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Industrial Ecology and the Ecocity

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Cities can be regarded as organisms, and analyzed as such, in an attempt to improve their current environmental performance and long-term sustainability.

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A modern city is the place of residence of hosts of organisms, human and otherwise, and we can picture the metabolism of a city as the sum of the metabolism of its inhabitants (Newcombe, 1979). Ecologists generally study organisms by modeling the flows of nutrients and energy entering individual organisms, of resources being stored for later use, and of residues leaving. All these flows occur within cities as well. Accordingly, the city itself can be viewed as an organism with a metabolism that can be studied. If we examine a city's metabolic flows—nutrients, energy, storage, residue—from an environmental perspective, a further topic can be studied: the potential environmental impacts of the residues. Finally, since we evaluate cities at least partly from a policy point of view, metabolic studies can provide the basis for discussions of the desirability of changes in the scale or type of a city's metabolism, and how such changes might best be accomplished.

Investigating a city as an organism, and thinking about what characteristics and policy approaches might make a city environmentally superior (what we might term an "ecocity"), fall within the purview of the emerging specialty of industrial ecology (Graedel and Allenby, 1995). Industrial ecology is the study of the flows of resources in the technological environment, of the effects of those flows on the natural environment, and of the influences of economic, political, regulatory, and social factors on the flow, use, and transformation of resources (White, 1994). Industrial ecology addresses itself to societal-level issues as well as to more directed topics such as pollution prevention and the design of products and processes in such a way that their environmental implications are minimal. In a clearly related societal issue, many groups worldwide are attempting to define what is meant by the engaging but fuzzy term "sustainable development." However sustainable development may be pictured, the tools and approaches of industrial ecology will be important in its implementation.

Thus, industrial ecology has the potential to speak to shorter-term issues such as our use of resources and our generation of residues, and to longer-term issues such as sustainability. These issues are not confronted only in cities, but it is in cities that their magnitude and impact are most striking, and where the potential for beneficial action is greatest.

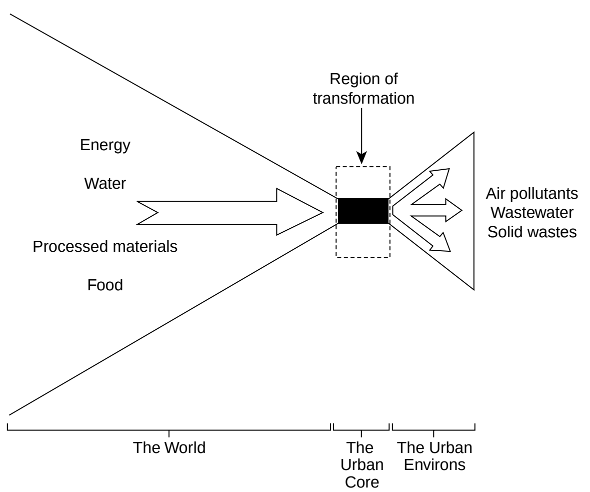

FIGURE 1 Generalized materials flows of urban metabolism. Materials are transported from throughout the world (a vast spatial scale) into the urban core, are transformed in order to sustain the human population, and are then released as wastes into the urban environs, a significantly smaller region adjacent to the urban core.

As centers of population and human activity, cities are also centers for flows of materials. The conceptual picture is shown in Figure 1. Cities gather resources of all kinds from near and far—steel beams from Indiana, porcelain from Europe, apples from New Zealand, coffee beans from Costa Rica. Some of this material is retained for long periods, such as the steel beams in multistory buildings. Other material—the New Zealand apple, for example—is transformed within a short time, and its residues discarded. Though wastes are seldom disposed of within the urban area itself, they generally move much shorter distances than the distances from which their progenitors were acquired. Cities are great attractors, but weak dispersers.

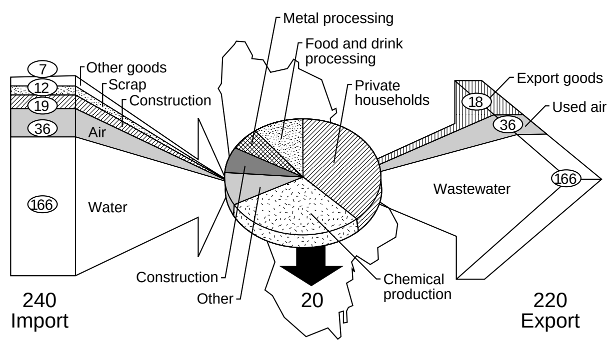

FIGURE 2 Urban metabolism. Flow of materials through the Bünz Valley, Switzerland, in metric tons per capita per year.
SOURCE: Brunner et al., 1994.

One of the few actual studies of the metabolism of an urban region was performed several years ago by Paul Brunner and coworkers at the Technical University of Vienna for the Bünz Valley in Switzerland (Brunner et al., 1994). Several features of the results, shown in Figure 2, are of particular interest. The first is the sheer magnitude of the flow: 220 metric tons per capita per year, on average. Also of note is that the most abundant resource flow, by far, is that of water. The water is not retained; it passes through the system in various uses, acquires a variety of contaminants, and leaves as part of the outflowing residue. The same is true, though at substantially lower throughput, for air used in combustion processes. The resource flows that have more complex fates are those of industrial chemicals and metals; of the 58 metric tons per capita that enter the region, 20 (more than a third) do not leave. Rather, they are added to the "built stock": roads, equipment, housing, and so forth.

Are there optimum flows of resources to an urban organism? Does the answer depend upon the size of the urban region, or its population density, or its culture? As yet, we have too few data on urban metabolism to answer these questions, but it is clear that the answers will relate not only to the urban organism itself, but also to its particular location, to the lifestyles of the inhabitants, and to its surrounding environment.

If we have a picture of resource and residue flows for a city, can we use that information to help determine the degree of environmental responsibility for the city? For the past two years, Gordon Geballe and I have directed a graduate seminar at Yale entitled "Designing the Ecocity," in which we have addressed this and related questions. A consensus of the research done for the seminars is that the following principles help define an ecocity:

- The city must be sustainable over the long term.
- The city must utilize a systems approach to evaluating its environmental interactions.
- The city design must be flexible enough to evolve gracefully as the city grows and changes.
- The open space of an ecocity must serve multiple functions.
- The city must be part of regional and global economies.
- The city must be attractive and workable.

Thus, stocks, flows, and metabolic analyses are an important part of the information relevant to a city's environmental performance, but only a part. To address the broader social and economic aspects of cities and environments, Megan Shane and I have developed an initial set of ecocity metrics and suggested appropriate criteria for rating city performance in each metric on a "high, medium, low" scale (Shane and Graedel, 1999). There are 10 metrics, divided among resource use, residue generation, human habitation, quality of life, and urban environmental management, as shown in Figure 3. Our preliminary assessment for Vancouver, British Columbia, the first application of this system, is also shown in Figure 3. Evaluated against the rating criteria, Vancouver did well in open space,

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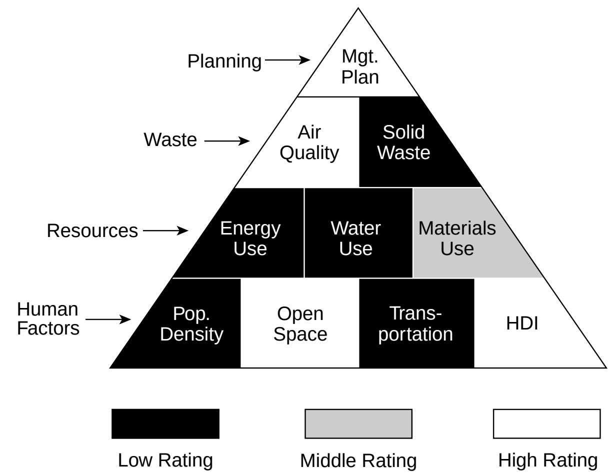

FIGURE 3 Ecocity metrics. The triangle shows the 10 metrics, and the shading shows a preliminary assessment, using those metrics, for Vancouver, British Columbia. HDI = Human development index, a measure of quality of life defined by the United Nations Development Programme.

air quality, quality of life, and environmental planning, but poorly in the use of water and energy, the generation of solid waste, sprawl, and reliance on private transportation. Overall, its ecocity assessment score was 9 points out a possible 20—a good start, but leaving plenty of room for further improvement.

While it is interesting to think of urban regions as organisms and ecosystems, and to devise ways to evaluate their environmental performance, such activities are more than merely intellectual exercises. Rather, they enable us to study the benefits to be derived from industrial and urban metabolic information. These benefits may be grouped into three categories, as indicated below.

Maintaining Human Systems. Urban complexes require that resources to support them be provided in sufficient magnitude and on a satisfactory time schedule. In the case of small urban areas, materials flows are seldom compromised by input or output capacity. As these organisms and ecosystems grow and evolve, limits to efficient connectivity often begin to emerge. In modern technological systems, especially those in densely populated urban areas, these limits are often related to infrastructure.

Urban infrastructure—roads, power lines, natural gas distribution systems, water supply systems, sewerage, etc.—has not traditionally been designed with flexibility and expansion in mind. Furthermore, it is customarily placed out of sight (and out of mind)—under streets, along railroad right-of-ways, within building walls—so that it is difficult to modernize. A recurring problem in growing cities is that infrastructure is unable to keep pace with growth in population and in industrial and commercial activity. By studying and predicting requirements for material flows, urban industrial ecologists can aid in accommodating needs or desires involving flows of resources of all types.

In a similar vein, urban industrial ecologists can evaluate and anticipate limits involving the management of residues. While infrastructure is still an issue here, knowledge of the assimilative capacity of the environments receiving the residues is crucial. Topics for study include the amount and characteristics of wastewater flows, the rate of generation of solid wastes, the disposal of toxic residues, and the like.

Implications for Population Density

It is interesting and unfortunate that we have little in the way of a clear idea of what the limits might be to resource supply and removal within densely populated areas. Might we be better able to reuse materials if population density is high? Will high population density be acceptable from a social point of view? From an infrastructure point of view? Can we reasonably hope to make cities more densely populated than Hong Kong (approximately 2000 people per hectare), and would we want to?

Urban industrial ecologists can respond to these issues not only by suggesting limits to supply and assimilative capacity, but also by working to develop alternative systems for delivering resources, for recycling materials within local metabolic systems rather than exporting them, and by finding ways to reduce flows while maintaining the services those flows now provide. These efforts may immediately determine the feasibility from a materials standpoint of reordering society for the purpose of improving long-term sustainability.

Maintaining Environmental Systems. The continued existence of a planet suitable for supporting life is clearly an important thing to think about; it is also clearly a function of the environmental stresses placed upon the planet by human activities. The levels of these stresses now and in the future can be informed by studies of urban metabolism, as the following examples show.

The air in the Los Angeles Basin of California was clear and healthy until the middle of the twentieth century. In the 1950s, however, a new phenomenon, photochemical smog, began to make the quality of the air progressively worse and worse. Although motor vehicles had been driven around Los Angeles for many years, there were finally enough of them and the tailpipe emissions were high enough that an environmental threshold had been exceeded. Future exceedences of this type may be able to be predicted, but only if the relevant environmental science is understood, the current residue flows have been determined, and future residence flows can be estimated.

Technological resources should cycle just as do nature's resources.

A second type of benefit from urban metabolic studies is the potential for determining the relative intensity of sources of residues. In a study of emissions of copper to the Swedish environment (Landner and Lindeström, 1999), neither industrial activity, nor mining, nor roof runoff proved to be the dominant source of copper, as was anticipated. Surprisingly, residues from automotive brake linings were the source of copper with the highest flow rate to the environment. With this information in hand, Sweden was able to place less emphasis on dealing with unimportant environmental flows of copper, and more on the crucial flows.

Redesigning Human Systems. Urban industrial ecology operates from the perspective that an ideal technological society is one in which materials, once extracted from their natural reservoirs, are retained in useful forms as long as possible through reuse and recycling. That is, technological resources should cycle just as do nature's resources. Such an achievement is only possible if considerable effort is made to enable it: products are designed to use recycled materials, materials are used in ways easy to recover, and so on.

Urban industrial ecology further contributes to resource cycling by identifying previously unappreciated or unmeasured reservoirs that may contain reusable material. A classic study of this type (Kimbrough et al., 1996), examined silver loss to the San Francisco Bay and the industrial and societal use of silver in the same area. Two important facts emerged:

- Most of the loss of silver to the bay occurred during X-ray film developing by small medical and dental offices. Once this silver source was identified, arrangements were made for regular pickup of discarded film developing baths. The result was an improved bay environment and the recovery of silver for future reuse.
- Approximately 10 percent of all silver used was retained on developed X-ray film in medical and dental offices. Since the information on those films can now be scanned into digital form and stored electronically, the X-ray film represents a significant stock of silver that can be "mined" in the future as needed.

Although research such as the silver study has thus far been rare, we can readily imagine that similar work will lead to information on other important but unappreciated reservoirs and on losses important to avoid in order to provide healthy environments.

Cities can be regarded as organisms, and analyzed as such, in an attempt to improve their current environmental performance and long-term sustainability. This is a relatively new area of study, and one where many more data need to be gathered before meaningful results will be derived. In addition, the topic of urban metabolism is not entirely within the purview of industrial ecology; fields such as urban planning, urban ecology, and social science have roles to play as well. Much work remains to be done.

Even though data are currently sparse, the demand for such data and for the revelations that will spring from it is increasing rapidly. The challenge of true sustainability for our fragile planet will be faced or avoided in cities more than in any other locale. We need promptly to determine how to define and develop ecocities, and then to act on our findings, or face what increasingly look to be unmanageable consequences.

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