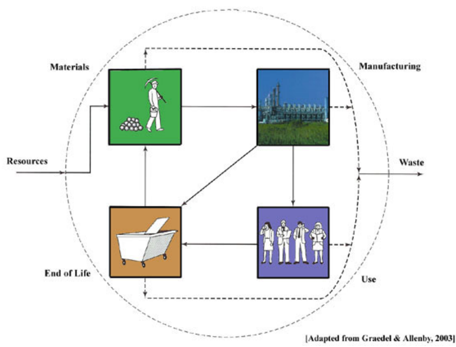
ENGS 171

INDUSTRIAL ECOLOGY

Introduction – Principles – Definitions



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Industrial Ecology Means and Objectives
= Course materials and objectives

1. (Knowledge of) Fundamental ways by which **industry** can make progress in the direction of sustainability;
2. (Knowledge of) Current, 'green' technological initiatives in various industries;
3. (General understanding of, and experience with) Design for environment by means of energy efficiency, materials choice, biomimicry, *etc*.;
4. (Ability to use) Systems thinking to view and redesign a **product**, and to improve its environmental performance;
5. (Ability to place) Engineering design in the broader context of sustainable practices;
6. (Ability to perform limited) Life-cycle assessments;
7. (Ability to decide in the presence of) Conflicting objectives and of incomparable quantities;
8. (Ability to build the) Business case for a product's sustainability, through product service models, business model canvas, or other business tools.

Starting point: Sustainability

Sustainability is often on people's lips nowadays.
Everybody seems to have an idea of what it means, and yet it is an elusive concept.

Most often, people approach the concept of sustainability in one of two ways:

1. The "bio type":

These people think foremost about nature and structure their thoughts around ecological systems, food webs, trophic levels, biodiversity, and productivity.
For them, sustainability is a matter of **carrying capacity**, with the expectation that it can actually be measured.

→ Expectation of a quantitative (scientific) approach.

2. The "ethic type":

These people have read texts by the likes of David Thoreau, Rachel Carson and Aldo Leopold, and they are driven by a **moral obligations** toward future generations.

→ Expectation of a subjective (normative) approach.

Demand on resources

A thought to ponder...

On the eve of Indian independence, Mahatma Gandhi was interviewed by a British journalist who asked him whether independent India could follow the British model of industrial development. Gandhi, in his famous response, said:

"It took Britain half the planet's resources to achieve its level of prosperity. How many planets would India require for its development?"

And, there is the "**Factor 10**":

- Population is expected to double before it levels off → **Factor 2**

- If everybody in the world aspires to the American standard of living, the rate of resource consumption would have to quintuple (assuming constant ratio between economic activity and material consumption) → **Factor 5**

$2 \times 5 = 10$

Thus, one can expect a ten-fold increase in demand for resources.
Yet, our mining activities already span the entire planet. So what should be done?

Our over-arching goal is to achieve Sustainability.

But how?

Nature shows us a way: Natural Ecosystems are sustainable.

IDEA: Let's try to imitate nature and strive to make our industrial systems work in the manner of natural systems.

In other words, let's engage in BIOMIMICRY (imitation / copying of nature).

This is the overarching objective of Industrial Ecology, to render our industrial systems sustainable by making them obey the laws of nature.

Note that Industrial Ecology is *one way* of working toward Sustainability.
There is no proof that it is the only way. For example, the Clinton White House and the US Business Council for Sustainable Development had advocated "eco-efficiency", meaning "adding maximum value with minimum resource use and minimum pollution, with the expectation that such an incremental approach will eventually lead to sustainability. However, William McDonough (D'73) has criticized this approach as "getting better at (potentially) doing the wrong thing."

Nature consists of a number of systems called "spheres":

- The *atmosphere* (air and what is in it)
- The *hydrosphere* (water in its liquid form)
- The *lithosphere* (land, rocks and below)
- The *biosphere* (all the living organisms).

To this, we now add the *anthroposphere* (from ανθρωποσ, Greek for the human person), the whole of human systems, which includes:

- The built environment (buildings, roads, and other infrastructure)
- Agriculture (also called the *Primary Sector*)
- The manufacturing industry (also called the *Secondary Sector*)
- The service industry (also called the *Tertiary Sector*)
- Energy infrastructure (power plants and transmission lines).

This *anthroposphere* includes:

- Materials (raw materials, processed materials, products, solid waste) } Each bound by a conservation principle
- Energy (fossil fuels, nuclear, renewable forms of energy) }
- Information (knowledge, inventions, communications, *etc.*). ← unlimited supply and growing

Natural Systems:

- No waste – Closing of materials loops
  The waste of a process is the food of another activity.

- Materials are metabolized.

- Use of energy at low temperatures, near thermodynamic reversibility; parcimonious use of energy

- No central control

- Great diversity of species and redundancy

- Nonlinearities in behavior (live or die)

ensure adaptability and resilience

Most current Industrial Systems:

- Much waste – Few materials loops closed
  Many resources are extracted from the environment and degraded forms of materials are returned to the environment.

- Materials undergo transformations.

- Use of energy at high temperatures, away from thermodynamic reversibility; inefficient use of energy

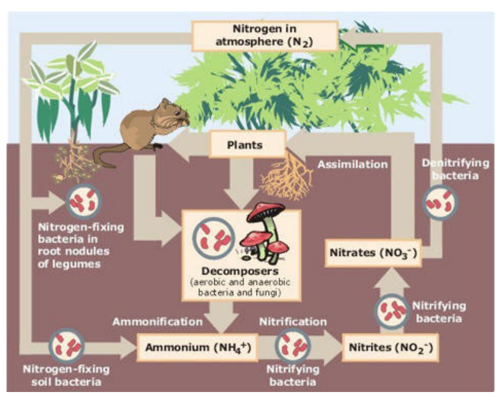
- Weak central control (free market tempered by some regulations)

- Moderate diversity of activities and redundancy (competition)

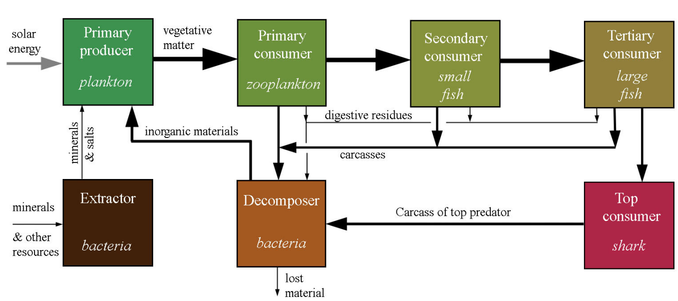
- Nonlinearities in behavior (make a profit or go out of business)

How natural ecosystems work

Either looking at
a single substance

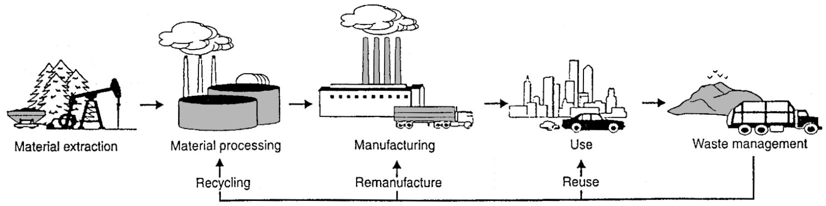


Or looking at
populations



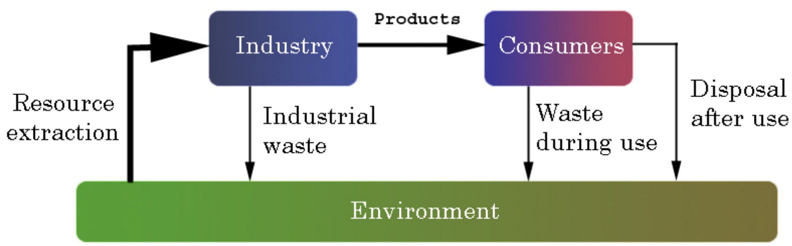
By contrast, a typical industrial system looks like:

Example



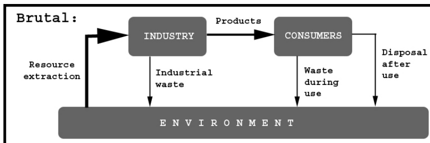
(Courtesy of D. Navin-Chandra, Carnegie Mellon University.)

Generic view

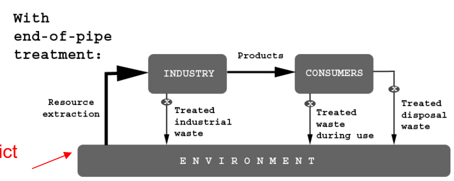


… mostly a one-way, open system !

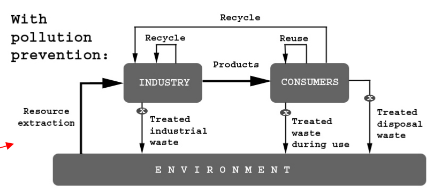
A progressive path toward a sustainable industrial system



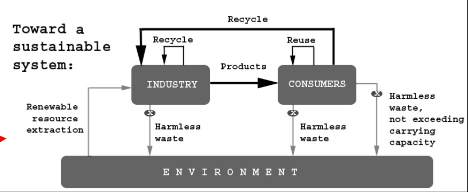
naive



improvement causing conflict between industrialists and environmentalists

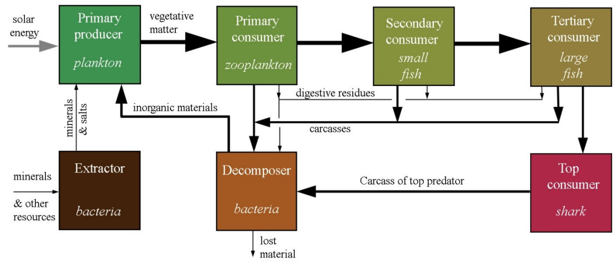


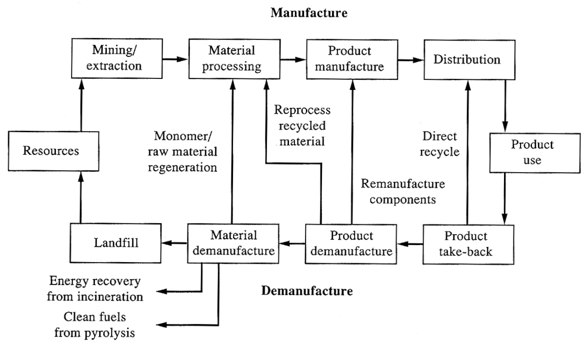
with increasing cooperation between various stakeholders



ideal situation and goal

What imitation of nature should look like

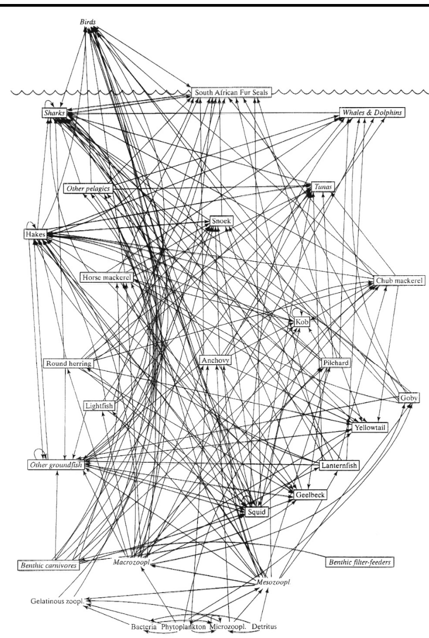




A product's life cycle from cradle to reincarnation.

An other aspect: Complexity

Natural ecosystems are usually quite complex, with many actors and relations.

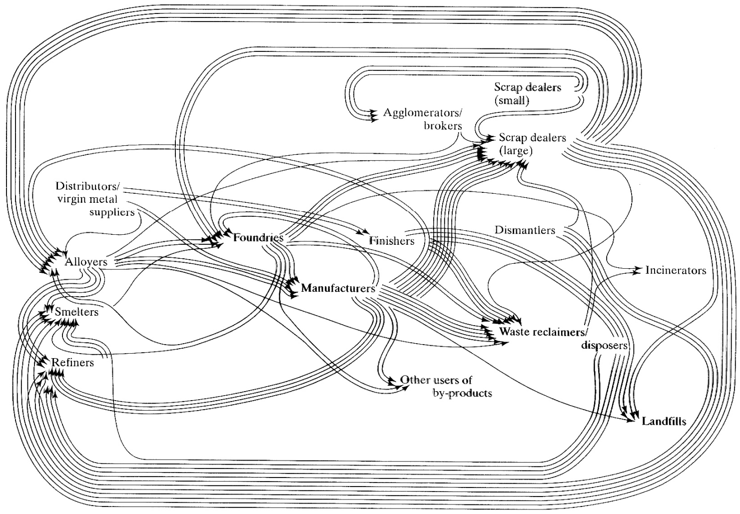


(a) A food web for the Benguela marine ecosystem off the southwest coast of South Africa. (Reproduced with permission from P.A. Abrams, B.A. Menge, G.A. Mittelbach, D.A. Spiller, and P. Yodzis, The role of indirect effects in food webs, in *Food Webs*, G.A. Polis and K.O. Winemiller, eds., New York: Chapman & Hall, 371–395, 1996.)

What about industry?

How do industrial systems compare to natural systems?

A better industrial system

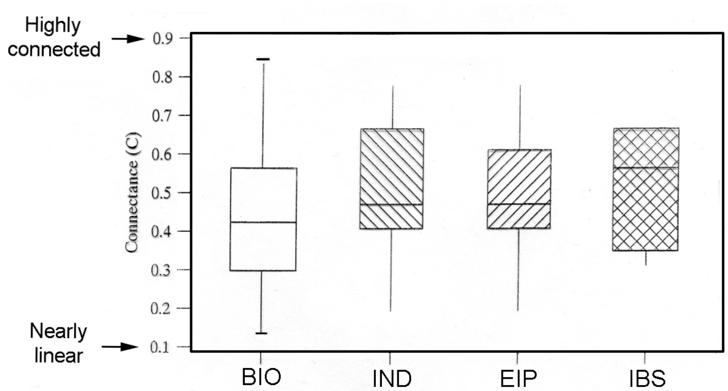


A diagrammatic representation of an industrial food web. In this diagram, each line represents one set of transactions between categories of interviewed firms. For example, the transactions of a firm that might send its wastes to four different waste disposal companies appears as only one line. Similarly, a firm that might buy from three different alloyers also receives a single line for these transactions. The magnitudes of the flows are not captured on this diagram. Also, flows to and from the consumers of the industrial goods are not shown in this diagram, nor are fugitive emissions to air, water and land. (Reproduced with permission from A.D. Sagar and R.A. Frosch, A perspective on industrial ecology and its application to a metals-industry ecosystem, *Journal of Cleaner Production, 5*, 39–45, 1997.)

Connectance level C:

$$C = \frac{\text{number of actual links}}{\text{total possible number of links}} = \frac{L}{S(S-1)/2} = \frac{2L}{S(S-1)}$$

L = number of links
S = number of species



Box plots of connectance in different types of food webs. BIO = 113 biological food webs; IND = 19 industrial food webs, consisting of 15 eco-industrial parks (EIP) and 4 integrated biosystems (IBS). (Biological data are from F. Briand and J.E. Cohen, Environmental correlates of food chain length, *Science, 238,* 956–960, 1987; industrial data are from C. Hardy and T.E. Graedel, Industrial ecosystems and food web theory, *Journal of Industrial Ecology, 6,* in press, 2002.)

THE BASIS OF INDUSTRIAL ECOLOGY

The Four Laws of Ecology

(Barry Commoner, 1971, 33-48)

1. Everything is connected to everything else.
2. Everything must go somewhere.
3. Nature knows best.
4. There is no such thing as a free lunch.

The equivalent of Commoner's "laws" for sustainability in industry are:

Eco-Industrial Principles and Industrial Ecology

1. Industry is an interrelated system of extraction, production, distribution, consumption and disposal.
2. Industrial production must be subject to "life-cycle analysis" so as to identify materials pathways (*Industrial Metabolism*).
3. The natural world is a source of models of efficiency and of renewable energy and resources.
4. Finite resources must be returned, recycled, reclaimed and/or reused in order to close materials cycles and minimize energy consumption. ("Technical nutrients" according to William McDonough)

Implications of Sustainability for Industrial Ecology

1. Not using renewable resources faster than they are replenished.
2. Not using non-renewable, non-abundant resources faster than substitutes can be found.
3. Not releasing waste faster than the planet can assimilate them.
4. Not significantly depleting the diversity of life on the planet.

"The fundamental task of Industrial Ecology is to … match the inputs and outputs of the man-made world to the constraints of the biosphere."
(Ernest Lowe, "Industrial Ecology – An organizing framework for environmental management, *Total Quality Environmental Management*, 73-85, Autumn 1993)

"The economy is a subsystem of the biosphere, not the other way around."
(David W. Orr, "Shelf Life", *Conservation Biology*, Volume 23, No. 2, 2009, quoting Herman Daly)

More definitions of INDUSTRIAL ECOLOGY

Tibbs (1992) & Ehrenfeld (1994):

1. Improving metabolic pathways (*ex*: less solvant)
2. Dematerializing the output (ex: lighter product)
3. Systematizing patterns of energy use
4. Balancing industrial in/output with natural capacity
5. Creating loop-closing practices
6. Aligning policy
7. Creating new structures and new linkages

Lowe (1993):

IE = recognition that industrial systems are natural systems
IE's toolbox:

1. Toward zero waste
2. Design for Environment (DFE)
3. Industrial metabolism (IM)
   [= big-view approach to materials/energy flows]
4. Management at the industry/nature interface
5. Creation and exploitation of information

Frosch (1994):

IE = force to change from a linear-open system toward a cyclical-closed system

Barriers to IE:
1. Technical hurdles
2. Insufficient information
3. Organizational obstacles
4. Regulatory issues and legal concerns

Graedel & Allenby (1995):

"*Industrial Ecology is the science of Sustainability.*"

1. Optimization of resources
   (less consumption, less waste)
2. Optimization of energy
3. Optimization of capital (human and monetary)

O'Rourke, Connelly & Koshland (1996):

2 principal goals in IE:
1. Closing loops
2. Paradigm shift
   (in our view of industry/nature relation)

2 strategies in IE:
1. Getting the information right
   (*ex*: LCA, ecofeedback)
2. Getting the price right
   (*ex*: Total cost accounting)