An Introduction to Sustainable Production and Consumption

By

Belinda Wong-Swanson[1]

Submitted to SEE Magazine, Hong Kong

18-Apr-05

Background

Have you ever wondered what it takes to produce the products we use in our daily life? What materials the products contain, how much water and energy were used during the process of making them? What happens to these products when we discard them? These are all questions associated with sustainable production and consumption.

Problems associated with human economic activity

Currently most of the world's energy is derived from non-renewable energy sources, primarily oil, gas and coal, that result in carbon dioxide emissions into the atmosphere. Much of the human economic activity is powered by such non-renewable energy sources. In addition many manufacturing processes use minerals for raw materials such as iron, copper and bauxite, generate carbon dioxide and sulphur emissions, and foul up the rivers and coastal waters nearby.

In *Macroscope*, written in 1975, de Rosnay tried to put a value on economic activities that are highly energy intensive.

> "A systemic approach to the processes that link the economy and ecology must try to go beyond the already outdated concept of monetary value and complete it with the concept of energy cost, expressed in a universal unit of energy. This unit might be the kilocalorie; it would allow, at the level of the control and use of energy, a unification of biological, ecological, and socioeconomic systems."[1]

De Rosnay further provided an estimate of the energy required by some major human economic activities (see Table 1). What is most striking about this table is the amount of energy it takes to produce aluminum relative to other materials. It

---

[1] Innov8 LLC, 624 Agua Fria Street, Santa Fe, NM 87501, USA. Email: info@innov8llc.com. URL: http://www.innov8llc.com. In her Ph.D. dissertation (Energy Analysis of Manufacturing Processes on the Moon, Order Number 9210280, UMI 1991,) she proposed to apply the principles of thermodynamic availability and Pinch Technology to minimize the impact on the lunar environment by human activities.

is over 1.5 times more energy intensive to produce one ton of aluminum than to fabricate an entire car!

Table 1. Estimates of magnitudes of kilocalories used in selected human activities and products.

Item	Estimated energy use
Energy from the sun	3.7×10^{18} Kcal/day
Total world consumption, 1974	58×10^{15} Kcal
Food consumption in France	45×10^{12} Kcal
Energy needed to produce:	
- aluminum (one ton)	50×10^{6} Kcal
- paper (one ton)	10×10^{6} Kcal
- steel (one ton)	7.5×10^{6} Kcal
- cement (one ton)	2.2×10^{6} Kcal
- petroleum (one ton)	1.3×10^{6} Kcal
Energy needed to produce a car (1.5 tons)	32×10^{6} Kcal
Energy needed to feed a man for 30 years (subsistence only)	32×10^{6} Kcal
Energy needs of a man	2,500 Kcal/day
Energy from one liter of gasoline	10,000 Kcal/day
Energy cost for one passenger on a transatlantic flight	6×10^{6} Kcal

The wasteful use of natural resources in everyday human economic activities is made apparent in *Lean Thinking*. The authors, Womack & Jones developed the value stream for a carton of cola to illustrate the amount of non-value creating steps, or waste, typical consumer products require. Huge mining equipment and large amounts of energy are used to mine bauxite. Trucks then transport the ore from the mines to chemical mills where the bauxite is reduced to powdery alumina. Next, carriers then transport the alumina to a smelter where an even more enormous amount of energy is used to reduce two tons of alumina to one ton of aluminum. The aluminum is transported by another carrier to a rolling mill, where further energy is used to reduce the aluminum thickness from 1 meter to three millimeters. In all, it takes approximately 319 days to bring mined bauxite to the grocery store shelf, **yet only 3 hours of that time actually contributes to a valued product.** Twenty-four percent of aluminum coming out of the smelter never makes it to cola cans and becomes scrap instead.[2]

Since the industrial revolution, all human economic activities have been merely the transformation of natural resources such as oil, water, and human labor into products and services. Human economic activities use four capitals[3]: human, financial, manufacturing and natural. Natural capital includes the air, water, soil, minerals, oil, plants, animals, deserts, wetlands, tundra, rainforests, oceans and rivers; it is the sum total of the ecological systems that support life.

We pay salary to workers for their labor, pay interests on loans from banks and investors, rent or purchase the equipment and facility to make the products, and pay for fuel and oil to run these operations. However traditional economic accounting principles do not put a price on the cleanliness of the air and water required by all living things. Until recently, when companies fouled the air and water, they moved on to another cleaner, less expensive location, leaving the public to pay for the cleanup. In fact, we even monitor the rates at which we use up human capital, natural capital, financial capital and manufacturing capital as an indicator of economic development.

Since the industrial revolution, science and technology have enabled humans to live longer and healthier, wealthier lives, able to be entertained instead of just to subsist. Figures 1 & 2[4] show the trends in birth and date rates from 1850-2000 and the growth in gross domestic products among developed and developing countries. They show that overall we are living longer and producing more. In living longer and being better off than our forefathers, we wrongly believed that science and technology could solve all problems.

Yet science and technology have not enabled us to reproduce natural capital. We tried in Biosphere 2[5]; we learned a lot about the ecosystem from the experiment but in the end it was not entirely closed and self-supporting, as it was powered by a power plant nearby. Other problems arose: the Biosphere 2 inhabitants were not able to grow adequate amounts of food to feed themselves and most lost weight. The experiment had to be shut down when the oxygen levels dipped below the level necessary for human respiration and nitrous oxide concentrations reached too high.

In reality, all our activities have led to diminishing our natural capital. In *Small is Beautiful*[6], E.F. Schumacher puts in more bluntly:

> "Modern man does not experience himself as a part of nature but as an outside force destined to dominate and conquer it… The illusion of unlimited powers, nourished by astonishing scientific and technological achievements, has produced the concurrent illusion of having solved the problem of production. The latter illusion is based on the failure to distinguish between income and capital where this distinction matters most. Every economist and businessman is familiar with the distinction, and applies it conscientiously and with considerable subtlety to all economic affairs - except where it really matters: namely, the irreplaceable capital which man has not made, but simply found, and without which he can do nothing."

New approaches to human economic activity

In the last two decades, many visionaries have developed ideas as to how we might extend our natural capital, perhaps even allow it to replenish. Oxymoronic sounding terms such as industrial ecology, ecological economics, industrial symbiosis have entered our vocabulary. What is most encouraging is that once you read about these ideas, the terms are not so oxymoronic after all. While they differ in their approach somewhat, and are occasionally even contradictory, they all have several common points.

- Look to nature, such as trees, ants, bees, to perform human economic activities in order to replenish the diminishing natural capital and to eliminate waste.
- Examine the interconnectedness and interactions between each human activity and its environment: the upstream supplier, the downstream customer, the people and culture, and the natural environment.
- Consider the locality when determining innovative solutions since one size does not fit all.

One of the things I like about my new HP printer is that the used ink cartridge is being recycled. Every new ink cartridge comes with a self-addressed, postage-paid envelope. All I have to do is put the used cartridge in the envelope and put it in a mailbox. The used cartridge is sent to HP's recycling operations center where the cartridge is then recycled for use in new consumer products. Imagine if this were to be the future of all consumer products, such as televisions, washers and dryers.

This is "cradle to cradle" production put forth independently by visionaries Walter Stahel, founder of the Product-Life Institute, and Michael Braungart, founder of EPEA International and co-founder of MBDC (McDonough Braungart Design Chemistry). They propose a service economy, as opposed to an economy in which goods are made and sold. In a service economy, consumers lease goods rather than buying them outright. The manufacturers own the products throughout the entire lifecycle. Goods are either reused, repaired, reconditioned or recycled (4R's) at the end of their regular useful life.[7]

For example, instead of buying a television, we wouldlease it from the manufacturer. When we are ready to replace it, we contact the manufacturer, select a new model. The manufacturer brings the new model, and takes away the used one. We the consumers always get the latest and greatest television, if we so choose, and we do not have to take care of proper disposal of the television. The manufacturer on the other hand will take the used television and reuse/ recycle the components for future products.

Benyus[8] urges us to take processes in the natural world, such as photosynthesis, natural selection, and self-sustaining ecosystems, and apply these designs to manufacturing processes to solve human problems. The examples she gives include: growing food like a prairie, gathering energy like a leaf, weaving fibers like a spider, finding cures like a chimp, computing like a cell,and running a business like a redwood forest.

Womack and Jones[2] teach us to eliminate waste through five steps:

- Specify the value of your product or service, as defined by your customers.
- Identify the value stream of your product or service. "Value stream is the set of all the specific actions required to bring a specific product or service through the three critical management tasks of any business: the problem-solving task running from concept through detailed design and engineering to production launch, the information management task running from order-taking through detailed scheduling to delivery, and the physical transformation task proceeding from raw materials to a finished product in the hands of the customer.
- Make the value-creating steps flow. Instead of having the product or service be performed in batches or disconnected processes and passed from one department to another, one should focus on the flow of value-creating processes that would deliver the product or service to customers based on the value they defined.
- Let the customers pull the product or service instead of pushing unwanted products or service onto customers.
- Strive for perfection continue to examine your value streams and improve your processes.

Hawken, Lovins and Lovins[3] provide four central strategies of natural capitalism:

- Radical resource productivity - using resources more effectively can slow resource depletion, lower pollution and increase worldwide employment with meaningful jobs.
- Biomimicry - redesigning industrial systems along biological lines to reduce the wasteful throughput of materials, i.e., reusing materials in continuous closed cycles, eliminating toxicity.
- Service and flow economy - shifting from an economy of goods and purchases to one of service and flow, i.e., from the acquisition of goods as a measure of affluence to an economy where the continuous receipt of quality, utility, and performance promotes well-being.
- Investing in natural capital - investing in sustaining, restoring, and expanding stocks of natural capital.

William McDonough and Braungart[9] went beyond the 4R's. Instead of reducing, minimizing and recycling waste, they believe that waste can be eliminated completely if products are designed properly in the first place. Their vision is for people to create the following:

- Buildings that perform like trees, taking in energy from the sun and producing useful by-products and purifying their own waste.

- Factories where water after manufacturing processes is cleaner than the drinking-quality water entering it.
- Products that at the end of their useful life would decompose and become food for plants and animals and nutrients for soil, or alternatively could return to industrial cycles to become high-quality raw materials for new products.
- Transportation that improves the quality of life while delivering goods and services.

Two successful examples

The examples described below show that making money and being sensitive to the environment does not have to be mutually exclusive. It also does not require high-technical expensive investments. They also demonstrate three common themes: imitating nature, maintaining a systems and interconnectedness perspective, and paying attention to local needs and impact to the local environment.

A. Beer: Making Bread And Mushrooms[10]

The Zero Emissions Research and Initiatives (ZERI) Foundation worked with a brewery to not only reduce waste from its brewer but added new sources of revenue stream. The brewery produces beer but also produces organic waste streams; water and lost energy. In order to maximize value added for the inputs of the brewery, ZERI searches for the best possible ways of using the generated waste in a cascading manner. Figure 3 is a flow diagram showing how organic waste and wastewater from the beer brewing process is used for producing bread and mushrooms, and feeding livestock and fish. Spent grains from the brewing process are rich in fibers and protein and are an excellent substitute for flour in bread. When mixed with other fibers such as rice straw, they are also a valuable ingredient in the substrate for the growing of mushrooms. Additionally, growing mushrooms on the spent grains make the spent grains more digestible to livestock and also increase the protein content. This will thus increase growth of animals and quality of meat. Waste from livestock is mixed with waste water from the brewery and sent to a biodigester where the organic waste is converted into nutrient solution and methane anerobically. The methane is stored in tanks and can be used in the brewery or sold. The nutrient solution flows into shallow basins where algae, through photosynthesis, digest it. These algae that have grown and multiplied on the nutrients then flow into a fishpond and become feed for fish. The fishpond itself emulates nature with different species living at different depths. With some fish swimming from the surface to the bottom, this guarantees a healthy system functioning much like any wild lake - and without the need for antibiotics. The ZERI process uses all the nutrients, protein and fiber from the spent grains, and the water from the process as a purification method. Not only does it eliminate waste, it creates jobs and income. It turns waste into value streams for both humans and nature.

B. Industrial by-products exchange (symbiosis) at Kalundborg, Denmark[11]
Symbiosis means co-existence between diverse organisms in which each may benefit from the other. At an industrial park in the Kalundbord Municipality of Denmark, businesses exist in a symbiotic relationship whereby by-products from one become raw materials for another. This symbiotic cooperation has developed spontaneously over a number of decades and today comprises some 20 projects. Figure 4 shows the by-products exchange between the companies. The symbiotic relationship is built upon a network cooperation between six processing companies, one waste handling company and the Municipality of Kalundborg: **Energy E2** Asnæs Power Station, the plasterboard factory **BPB Gyproc A/S**, the pharmaceutical plant **Novo Nordisk A/S**, the enzyme producer **Novozymes A/S**, the oil refinery **Statoil A/S, Bioteknisk Jordrens Soilrem A/S** as well as the waste company **Noveren I/S** and **Kalundborg Municipality**.
The following description of the relationships are extracted directly from www.symbiosis.dk

STEAM AND HEAT

Asnæs Power Station produces heat for the city of Kalundborg and process steam for the Statoil Refinery, Novo Nordisk A/S and for Novozymes A/S. The combination of heat and power production results in a 30% improvement of fuel utilization compared to a separate production of heat and power. Approximately 4,500 households in Kalundborg receive district heat from Asnæs Power Station. District heat has replaced approx. 3,500 small oil-fired units. Statoil Refinery receives process steam and water from Asnæs Power Station. The steam covers about 15% of the refinery's total consumption of steam. The refinery uses the steam for heating oil tanks, pipelines etc. Novozymes A/S and Novo Nordisk A/S use steam from Asnæs Power Station for the heating and sterilization of the processing plants. Some of the cooling water from Asnæs Power Station is used by a fish farm producing 200 tonnes of trout and salmon on a yearly basis. The fish have better growth conditions in the heated water.

WATER

The Kalundborg Region as well as the industrial companies are large consumers of water. This is why the Symbiosis companies are seeking to recycle as much water as possible. Asnæs Power Station has, for example, reduced its total water consumption by 60%. Previously Asnæs Power Station used ground water for its power and heat production only. The ground water has now been substituted by surface water from the lake of Tissø and treated wastewater from Statoil. These efforts have enabled Asnæs Power Station to reduce its ground water consumption by 90%. Earlier, Novozymes A/S also used ground water exclusively for processes requiring drinking water quality. 1 million cubic meters of ground water have now been substituted by lake water from Tissø whose water has been processed up to drinking water quality by Kalundborg Municipality. As the water from Tissø is not an unlimited resource, the consumption of lake water has gone down by 50%.

Asnæs Power Station has accomplished this reduction by recycling its own wastewater.

WASTEWATER

The wastewater is led to a recycling reservoir together with the runoff from the surrounding fields and surplus water from Tissø in the winter period. The recycling reservoir has a capacity of 220,000 cubic meters of water, which are used in the power station processes. The wastewater from Novozymes A/S and Novo Nordisk A/S is part of a genuinely symbiotic relationship: Novozymes A/S treats all wastewater up to a level corresponding to the wastewater of an ordinary household. From Novozymes A/S, the treated wastewater is pumped to the treatment plant of Kalundborg Municipality where a final treatment process takes place. The Novozymes A/S wastewater is of a relatively high temperature making it easier for the municipal treatment plant to treat its wastewater. In this collaboration process, the environment is also the winner as the overall discharge of nitrogen into Jammerland Bugt is very limited. Wastewater is also discharged from Asnæs Power Station into the treatment plant of Kalundborg Municipality.

Refinery gas

An “eternal” flare of surplus gas is part of the safety system in any refinery. Statoil's refinery flare has been reduced to a mere night-light, because the refinery now exploits its own surplus gas internally. Formerly a large portion of the gas was transported by pipeline to BPB Gyproc and Asnæs Power Station to be used in their production. (See e.g. section on liquid fertilizer).

Gypsum

The desulphurisation plant of Asnæs Power Station, which removes sulphur dioxide (SO2) from the flue gas, produces about 200,000 tonnes of gypsum on a yearly basis. Desulphurisation is a chemical process in which sulphur dioxide (SO2) is removed while forming the by-product gypsum. The gypsum is sold to BPB Gyproc A/S, a company that manufactures plasterboard products for the construction industry. The gypsum from the power station reduces the import of natural gypsum significantly. Being more uniform and purer than natural gypsum, power station gypsum is therefore well suited for the plasterboard production. Gypsum stemming from the municipal recycling station of Kalundborg is delivered to BPB Gyproc A/S, thereby contributing - on a smaller scale - to reducing imports of natural gypsum and the amounts of solid waste for landfilling.

Ash

Asnæs Power Station removes fly ash from the smoke while producing about 30,000 tonnes of fly ash on a yearly basis. Ash deriving from orimulsion firing is recycled in a plant in Great Britain. Nickel and vanadium are reclaimed from this ash. The largest ash customer is Aalborg Portland. The ash is recycled in the cement industry.

NovoGro®

Enzyme production at Novozymes A/S is based on fermentation of raw materials such as potato flour and cornstarch. The fermentation process generates about 150,000 cubic meters of solid biomass - the so-called

NovoGro 30®. At the same time, 90,000 cubic meters of liquid biomass, NovoGro® is developed. After inactivation and hygienisation, NovoGro® is used by some 600 West Zealand farmers as fertilizer in the fields, thereby reducing their need for commercial fertilizers. NovoGro® contains the by-products nitrogen, phosphorus and lime.

Yeast slurry

The insulin production of Novo Nordisk A/S also provides feed for pigs. The insulin production builds on a fermentation process in which some of the main ingredients are sugar and salt, which are converted into insulin by adding yeast. After a heating process, the yeast, a residual product in this production, is converted into a very appreciated feed: yeast slurry. Sugar water and lactic acid bacteria are added to the yeast, making the product more attractive to pigs. Novo Nordiskís yeast slurry replaces approx. 20% of the soy proteins in traditional feed mixes. Last year, over 800,000 pigs were fed on this product, containing yeast slurry.

Liquid fertilizer

Statoil's desulphurisation plant reduces the sulphur contents of the refinery gas whereby SO2 emissions are reduced significantly. The by-product is ammoniumthiosulphate, which is used in the production of approx. 20,000 tonnes of liquid fertilizer roughly corresponding to the annual Danish consumption.

Sludge

Sludge is a major residual product stemming from the municipal water treatment plant in Kalundborg. The sludge is utilized at A/S Bioteknisk Jordrens Soilrem as a nutrient in the bio-remediation process. In this way, a waste product from one process is applied as a useful resource in another process

Other waste

Noveren I/S collects waste from all Symbiosis companies. Waste that is an integral part of various processes. In return, the participating companies receive raw materials. Noveren I/S produces electricity on the basis of landfill gas. This electricity is resold to power companies. In addition, Noveren I/S delivers a total of approx. 56,000 tonnes of combustible waste on a yearly basis corresponding to an energy consumption of approx. 6,500 private households in terms of power and district heating.

The Profits

- **Total water consumption -** The Symbiosis companies have reduced the overall consumption by 25% by recycling the water and by letting it circulate between the individual Symbiosis partners. A total of 1.9 mio cubic meters of ground water and 1 mio cubic meters of surface water are saved on a yearly basis.
- **Oil -** The Symbiosis partners have reduced their oil consumption by 20,000 tonnes per year,

corresponding to a 380-tonne reduction of sulphur dioxide outlet on a yearly basis. The major reductions have been achieved by Novozymes A/S, Novo Nordisk A/S and Statoil that have used process steam from the production at Asnæs Power Station.

- **Ash -** The combustion of coal and orimulsion at Asnæs Power Station results in approx. 80,000 tonnes of ash, which are used in the construction and cement industries for the

manufacturing of cement or the extraction of nickel and vanadium.

- **Gypsum -** Every year BPB Gyproc A/S receives up to 200,000 tonnes of gypsum from Asnæs Power Station. This figure corresponds to the large majority of the company's annual consumption. The gypsum substitutes the natural gypsum used in the production of plasterboards.
- **NovoGro® -** NovoGro® from Novozymes A/S substitutes the use of lime and part of the commercial fertilizer on approximately 20,000 hectares of farmland.
- **Wastewater -** The collaboration of Novozymes A/S, Asnæs Power Station and Kalundborg Municipality, in the area of wastewater treatment, reduces the environmental impact on Jammerland Bugt considerably.
- **Sludge -** The recycling of sludge stemming from the treatment plant brings about a reduction in production time at A/S Bio-teknisk Jordrens Soilrem, synonymous with expenditure cuts and improved economy.
- **Other Waste:** On a yearly basis, Noveren I/S receives:
  - 13,000 tonnes of newspaper / cardboard which after a quality check are sold to cardboard and paper consuming industries in Denmark, Sweden and Germany producing new paper, new cardboard, egg boxes and trays for e.g. the health sector.
  - 7,000 tonnes of rubble and concrete that are used for different surfaces after crushing and sorting.
  - 15,000 tonnes of garden / park refuse delivered as soil amelioration in the area.
  - 4,000 tonnes of bio waste from households and company canteens. The bio waste is used in the compost and biogas production.
  - 4,000 tonnes of iron and metal, which is resold after cleaning for recycling.
  - 1,800 tonnes of glass and bottles that are sold to producers of new glass.

Advantages of the Symbiosis

The exchange of resources between industrial companies provides a number of advantages:

- Recycling of by-products. The by-product of one company becomes an important resource for another company.
- Reduced consumption of resources, e.g. water, coal, oil, gypsum, fertilizer, etc.
- Reduced environmental strain: reduced CO2 and SO2 emissions, reduced discharges of wastewater and less pollution of watercourses etc.
- Improved utilization of the energy resources. Waste gases are used in the energy production.

Summary
Since the industrial revolution, the production of goods and services have led to economic development and are responsible for people living longer, enjoying greater wealth and better living standards. Yet, these activities have also led us to diminish natural capital at an alarming rate. In the last two decades, people are taking notice of this human destruction and many have proposed promising solutions that would allow people to continue economic activities while replenishing the natural capital. Several common threads among the various sustainable production approaches covered in this article are:

- Apply biomimicry in our system and processes
- Consider the interconnectedness between each human activity with its environment.
- Evaluate the impact to the local society and natural environment.

Many of these approaches have been put successfully into practice. Over and over they have shown that these approaches could lead to increased revenue, reduced operating costs, while being responsible to society and the environment.

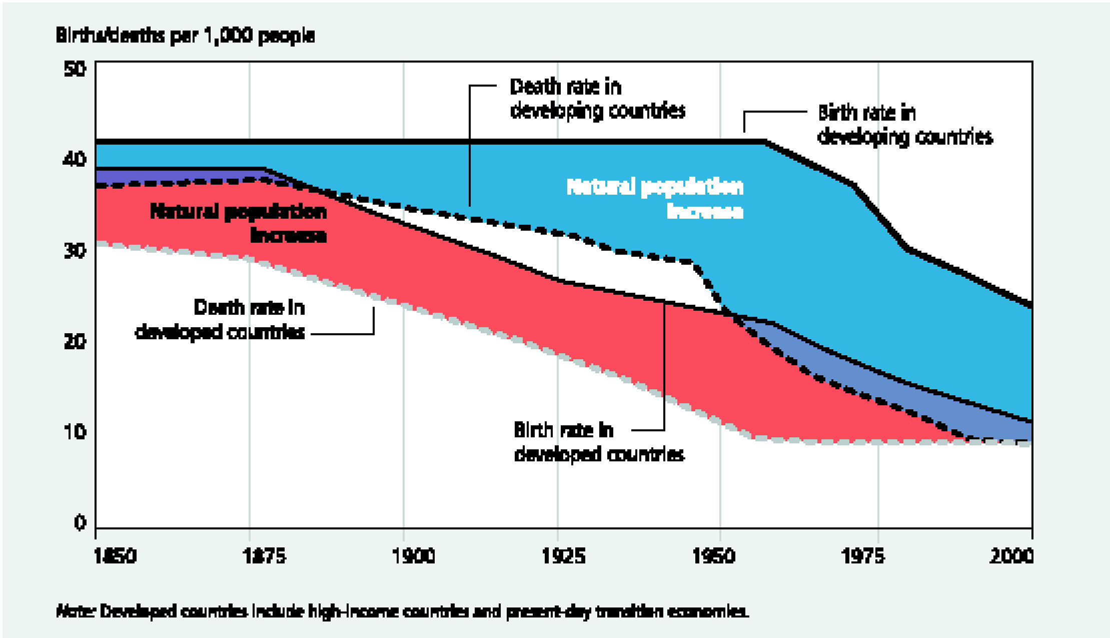
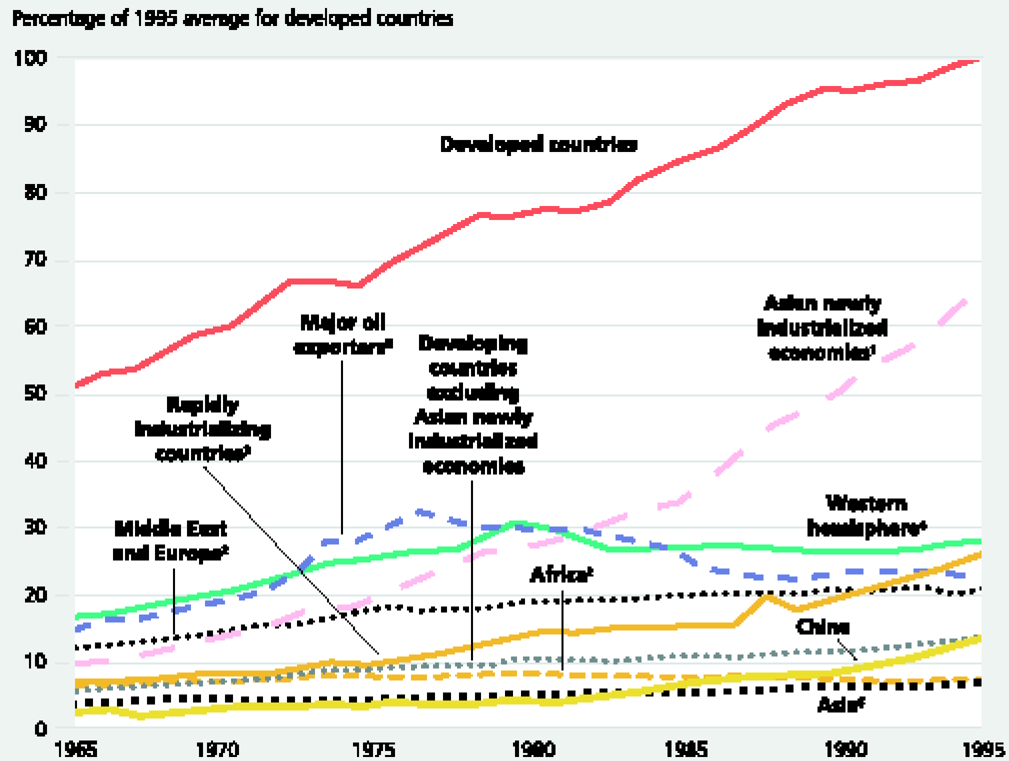


Figure 1 Trends in birth and death rates 1850-2000 [4, p. 18].



1. Asian newly industrialized economies: Hong Kong (China), Republic of Korea, Singapore, and Taiwan (China).
2. Excluding major oil exporters.
3. Consists of Chile, Indonesia, Malaysia, and Thailand.
4. Excluding major oil exporters and Chile.
5. Excluding Iraq.
6. Excluding China, Hong Kong (China), Indonesia, Republic of Korea, Malaysia, Singapore, Taiwan (China), and Thailand.

Figure 2. Real GDP per capita for developed and developing countries 1965-1996[4, p. 26].

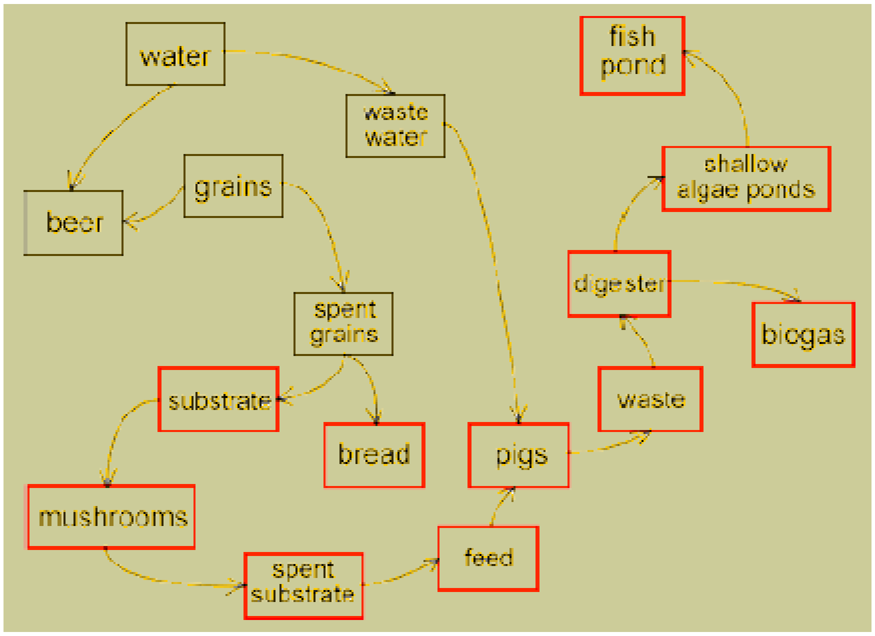


Figure 3. Flow diagram of ZERI's beer to bread and mushroom process.

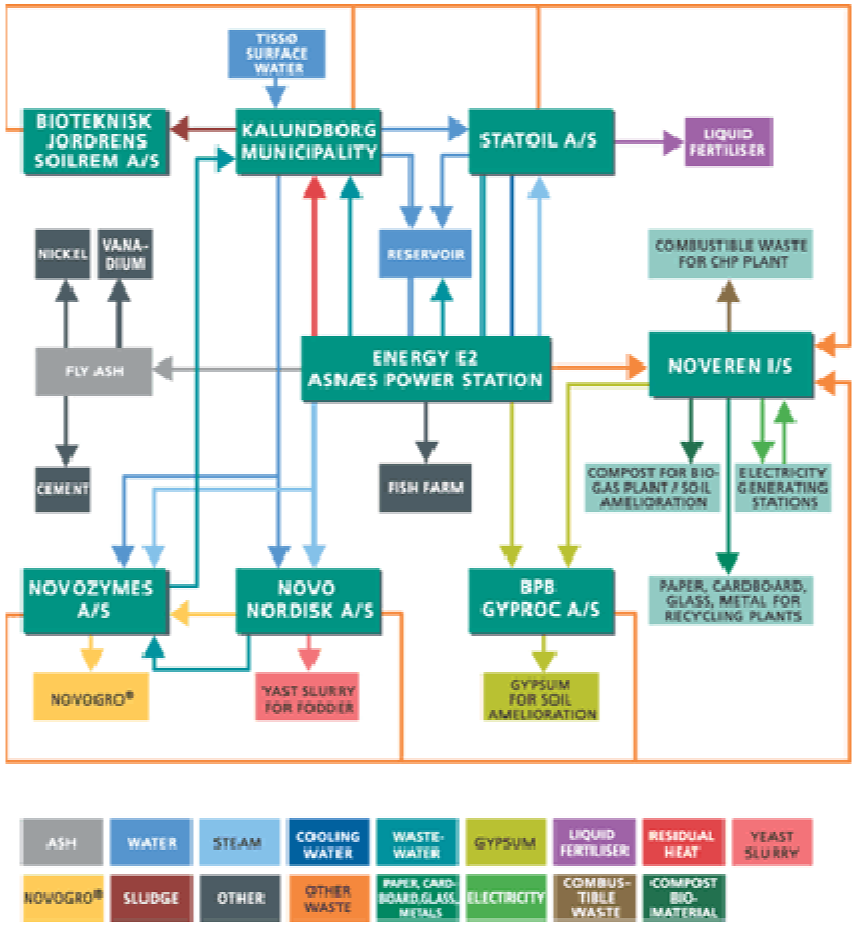


Figure 4. Industrial symbiosis at Kalundborg, Denmark.

References:

1. The Macroscope: A New World Scientific System, Joël de Rosnay. English translation copyright by Harper & Row, 1979. First published in France under the title *Le Macroscope. Vers une vision globale*. Editions du Seuil, 1975.
2. Lean Thinking - Banish Waste and Create Wealth in Your Corporation. James P. Womack and Daniel T. Jones, Simon & Schuster 1996.
3. Natural Capitalism - Creating the Next Industrial Revolution by Paul Hawken, Amory Lovins, L. Hunter Lovins, Back Bay Books, 1999.
4. Beyond Economic Growth - An Introduction to Sustainable Development, 2nd edition. Tatyana P. Soubbotina, The World Bank, Washington, D.C.
5. A comprehensive results of the Biosphere 2 experiment might be found in the publication Biosphere 2: Research Past and Present, edited by Marino and Odun. Other (non-controversial) sources of information about Biosphere 2 include: http://www.biospheres.com/; http://www.desertusa.com/mag99/apr/stories/bios2.html; www.gpc.edu/~kpittma2/BIOSPHERE%202.doc
6. Small is Beautiful - Economics As If People Mattered by E.F. Schumacher, Perennial 1973.
7. The Product-Life Factor by Walter R. Stahel. Mitchell Prize Winning Paper 1982. http://www.product-life.org/milestone2.htm
8. Biomimicry: Innovation Inspired by Nature. Janine M. Benyus, Perennial 2002.
9. Cradle to Cradle. William McDonough & Michael Braungart, North Point Press, 2002.
10. Zero Emisisons Research and Initiatives. http://zeri.org/index.cfm?id=projectBrewery
11. Industrial Symbiosis at Kalundborg. http://www.symbiosis.dk/