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A. K. Glasmeier

Industrial Metabolism

The word 'metabolism' comes from the Greek, meaning to change or transform. The concept in biology describes the combined effect of numerous biochemical reactions that convert the materials in a living cell to provide for its growth and maintenance. While the concept of metabolism is uniformly accepted at the cellular level and for individual organisms, its application to larger systems of living organisms or human societies remains underdeveloped. The term 'industrial metabolism' derives from the notion that industrial economies, like biological organisms or natural ecosystems, can be understood as systems for material transformation with distinct metabolic pathways that evolve over time. Industrial metabolism offers a useful perspective for the study of collective human behavior and its effect on the materials cycles that comprise the workings of the natural environment.

Social analyses have considered industrial production and resource-use statistics as social indicators since the dawn of the Industrial Revolution. In the decades since the 1960s, industrial metabolism has been used as a paradigm to describe the exchange of materials among industrial operations in a way analogous to the description of material and energy balances in natural ecological systems. This metabolic analysis contributes to the formulation of technological, economic, and policy instruments aimed at addressing social environmental concerns. In the context of modern social and political awareness about environmental quality the concept offers an analytical framework that is practically motivated to improve the quality of the natural environment through changes in industrial and social norms.

Industrial metabolism examines the exchange of materials and energy between human society and nature at all spatial scales, applying the same analytical parameters to describe material fluxes within and between natural and human systems. At the largest scale this includes study of anthropogenic contributions to atmospheric concentrations of trace gases and the flow of excess nutrients from agricultural activities to water bodies. At smaller scales, industrial metabolism addresses the use of resources in the human economy through the development of resource-accounting frameworks for political and economic entities as well as life-cycle analyses of the materials used in the manufacture of industrial and consumer products.

Emphasis is placed on following the 'material flow' from its origins (e.g., mined ore) through the industrial processes used for its transformation, to the products that contain it, and finally to its disposal or re-entry into the industrial system. At its most comprehensive, industrial metabolism links to human and ecosystem metabolism, for instance by considering the life cycle of metals and organic chemicals in plant tissue and the human diet. The information is used to construct a 'materials balance' of a system and draw conclusions regarding the actions needed to improve the environmental character of its metabolism. Possible indicated actions might include industrial process change, product substitution, consumer education, government regulation, development of enabling technologies, installation of new resource recovery capacity, and economic incentives by government (see *Global Environmental Change: Human Dimensions*).

To determine existing and potential metabolic pathways, industrial metabolism considers the social dynamics that influence the integrity of the natural environment. To establish quantitative relationships between material flows and social dynamics, industrial metabolism compares indices of industrial production and social consumption to social and demographic variables such as population, gender, age, land use, and economic activity. To aid in the formulation of public policy, industrial metabolism bases its findings in the context of government institutions, economic incentives, and cultural biases that influence the flow of physical resources and their impact on the natural environment.

1. Natural History of Chemistry

One main thrust of research in industrial metabolism compares the natural history of the basic biogeochemical reactions observed in planetary evolution and contemporary ecosystems with those employed by industrial society. By studying the basic chemical processes observed in nature for achieving beneficial transformations of materials, this inquiry seeks to identify industrial processes that minimally perturb global biogeochemical cycles and least interfere with the services provided to humans by nature.

From a historical perspective, the Earth represents an evolved system for recycling materials. Over geological periods the planet has allowed for the biogeochemical feedback necessary to arrive at a state hospitable to human life over the majority of the globe. Characteristic of this evolution is the natural system's ability to find uses for discarded by-products. For instance, at the planetary scale we find the development of organisms using photosynthesis to produce energy. The life-forms employing this process came to dominate a planet rich in atmospheric oxygen, the waste product of previous life. This system attribute, a product of evolution, is also evident over shorter timescales in natural ecosystems. For these systems, scientists describe a complex web of life supported by the wastes from animals and plants, identifying the significance of those wastes as providing the basic nutrients for regeneration.

Industrial metabolism notes that in selected instances the need to find uses for waste products drives the evolution of processes used in human industry. For example, the search for uses for unwanted coal tar led to the birth of the synthetic dye industry at the beginning of the twentieth century in Western Europe. Natural gas, a leading energy source at the end of the twentieth century, was once 'flared' at wellheads before its value was recognized for energy and commercial products from nitrogen fertilizer to synthetic rubber. Chlorine entered the human environment initially as a by-product from the manufacture of sodium chemicals and eventually became the far more marketable product. Following the evolutionary principle evident in natural, as well as human, systems, industrial metabolism seeks to reveal opportunities for using waste materials from contemporary industrial systems (see *Sustainability Transition: Human–Environment Relationship*).

Industrial metabolism stipulates that resource use and waste generation can be avoided if human industry can learn from the design models found in nature and overcome the barriers to replicating natural systems for material transformation in human industry (see *Industrial Ecology*). One of the most basic differences between natural and human-made systems derives from the fact that natural systems are driven by solar energy in its different forms, which contrasts with human energy production as a relatively diffuse spatial source. The intensive use of energy to generate conditions of high pressure and temperature for human production processes further distinguishes human from natural metabolic processes that typically occur under conditions of ambient pressure and temperature. Human-made material transformations also generally follow a series of linear discrete transformations (i.e., unit operations) in contrast to the more continuous processes found in nature. In addition to learning from the design of natural systems, industrial metabolism seeks to identify, and engineer, natural processes to replace commercial ones and thus reduce human resource use and waste generation (see *Greening of Technology and Ecotechnology*).

2. *Resource Accounting*

A complementary thrust of industrial metabolism research explores the actual physical flow of materials within industries and regions. Materials-flow analyses rely on the law of conservation of mass (i.e., no new mass is created or destroyed in a closed system) to provide a complete materials balance equating the quantities identified as inputs with those labeled as outputs. Employing the materials balance principle allows for estimation of material flows in industrial and consumer products as well as in by-products and wastes even when data are missing. The analysis may include material flows apparent to the public, for example in household wastes, as well as the hidden material flows occurring in mines, quarries, power plants, factories, farms, and disposal sites.

Because both large- and small-scale flows have an impact on the environment, industrial metabolism examines bulk materials, typically measured in millions of tons, as well as toxic materials measured in micrograms. Large-scale flows such as hydrocarbon fuels used to supply energy, and fixed nitrogen used for food production, have an impact on global biogeochemical cycles that govern climate and ecosystems. Smaller volume flows that enter the human food chain may pose chronic or acute threats to human health and threaten the biological balance found in natural ecosystems.

The industrial metabolism of any material must be determined within the boundaries of a defined system. Once within system boundaries, flows must also cross an internal boundary in moving from 'nature' to the 'human' domain in order to be included in the account. Geographically based analyses examine the industrial metabolism of material sources and sinks formed by industrial, agricultural, and urban activity, and the surrounding environment. Analysts can also map material flows for individual facilities or entire sectors, provided that they consistently define how to evaluate indirect material flows occurring outside the sector under study. Finally, the material itself may provide the boundary, if the effort calls for improved understanding of its metabolism independent of other associated flows.

Criteria for including materials in the metabolic analysis range from narrowly restrictive to broadly inclusive. Some account only for those material flows associated directly with economic transactions. Other frameworks include hidden material flows such as mine tailings from metal production, overburden removed to access coal seams, and eroded soil from agricultural land. Still other accounting frameworks tabulate the translocation of dirt and rock for infrastructure such as road building and harbor dredging.

3. *Future Development*

Several factors motivate contemporary interest in industrial metabolism as a framework for analyzing the environmental impact of human economies. Research aimed at developing operating industrial economies that do not damage the natural environment, benefit from the study of how natural systems are able to operate without permanently depleting natural resources or damaging life-support systems. Resource accounting offers a compact and transparent method to convey environmental information to government officials, resource managers, and industrial operators whose decisions influence environmental quality.

Challenges to industrial metabolism include the need to refine methods for materials-flow analysis to counter limits in the ability of government and industry to monitor all environmentally important materials streams. Far more work needs to be done in the realm of environmental science to establish causative relationships between human emissions and damage to the environment. Finally, the inescapable influence of specific geographical and cultural features on human–environment interactions requires models of individual and collective behavior to describe and improve environmental quality at the local level where humans reside and interact with one another.

See also: Ecology, Political; Environment and Development; Environment Regulation: Legal Aspects; Environmental Change and State Response; Environmental Policy; Human–Environment Relationship: Indicators; Sustainable Development

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I. K. Wernick

Industrial Policy

Industrial policy is an approach to economic policy in which the state gives direct support to particular firms and industries. Since the modern state has a pervasive influence on economic activity, virtually every industry is influenced by its actions. Even general codes typically have a differential impact upon particular firms and industries. There is thus a sense in which every industry is shaped by state action and when the state acts in a deliberate and purposive way to affect the fate of an industry, either on its own behalf or in response to pressures from the industry itself, one can speak of industrial policy in the generic sense of the term. The term might be extended still further to refer to cases where a lead enterprise, and/or an employer association, pursues a strategy for the industry as a whole. But we generally reserve the term for what might be called industrial policy in the large. This is an approach in which particular firms and industrials are supported in pursuit of *national* economic policy goals. Such policy is generally conceived in terms of a broader plan, or strategy, of national economic development. Instruments of support range from tariff protection and import restrictions, tax concessions, subsidies, and targeted services to direct intervention through institutions of the state itself, including the state's own research and development laboratories, state schools and universities and state-owned enterprises. Indeed, industrial policy is a major justification for the state to undertake these activities directly on its own account.

Industrial policy in this larger sense was practiced widely in the early postwar decades, although the term itself seems to date from the 1970s, when this approach to national economic development became the subject of a widespread debate. In more recent decades industrial policy has fallen out of favor, so much so that the term has taken on a pejorative connotation. Its proponents have tended to use various euphemisms and circumlocutions, although one is hard pressed to point to a particular word or phrase that has taken its place. These changes reflect a major shift in the intellectual and political climate of the late postwar period. In some ways, the climate has now shifted back once again in favor of an industrial policy, although one which is understood and practiced very differently from that of the early postwar decades.

In the first few decades after World War II, among the advanced developed countries the leading practitioners of industrial policy were France and Japan. In France, the postwar policy was associated with the Commissariat du Plan (The Planning Commission)

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