

Industrial ecology

A systems perspective and forward-looking analysis provide effective tools for industrial ecology to inform the decision-making process. **Professors Marian Chertow, Marina Fischer-Kowalski, Roland Clift and Tom Graedel** explain how



How would you summarise the study and application of industrial ecology (IE)?

MC: Perhaps the most basic tenet of IE is that embedded energy and materials should be preserved. Each time we dispose of something, such as an old cell phone, we are precluding the reuse of all of the complex materials and various types of energy that went into making this item in the first place. One excellent analysis by industrial ecologist Eric Williams and colleagues measured the total quantity of embedded materials and energy used to manufacture a typical, very small microchip. Making a two gram microchip requires 32 kg of water, 1.2 kg of fossil fuel, and 72 g of chemicals. This example illustrates that much resource use is hidden and, as a result, the full set of impacts does not get counted. Industrial ecology is dedicated to making implicit resource use more explicit from the beginning to the end of use cycles.



From Top to Bottom:
Professors Marian Chertow, Marina Fischer-Kowalski, Roland Clift and Tom Graedel

MFK: Social scientists think social change comes about for social reasons. Engineers tend to think social change results from technological innovation; and economists believe it relates to changing prices. Industrial ecology seeks to bridge these separate strands. It teaches social scientists how much energy sources and conversion technologies matter for social functioning. It teaches engineers and economists that solutions cannot rely on technology or price alone – social processes matter and may make all the difference. In particular, the grand objectives such as preventing dangerous climate change, preserving biodiversity, or securing a healthy life for people in Africa, require radical changes involving the whole range of social, technological and economic processes.

Why would businesses be interested in industrial ecology and how could they adopt it successfully?

MC: I believe there is a whole new rationale for interest in IE by the private sector as businesses feel anew the multi-faceted problem of the competition for physical resources. Proctor & Gamble or Hindustan Lever, for example, cannot see the problem of water in India as anything but a threat to core business. The business sense of industrial ecology does not lie in cosmetic 'green washing' or in

social responsibility alone, but in the future of these and thousands of other small and large companies to achieve sustainable resource management. To survive and thrive in this dynamic struggle, businesses need to understand clearly how key resources are being utilised and distributed within the facility, the business sector, the supply chain, even on a global scale. Paying resolute attention to the tracking of material, energy, and water flows is a hallmark of industrial ecology as is taking into account all phases of a product throughout its lifecycle. By adopting these types of systems perspectives, businesses will gain from IE insights.

What progress has been made in the successful integration of industrial ecology? What has been the greatest advancement so far?

RC: In some parts of the world, including the European Union, life cycle thinking is now embedded in legislation and regulation. It is also recognised, largely due to pioneering research carried out by industrial ecologists, that a country's environmental impact is indicated by what it consumes, rather than what it produces. At a sub-national level, cities can allow their inhabitants the same welfare at lower levels of energy and material consumption, and at lower cost through intelligent design of infrastructure. Commercial concerns are also increasingly adopting an industrial ecology approach in strategic planning. For some, this has gone beyond product labelling, to reporting and documenting the environmental and social impacts of their supply chains, as well as declaring commitments to decouple economic activity from impact, efforts much more ambitious than any national policy.

Can we recycle our way into sustainability?

TG: It is worth noting that even if we were to achieve a 100 per cent recycling rate, our increasing demand for materials is likely always to be higher. Therefore, we cannot recycle our way into sustainability. However, recycling will help us save energy, minimise environmental impact, and preserve resources in the long term, but we must also change what and how we consume if we are to reach true sustainability.

Systems thinking

Two forward-thinking institutions, **Yale University Centre for Industrial Ecology** and the **International Society for Industrial Ecology**, utilise the expertise of a global community to deliver new perspectives on sustainability

INDUSTRIAL ECOLOGY (IE) is a multidisciplinary field that analyses material, water, and energy flows of industrial and consumer systems at a variety of spatial scales, drawing on environmental and social science, engineering, business and policy. The modern notion of industrial ecology began with a widely read article published in *Scientific American* in 1989 by Robert Frosch and Nicholas Gallopoulos who realised that “the traditional model of industrial activity in which individual manufacturing processes take in raw materials and generate products to be sold plus waste to be disposed of should be transformed into a more integrated model: an industrial ecosystem”, in which “the consumption of energy and materials is optimised, waste generation is minimised and the effluents of one process serve as the raw material for another process”.

Since 1998, Yale’s Centre for Industrial Ecology (CIE) has played a leadership role in researching theory, policy issues, economic, environmental and social factors, as well as material and energy life cycles, pertaining to IE. It is home to the *Journal of Industrial Ecology*, the leading peer-reviewed journal in the field. The International Society for

Industrial Ecology (ISIE) was formed in 2001 as a means of bringing together the global interest that had arisen in this new area since the publication of the *Scientific American* article among researchers, managers, and decision makers as a way of finding innovative solutions to complex environmental problems.

INDUSTRIAL SYMBIOSIS

Marian Chertow, Associate Professor and Director of the Industrial Environmental Management Program at Yale, is one of the faculty members at the forefront of this research. Although there are numerous subdivisions of IE, Chertow finds that her strongest interest lies in industrial symbiosis. She explains that while mutually beneficial, symbiotic relationships are common in nature, they are often neglected in our industrial society. Chertow hopes to reverse this trend through her pioneering research. Using a collaborative approach, industrial symbiosis focuses on resource flows through clusters of geographically proximate businesses. By sharing resources and reducing waste, water, and energy use, industries can work in harmony to reduce their environmental impact and cost.

“My early research was concerned with describing and categorising industrial symbiosis when it was first being observed in the 1990s,” Chertow explains. “Since then, I have led numerous investigations concerning which factors motivate industrial symbiosis, under what circumstances it emerges, how ubiquitous and resilient the resulting industrial ecosystems are, their significance in economic and environmental terms, and the depth of the ecological analogy.” Because many industrial operations occur in urban areas, Chertow has also become interested in the Industrial Ecology of cities and has joined with other ISIE members to determine the ‘urban metabolism’ of Singapore and cities in China, India, and the US.

SOCIAL METABOLISM

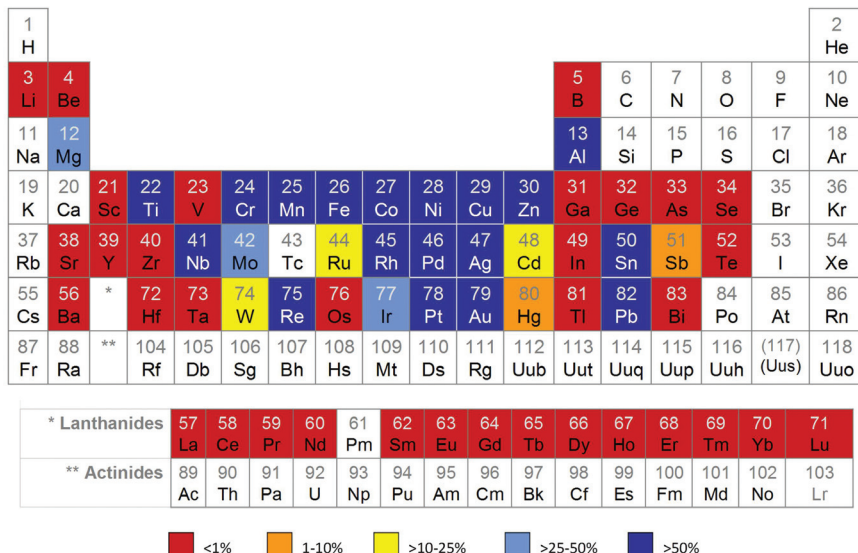
If social systems, such as cities or nation states, increase their population and income, they also increase their requirement for natural resources and the amount of waste they produce. This depletes natural resource stocks and creates environmental pollution. How much the burden upon the environment grows with increasing welfare is not a given – it is a matter of efficiency, lifestyles and equity. Professor Marina Fischer-Kowalski, Director of the Institute for Social Ecology at Alpen-Adria University in Vienna, Austria, investigates how to integrate resource use considerations into land use planning in order to achieve a more sustainable urban environment.

Applying a metabolic understanding to social systems, Professor Fischer-Kowalski’s work measures the pressures of economic and societal processes upon nature. The question is how to achieve human welfare at lower environmental cost. Fischer-Kowalski is designing useful tools for material and energy flow analysis (MEFA) that help to define best practices and to generate future scenarios to understand where dangerous tipping points lie.

LIFE CYCLE ASSESSMENT

Roland Clift, Emeritus Professor of Environmental Technology and Founding Director of the Centre for Environmental Strategy (CES) at the University of Surrey in the UK, helped to pioneer the approach of environmental and social life cycle assessment

FIGURE 1. The periodic table of global average end-of-life recycling rates for 60 metals (Graedel et al, 2011).



<1%
 1-10%
 >10-25%
 >25-50%
 >50%



INTELLIGENCE INDUSTRIAL ECOLOGY

OBJECTIVES

Yale Centre for Industrial Ecology was established in 1998 to provide an organisational focus for research in industrial ecology.

The International Society for Industrial Ecology (ISIE) is an interdisciplinary forum of natural and social scientists, engineers, policymakers and practitioners that advances systems based analysis methods, tools and solutions in pursuit of sustainable technology, product and service systems, and economies.

KEY COLLABORATORS

Professors Marina Fischer-Kowalski, Roland Clift and Thomas E Graedel

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MARIAN CHERTOW is Associate Professor and Director of Industrial Environmental Management at Yale FES and has been appointed at the National University of Singapore since 2001. She will serve as President of ISIE from 2013-14.

ROLAND CLIFT, CBE, FREng, is Emeritus Professor of Environmental Technology and Founding Director of the Centre for Environmental Strategy at the University of Surrey. In 2009-2010 he was President of ISIE and is now the Executive Director.

MARINA FISCHER-KOWALSKI is Director of the Institute for Social Ecology at Alpen Adria University. She was lead author of the 2011 report 'Decoupling natural resource use and environmental impacts from economic growth' for the United Nations Environment Programme's International Resource Panel. She served as 2007-08 President of ISIE.

THOMAS E GRAEDEL is Professor of Industrial Ecology at Yale FES. He was elected to the US National Academy of Engineering for 'outstanding contributions to the theory and practice of industrial ecology' and was the first President of ISIE.

which analyses the impacts of supply chains from 'cradle to grave'. Life cycle assessment (LCA), to reveal the environmental and resource impacts of supplying goods and services, is well established, following more than 20 years of active development. It has led to many changes in consumer products including labels, such as the carbon footprint, to help consumers decide on their purchases. It has also led to new products. An example is low-temperature detergents. Once LCA revealed that water heating causes the biggest impacts in the supply chain delivering clean clothes, the manufacturers produced detergent for lower wash temperatures. LCA also enables us to quantify the environmental benefits of industrial symbiosis and of closed-loop systems where materials are cycled continually.

Clift explains that the current challenge is to ensure that the quantifiable environmental and economic aspects of supply chains do not mask the less obvious social impacts. Finding transparent ways to reveal social impacts is the next essential step in making supply chains truly more sustainable.

ANTHROPOGENIC CYCLES

Professor Thomas E Graedel, Director of the Centre for Industrial Ecology at Yale, took the lead on a recent UN Environment Programme report on the criticality of metals. Along with the Global Metal Flows Working Group, he assessed the recycling rates of nearly all metals and found that recycling effectiveness as a consequence of economic, technological and societal factors is still quite low. It was revealed that less than one-third of metals had an end-of-life recycling rate over 50 per cent and 34 elements were below 1 per cent (see Figure 1).

This is a shocking statistic considering that, in principle, metals can be used infinitely to minimise material mining and processing. Metals are a finite resource, but their potential to meet future demand is drastically improved if an effort is taken to close the loop in this open-ended system. Clean technologies, such as hybrid cars and wind turbines, rely on metal for their constituent parts (batteries, magnets etc.) and as technology develops, the demand for these materials will grow. Evaluating stocks, rates of growth and decay allows us to make informed inferences about the future, but scenarios of future use intensity, discard, and recycling – if they are to be informative – will require good spatial and temporal resolution (for example, using geographic information systems and remote sensing).

CIRCULAR INDUSTRIAL ECOLOGY IN ASIA

Industrial ecology has a strong focus on Asia, where the most prodigious industrial activity in the world is occurring and where rapidly growing urban communities may arguably determine the world's environmental future. Consequently, Japan initiated its Eco-Town programme in 1997 guided by its Recycling-based Society Law and 26 eco-towns were established between 1997 and 2006. Japanese industrial ecologists are now contributing to the idea of 'resource circulating societies'. South Korea started an eco-industrial park programme in 2005 and strives to establish 20 eco-industrial parks by 2014. Most recently, South Korean leaders have led a green growth initiative emphasising more efficient use of resources such as water, waste, energy-efficient buildings and low-carbon transportation and renewable energy.

With its far-reaching proposal of creating a 'circular economy' in its 11th five-year plan and the implementation of the Circular Economy Promotion Law in 2009, China officially announced its commitment to move from a linear model of high levels of throughput and waste in its economy to a cyclic model emphasising resource productivity and industrial ecology-type goals in consumption, production, and disposal at three spatial scales: local, industrial park, and city. "IE ideas are desirable in many developing countries to help manage growth. China's progressive Circular Economy Promotion Law illustrates that adaptations of industrial ecology tools are possible for the developing world and many other countries are investigating the adoption of similar initiatives," affirms Chertow.

MOVING FORWARD

Graedel, Fischer-Kowalski and Clift are all former Presidents of the International Society for Industrial Ecology and Chertow becomes the Society's leader following the term of current president Gregory Keoleian, Professor of Sustainable Systems at the University of Michigan. Chertow is keen to ensure the growing influence of industrial ecology as a systems science and source of solutions.

The need to understand the relationship of human and industrial systems within the broader natural systems that surround them bonds the work of Chertow, Clift, Fischer-Kowalski, Graedel and many others in a common commitment to the development of a powerful and compelling new field.



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