It is important to recognize that industrial ecology is not merely naive technological optimism. The data on human perturbation of complex fundamental natural systems are sparse and uncertain, and do not support a facile certainty that the human species can migrate itself to a relatively stable, desirable carrying capacity without significant economic, social, and cultural dislocations, or even precipitous population fluctuations. Rather, industrial ecology pragmatically incorporates as an operative assumption the possibility of a reasonably smooth transition to a stable carrying capacity. Realism dictates that progress from the present point in human history must occur — if it is to occur at all — within the degrees of freedom that actually exist, not those that wishful thinking would create. Of the four options listed here, then, industrial ecology appears to be the only practical, viable path.

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Biographical Sketches

Braden R. Allenby is the Environment, Health and Safety Vice President for AT&T, an adjunct professor at Columbia University's School of International and Public Affairs, the inaugural Batten Fellow at Darden Graduate School of Business at the University of Virginia, and a visiting lecturer in ethics at Princeton Theological Seminary. From 1995 to 1997, he was Director for Energy and Environmental Systems at Lawrence Livermore National Laboratory. He graduated cum laude from Yale University in 1972, received his Juris Doctor from the University of Virginia Law School in 1978, his Masters in Economics from the University of Virginia in 1979, his Masters in Environmental Sciences from Rutgers University in the Spring of 1989, and his Ph.D. in Environmental Sciences from Rutgers in 1992. During 1992, he was the J. Herbert Holloman Fellow at the National Academy of Engineering in Washington, DC. He is a member of the editorial boards of *The Journal of Industrial Ecology, The Journal of Sustainable Product Design, The Bulletin of Science, Technology and Society, and Environmental Quality Management*; and a former member of the Secretary of Energy's Advisory Board and the DOE Task Force on Alternative Futures for the DOE National Laboratories. Dr. Allenby has authored a number of articles and book chapters on industrial ecology and Design for Environment; is co-editor of *The Greening of Industrial Ecosystems*, published by the National Academy Press in 1994, and of *Environmental Threats and National Security*: *An International Challenge to Science and Technology*, published by Lawrence Livermore National Laboratory; and is co-author or author of several engineering textbooks, including *Industrial Ecology*, published by Prentice-Hall in January of 1995, *Design for Environment* published by Prentice-Hall in 1996, *Industrial Ecology and the Automobile*, published by Prentice-Hall in 1997, *and Industrial Ecology: Policy Framework and Implementation*, published by Prentice-Hall in 1998. He is a Fellow of the Royal Society for the Arts, Manufactures & Commerce.

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Prior to this Dr. Gilmartin was responsible for institutional long-range and strategic planning at the Livermore Laboratory after twenty years in technical and management roles on laser research and development programs with applications to radar, fusion energy, isotope separation, and strategic defense at Livermore and at the Massachusetts Institute of Technology: Lincoln Laboratory.

Dr. Gilmartin received his B.S. (1962) in Physics from Georgetown University, M.S. in Physics (1964), and Ph.D. in Electrical Engineering (1968) from Purdue University. He has more than 20 publications in areas of laser systems and applications, and of energy and environmental issues.

Thomas E. Graedel is Professor of Industrial Ecology and Director, Center for Industrial Ecology, School of Forestry and Environmental Studies, Yale University. B.S., Chemical Engineering, Washington State University, 1960; M.A., Physics, Kent State University, 1964; M.S., Ph.D., Astronomy, University of Michigan, 1967, 1969

Professor Graedel joined Yale University in 1997 after 27 years at AT&T Bell Laboratories. He was the first atmospheric chemist to study the atmospheric reactions of sulfur and the concentration trends in methane and carbon monoxide. As a corrosion scientist, he devised the first computer model to simulate the atmospheric corrosion of metals. This work led to a voluntary position as corrosion consultant to the Statue of Liberty Restoration Project in 1984-86. One of the founders of the emerging field of industrial ecology, he co-authored the first textbook in that specialty and has lectured widely on its implementation and implications. His matrix assessment tool, developed while at AT&T, is a widely-used standard for the environmental assessment of products and services. His current research includes studies of the stocks and flows of materials in the industrialized society, especially in very large cities and in environmentally-sensitive regions. His studies of the cycles of industrially-used metals explore aspects of resource availability, potential environmental impacts, opportunities for recycling and reuse, and resources policy initiatives. Overall, he has published nine books (with total sales of more than 33,000 copies) and over 240 technical papers in various scientific journals.