School of Industrial and Information Engineering
Course 096125 (095857)
Introduction to Green and Sustainable Chemistry

POLITECNICO DI MILANO

Industrial Ecology (IE) – a Global Vision.

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The Fundamental Equation.

An useful way to focus the most efficient answer that society con give to environmental safety and to social stress is to examine the main factors involved in the generation of those stress.

Fundamental Equation : **(IPAT = C·r·a_p)**

$$\text{Environmnetal Impact} = \text{Population} \times \frac{\text{GDP}}{\text{person}} \times \frac{\text{Environmental Impact}}{\text{GDP unit}}$$

Population dimension

Average Pro-capite consumption

Resource consumed per unit of consumption

(persons N°)

(Res. unit/ persons)

(Pol. unit/ Res. unit)

GDP = gross national product (measures the economic and industrial activity)

Dissipation of Elements: *Inherently Dissipative* and *Potentially Recyclable* Materials.

Thus, there are really three important classes of materials use:

(1) Uses that are economically and technologically compatible with recycling under present prices and regulations;

(2) uses that are not economically compatible with recycling but where recycling is technically feasible, for example, if the collection problems were solved; and

(3) uses for which recycling is inherently not feasible.

Admittedly there is some fuzziness in these classifications, but it should be possible to arrive at some reconciliation. Generally speaking, it is arguable that most structural metals and industrial catalysts are in the first category; other structural and packaging materials, as well as most refrigerants and solvents, fall into the second category. This leaves coatings, pigments, pesticides, herbicides, germicides, preservatives, flocculants, anti-freezes, explosives, propellants, fire retardants, reagents, detergents, fertilizers, fuels, lubricants, and the like in the third category.

Issues in the Dissipative Use of Resources.

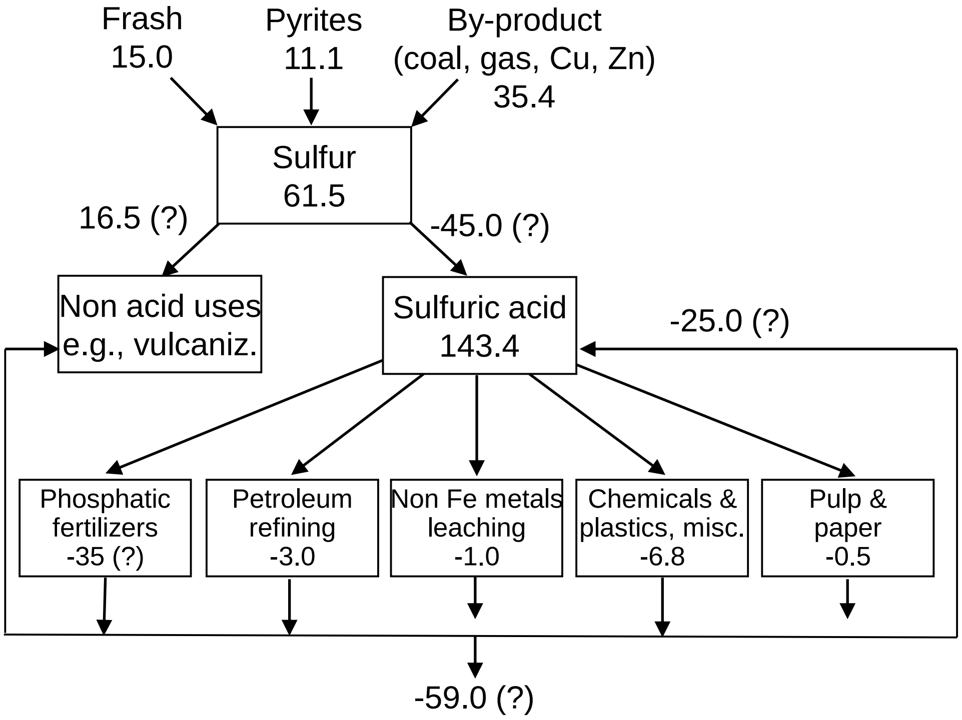
Examples of dissipative use:

Class 3 materials:

- Sulfur
- CFC’s
- Ammonia
- Phosphoric acid
- Chlorine
  - Although can be classified as class 2 when used in plastics and solvents

Substance	**10^6 T**	**Dissipative Uses**
Chemicals		
Chlorine	25.9	Acid, bleach, water treatment, PVC, solvents, pesticides, refrigerants
Sulphur	61.5	Acid (H_2SO_4), bleach, chemicals, fertilizers, rubber
Ammonia	24.0	Fertilizers, detergents, chemicals, HNO_3
Phosphoric acid	93.6	Fertilizers, chemicals
NaOH	35.8	Bleach, soap, chemicals
Na_2CO_3	29.9	Glass, Chemicals
Heavy metals		
Copper sulphate	0.10	Fungicide, algaecide, wood pre, catalyst
Na dichromate	0.26	Plating, tanning, algaecide
Lead Oxides	0.24	Pigment, glass, coating
Zinc sulphide	0.46	Pigment
Zinc oxide	0.42	Pigment, tires
Titanium dioxide	1.90	Pigment
Alkyl lead	?	Gasoline additive
Arsenic	?	Wood preservative, herbicide
Mercury	?	Fungicide, catalyst, Cl_2 production

Sulfur Example.



Frash
15.0

Pyrites
11.1

By-product
(coal, gas, Cu, Zn)
35.4

Sulfur
61.5

16.5 (?)

-45.0 (?)

Non acid uses
e.g., vulcaniz.

Sulfuric acid
143.4

-25.0 (?)

Phosphatic
fertilizers
-35 (?)

Petroleum
refining
-3.0

Non Fe metals
leaching
-1.0

Chemicals &
plastics, misc.
-6.8

Pulp &
paper
-0.5

-59.0 (?)

*Millions of metric tons

Example of dissipative use:

- Nearly all sulfur mined is dissipated or discarded
- Mostly used for sulfuric acid – used in non-recyclable chemicals
- Thus sulfur mainly falls into the third category

But… … gypsum!

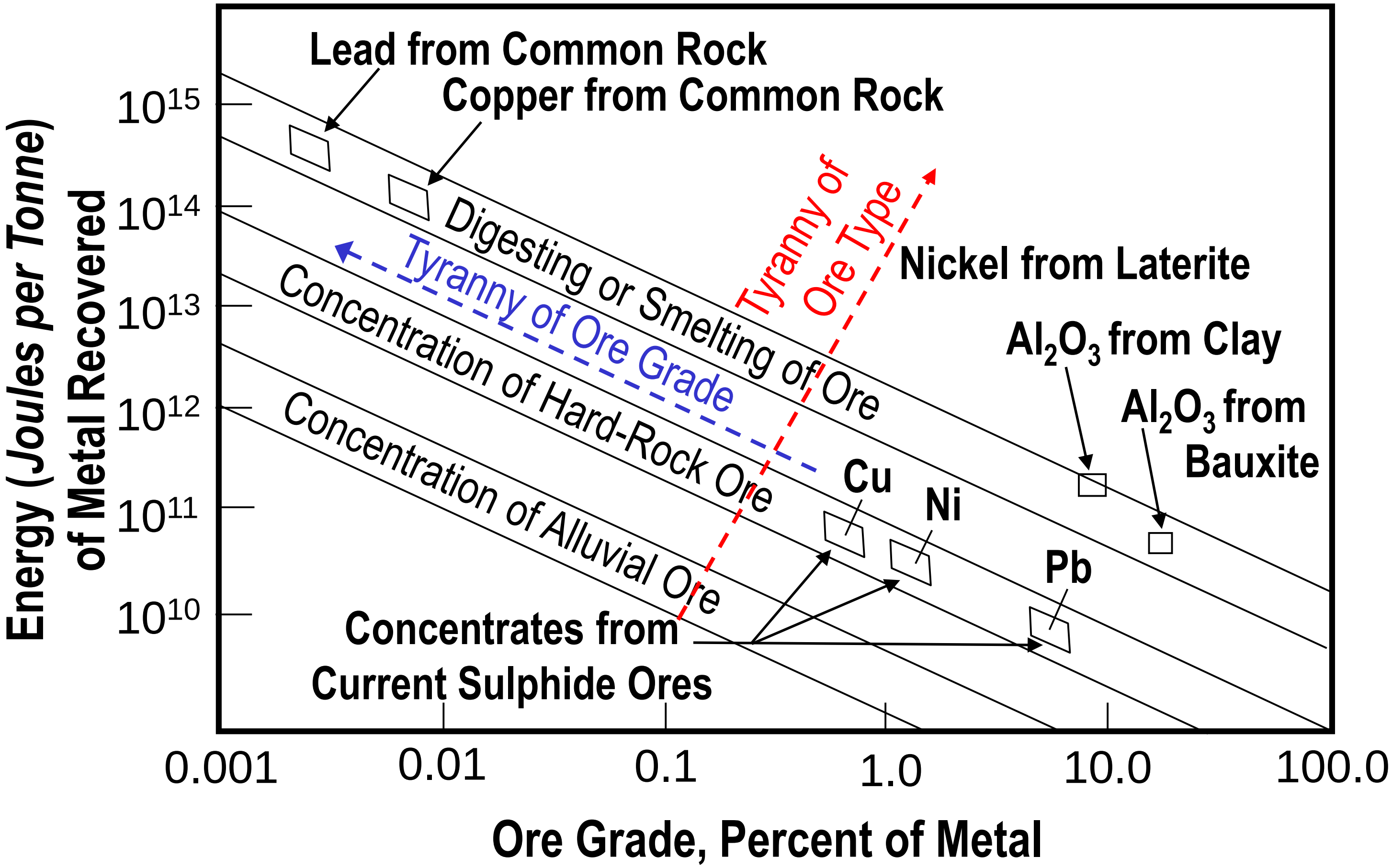
Anthropogenic Nutrient Fluxes, (Tera grams/year, *Tg/y*).

	Carbon			**Nitrogen**			**Sulfur**	
	Tg/yr	**%**		***Tg/yr***	**%**		***Tg/yr***	**%**
To atmosphere, total	**7,900**	**4**		**55.0**	**12.5**		**93**	**55.5**
Fossil fuel combustion and smelting	**6,400**			**45.0**			**92**	
Land clearing, deforestation	**1,500**			**2.6**			**1**	
Fertilizer volatilization [A]				**7.5**				
To soil, total				**112.5**	**21**		**73.3**	**23.4**
Fertilization				**67.5**			**4.0**	
Waste disposal [B]				**5.0**			**21.0**	
Anthropogenic acid deposition				**30.0**			**48.3**	
Anthropogenic (NH_3, NH_4^+) deposition				**10.0**				
To river and oceans, total				**72.5**	**25**		**52.5**	**21**
Anthropogenic acid deposition				**55.0**			**22.5**	
Waste disposal [B]				**17.5**			**30.0**	

[A] Assuming 10% loss of synthetic ammonia based fertilizers applied to land surface (75 Tg/yr)

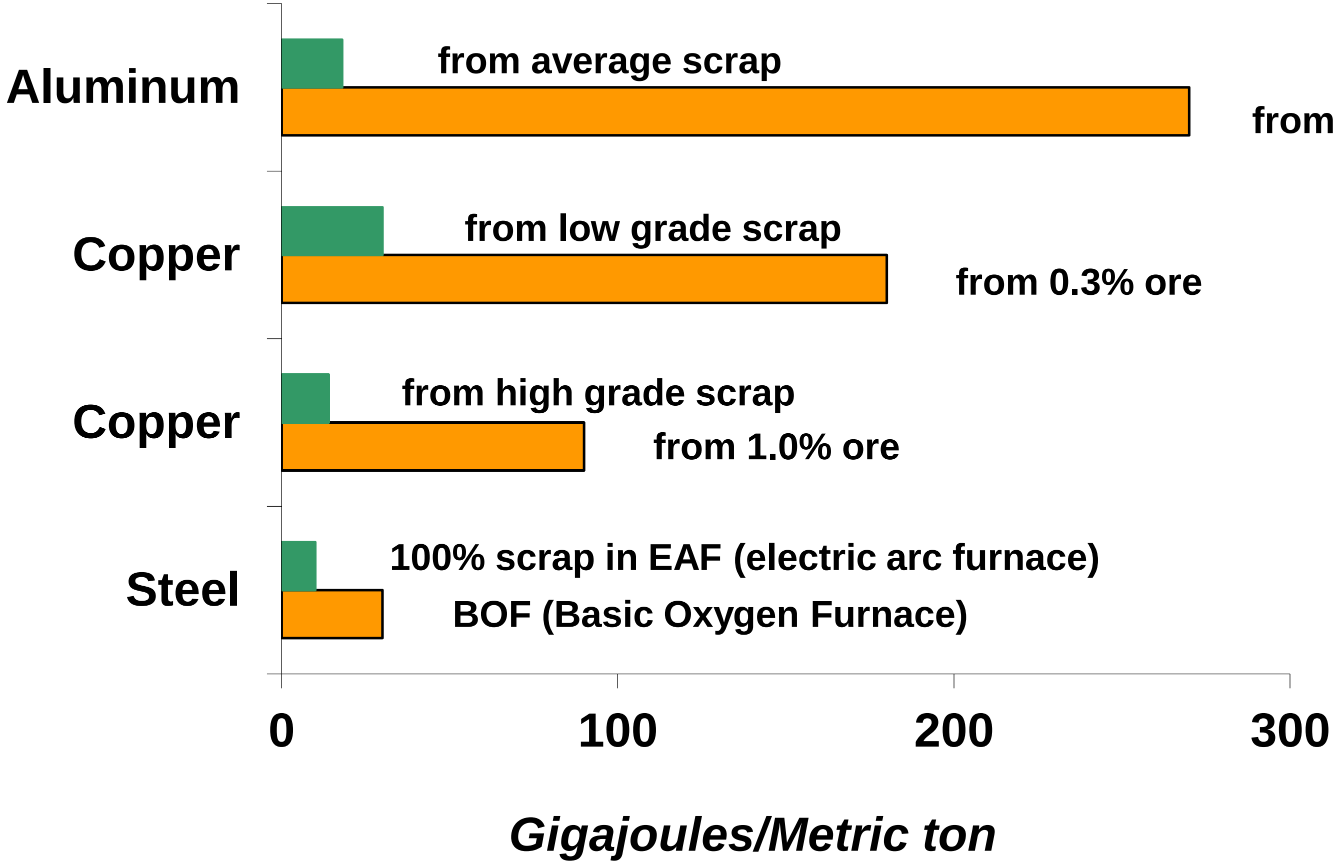
[B] Total production (= use) less fertilizer use, allocated to landfill. The remainder is assumed to be disposed off.

Ore RESERVES are not Infinite: The “Tyrannies” of ore Type and Grade.

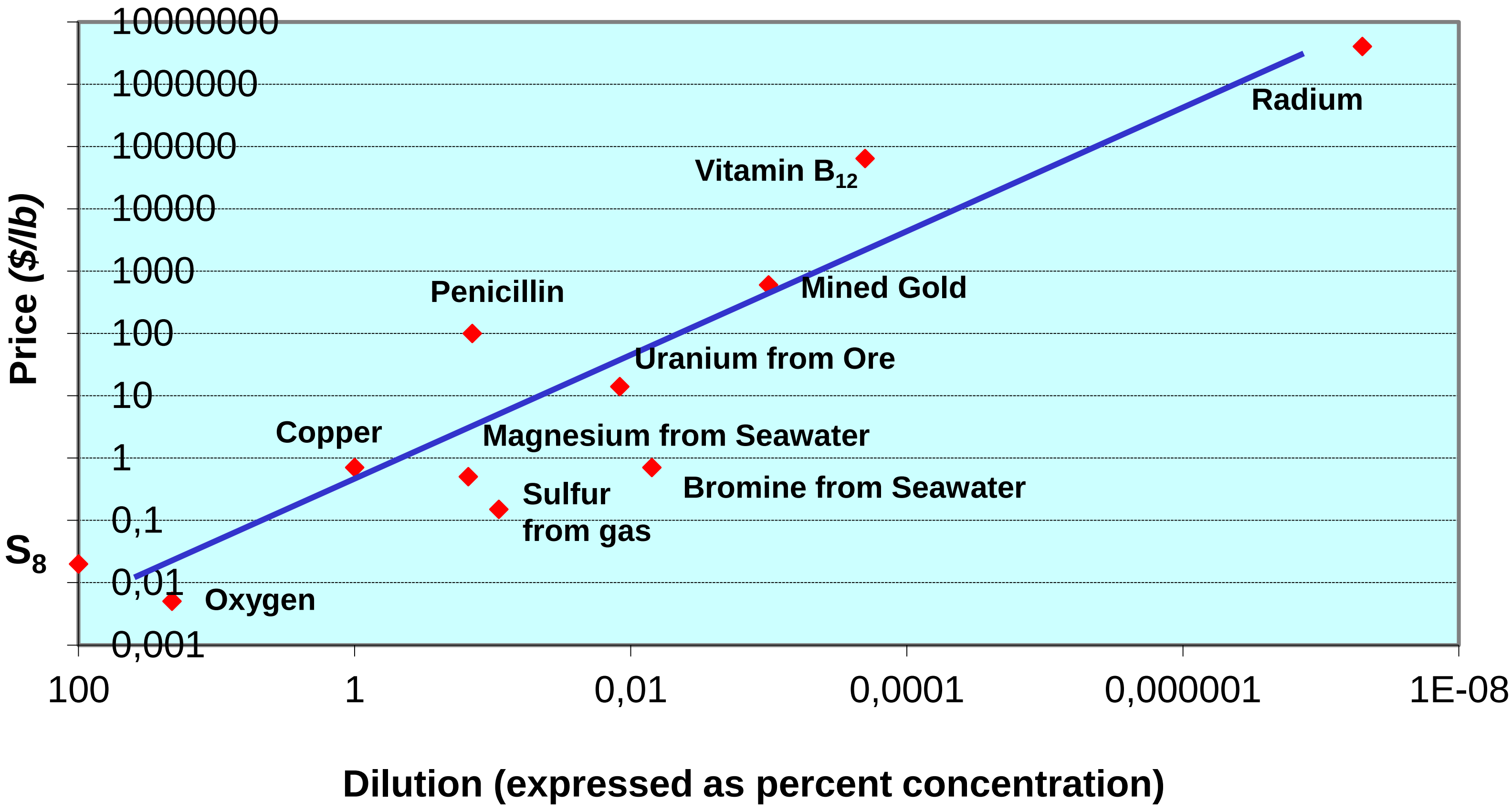


from Kellogg

Energy Requirements for Production of Metals from Primary and Secondary Materials.



Should we Mine Waste Streams? Consider the Sherwood Diagram: Value vs. Dilution.



An Economic Opportunity?

Metal	Minimum concentration recoverable, from Sherwood Diagram (mass fraction)	Total loading in hazardous streams (*tons/yr*)	Recoverable fraction of metal in waste	Per cent of metal recycled from waste streams
Antimony	0,00405	17,000	0.74-0.87	35
Arsenic	0.00015	440	0.98-0.99	3
Barium	0.0015	59,000	0.95-0.98	1
Beryllium	0.012	5,300	0.54-0.84	11
Cadmium	0.0048	16,000	0.82-0,.97	8
Chromium	0.0012	90,000	0.68-0.89	5
Copper	0.0022	110,000	0.85-0.92	10
Lead	0.074	190,000	0,84-0,95	56
Mercury	0.00012	5,400	0.99	16
Nickel	0.0066	3,000,000	1.00	0.1
Selenium	0.0022	2,000	0,93-0,95	29
Silver	0,000035	17,000	0.99-1.00	1
Thallium	0.00004	280	0.97-0.99	5
Vanadium	0.0002	4,400	0.74-0.98	1
Zinc	0.0012	270,000	0.95-0.98	12

Ecology Definition.

“Ecology is the scientific discipline that it is concerned with relationships between organisms and their past, present, and future environments.”

Source: Ecological Society of U.E.

Levels of ecologic organization:

- Community*
- Ecosystems
- Ecoregions

A variable association of interacting populations, plants and animals living together in a common environment.*

Primary Producer

- Organisms that capture solar energy which inhabit the trophic levels of the food chain in ecosystems *(1st, 2nd, and 3rd trophic levels)*

* Reschke, C., 1990. *Ecological Communities of New York State*. New York Natural Heritage Program, N.Y.S. Department of Environmental Conservation. Latham, NY.

Trophic Levels.

- 1st trophic level: plants in terrestrial ecosystems, aquatic members as plants, algae, phytoplankton, etc.
- 2nd trophic level: primary consumers as animals, zooplankton, insects, etc.
- 3rd trophic level: secondary consumers as birds, mammalian carnivores, fish, etc.
- Higher trophic level: humans in food chain
    - Pollutant accumulation in level transport: PCB (polychlorinated biphenyls), DDT, certain pesticides, mercury compounds in fish, heavy metals in plant and animals.

Examples of Community.

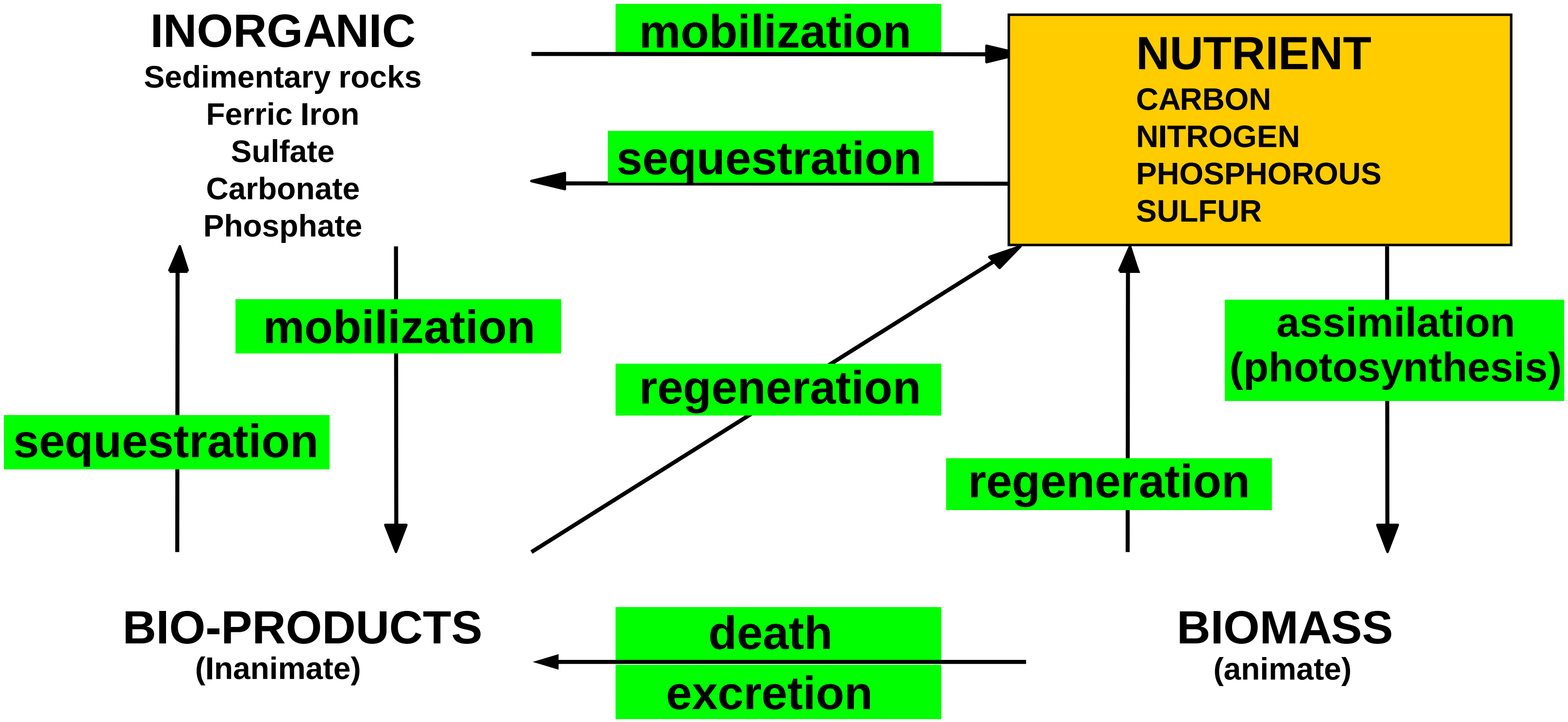
Related Definitions.

Emphasis on interrelationship of the various living and non-living components. No one thing exists alone and no event occurs independent of others.

- **Ecosystem**
  - any geographic area which include all of the organisms and non living parts of their physical environment.
- **Biodiversity**
  - Biological diversity, or biodiversity, refers to the variety of life forms at all levels of organization, from molecular to landscape.
    - Each specie play a functional role in the community
    - The stability is a function of biodiversity
    - Remarkable effects following the loss of a specie
    - Relevant impact after introduction of an exotic specie.

Examples of Ecosystems.

Bio-Geo-Chemical Cycles involved in Ecology.



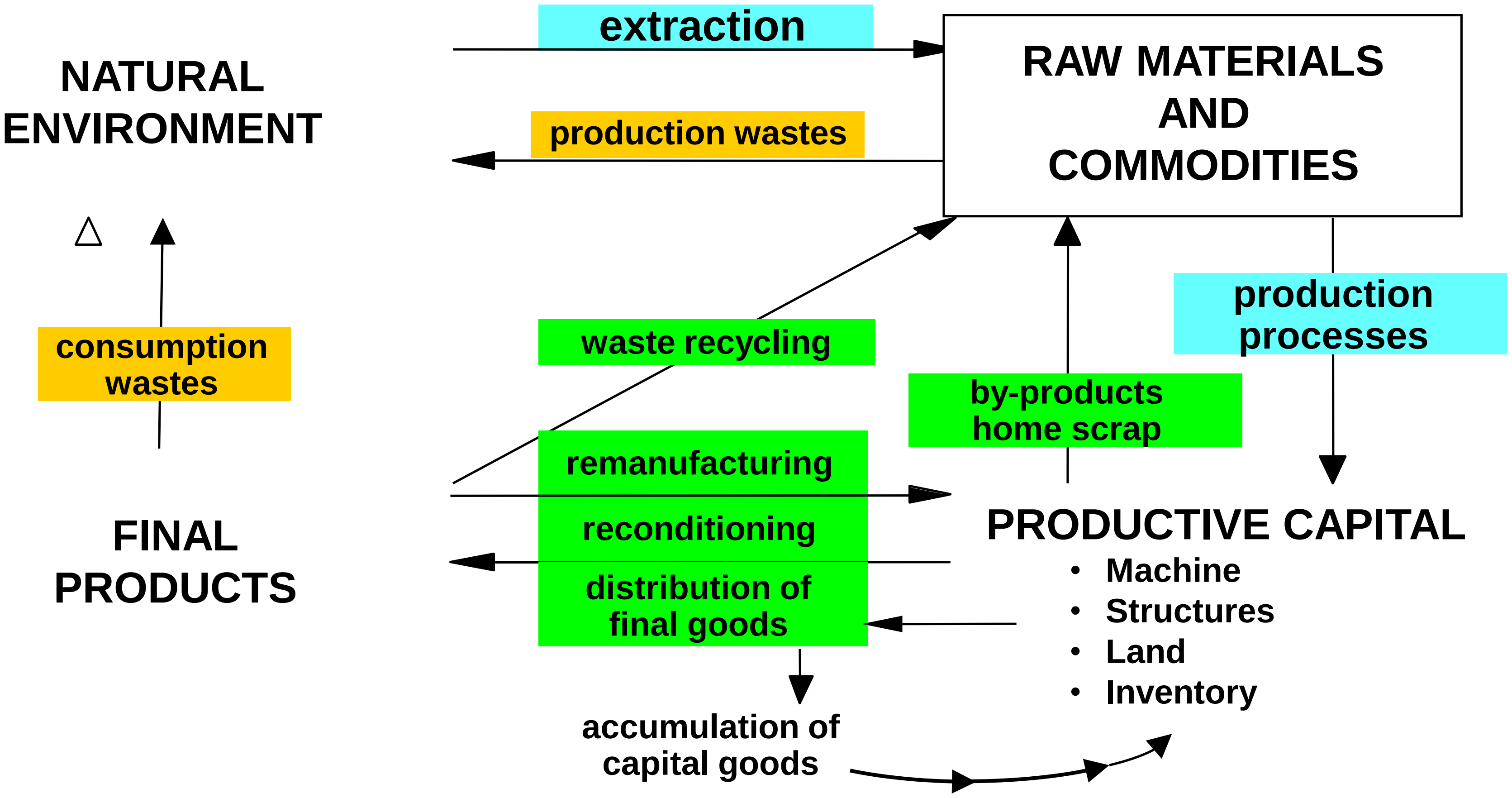
Bio-Geo-Chemical Cycle Scheme (CLOSED)

Source: Ayres

Comparison of Natural Ecosystems and Current Industrial Systems.

- The basic unit of a natural ecosystem is the organism, whereas the basic unit of an industrial system is the firm
- Natural ecosystems take materials in closed loops whereas, with current practice, materials go across essentially one-way path through industrial systems
- Natural systems completely recycle materials, whereas in industrial systems the level of recycling is often very low
- Organisms have a tendency to concentrate materials such as CO_2 from air in biomass whereas industrial systems tend to dilute materials to a level where they cannot be economically recycled, but still have the potential to pollute.
- The major function of organisms is reproduction whereas the main function of industrial enterprises is to generate economically goods and services
- Reservoirs of needed materials for natural ecosystems are essentially constant (O_2, CO_2 e N_2 from air as examples) whereas industrial systems are faced with largely depleting reservoirs of materials (essential mineral ores)
- Recycling gives essentially constant reservoirs of materials.

Industrial Material Cycles.



Scheme of Industrial Materials Cycle (CLOSED)

Source: Ayres

Industrial Ecology : Concepts and Objectives – Definition.

- **Industrial Ecology is the study of the means by which humanity can deliberately and rationally approach and maintain a desirable carrying capacity, given current economic, cultural, and technological evolution**

Graedel and Allenby, 2010

- The study of the flows of materials and energy in industrial and consumer activities, of the effects of these flows on the environment, and of the influences of economic, political, regulatory, and social factors on the flow, use and transformation of resources

White, 1994, in the preface of The Greening of Industrial Ecosystems

- It is a systemic, comprehensive, integrated view of all of the components of the industrial economy and their relationship with the biosphere. It emphasizes the biophysical basis of human activities: the complex patterns of material flows both within and outside of the industrial system. This in contrast with the current approaches which consider the economy mostly in terms of abstract monetary units or energy flows*. It considers technological dynamics as a crucial element to achieve a transition from the actual unsustainable system to a viable industrial ecosystem*.

Industrial Ecology: Historical view.

1970s: first papers and environmental regulation, introduction of non-waste technology; the Japanese Industry-Ecology Working group

1980s: end-of-pipe measures, more papers but no attention;

1989: Robert Frosch and N Gallopoulos in The Scientific American; Robert Ayres introduces Industrial Metabolism

- Based on mass conservation principle,
- Identify and trace energy and material flows between systems

1991: Further defined by Harden Tibbs as "designing industrial infrastructures as a series of interlocking man-made ecosystems that interface with natural ecosystems"

1995: Concert of industrial and surrounding systems (Graedel / Allenby)

1995: Multidisciplinary study of industrial and economic systems (IEEE)

1996: Merging systems thinking w/ system engineering and economics (O'Rourke et al.)

Four Design Principles for Industrial Ecology (1977-2000).

Explicitly derived from systematic application of system theory.

Deal with the Second Law of Thermodynamics, hierarchy, and attractors

1. ***Interfacing***. The interference between man-made systems and natural ecosystems must reflect the limited ability of natural ecosystems to provide energy and absorb waste before their survival potential is significantly altered, and that the survival potential of natural ecosystems must be maintained.
2. ***Mimicry***. The behavior and structure of large-scale societal systems should be as similar as possible to those exhibited by natural ecosystems.
3. ***Biotechnology***. Whenever feasible, the function of a component of a societal system should be carried out by a subsystem of the natural biosphere.
4. Non-renewable resources are used only as *capital expenditures* to bring renewable resources in line. Resources are not inherently renewable, it is how we use them that makes them renewable.

Industrial Metabolism (IM).

Definition: "the whole integrated collection of physical processes that convert raw materials and energy, plus labor, into finished products and wastes in a (more or less) steady-state condition". An **industrial ecosystem** works through groups of industrial concerns, distributors, and other enterprises functioning to mutual advantage, using each others' products, recycling each others' potential waste materials, and utilizing energy efficiently to maximize:

$$\frac{\text{Market value of product}}{\text{Consumption of materials and energy}}$$

IM is analogous to the process of a living organism: takes in food for self/storage and excretes wastes. Based on the principle of conservation of mass, applies green chemistry at the molecular level and green engineering within individual unit processes at the factory level, at the industrial ecosystem level, even globally.

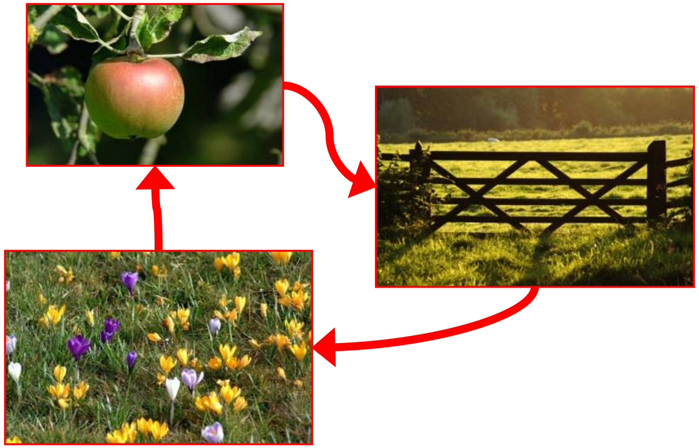
Kay (2001)

Differences: Organisms reproduce themselves, specialized, change over long period of time. Firms produce products or services, not specialized, can change quickly.

Natural and Industrial Ecosystems.

The analogy of industrial systems to natural systems:

- Both have cycles of energy and nutrients/materials.
- Strategies of nature to meet sustainability:
    - recycling/decomposing
    - renewing
    - conservation and population control
    - toxins stay in place
    - multiple functions of one organism



Ecological Integrity.

Three facets of self-organization:

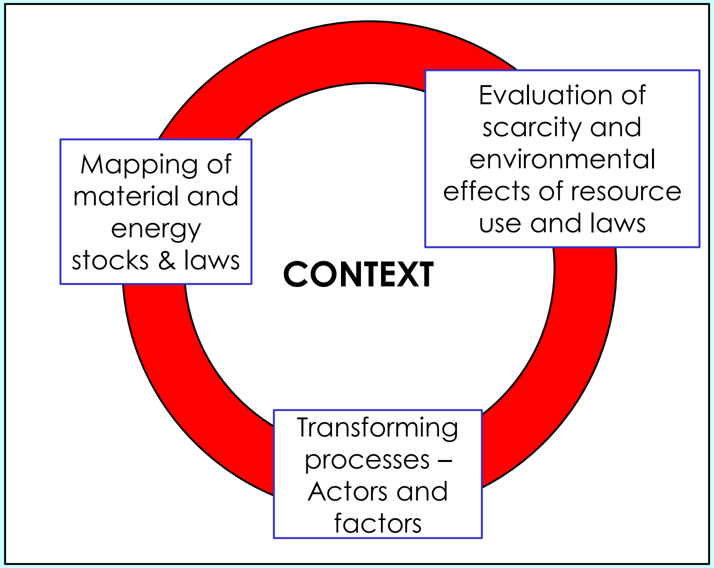
1. Current well-being
   - Ecological health of the system

2. Resiliency
   - Stress response capability of the ecosystem

3. Capacity to develop
   - System's potential to continue to self-organize

(Kay and Regier 2000)

Framing Industrial Ecology.



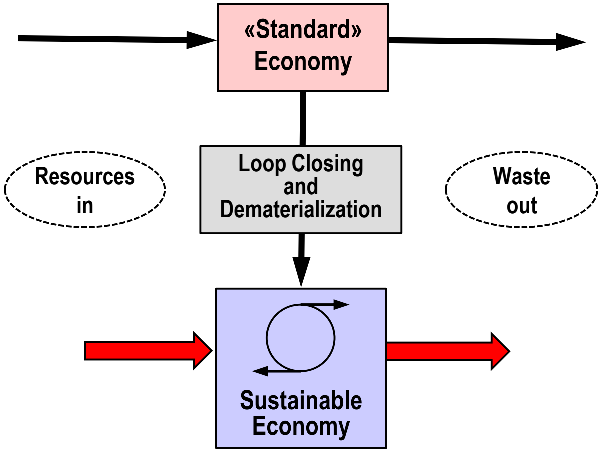
Industrial ecology is the study of the flows of materials and energy in industrial and consumer activities, of the effect of these flows on the environment, and of the influence of economic, political, regulatory and social factors on the flow, use and transformation of resources.

The objective of industrial ecology is to understand better how we can integrate environmental concerns into our economic activities. This integration is necessary to promote sustainable development at the global, regional, and local levels, which will result in:

- **Sustainable use of resources**
- **Ecological and human health**
- **Environmental equity**

IE Targets.

- Industrial Systems (technological changes and environment)
  - viewed in the context of surroundings, not in isolation (LCA, product stewardship, …)
- Optimization of entire materials cycle (dematerialization, DFE)
  - virgin to finished material
  - component to product
  - obsolete product to disposal ("industrial metabolism“)
- Optimization of resources, energy, capital
  - eco-industrial parks;
  - environmental policy;
  - eco-efficiency

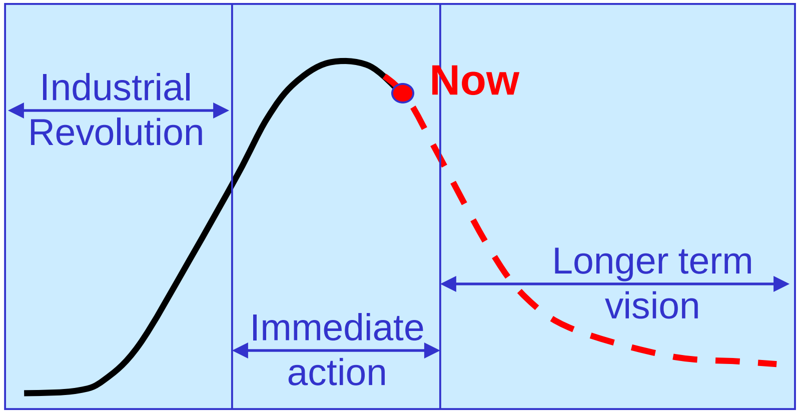


Both Economies Have the Same GDP

Industrial Ecology: Perspectives.

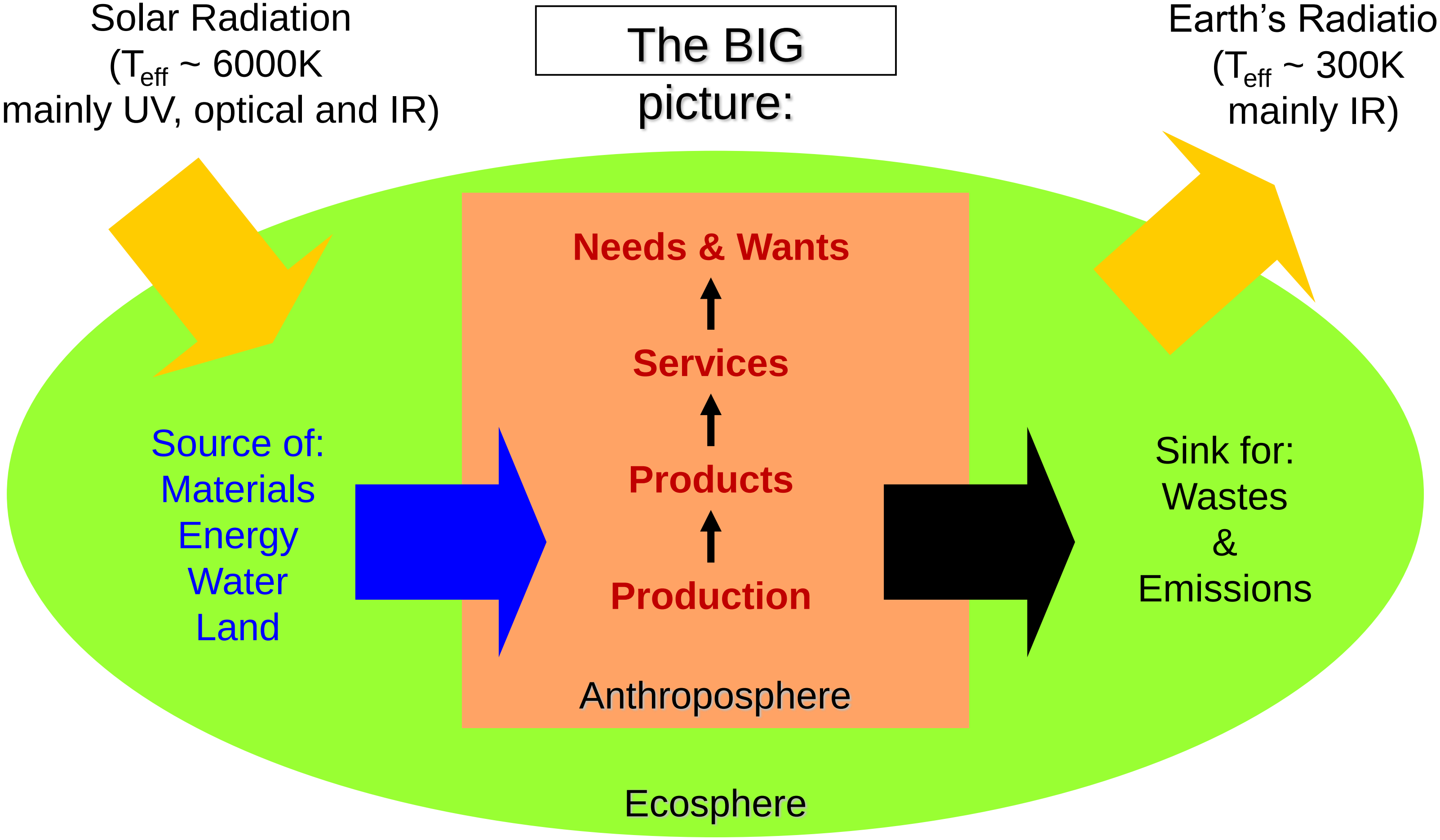
Five perspectives

1. Long term habitability
2. Mitigating disruptions for fundamental life-supporting cycles
3. Global scope rather than transitory issues
4. Identify and avoid instances where human activity overwhelms nature
5. Understanding and modifying behavior rather than condemning.



Development status

Environment as Source of Resources and Sink for Wastes.



Solar Radiation
(T_{eff} ~ 6000K
mainly UV, optical and IR)

The BIG picture:

Earth's Radiation
(T_{eff} ~ 300K
mainly IR)

Source of:
Materials
Energy
Water
Land

Needs & Wants

Services

Products

Production

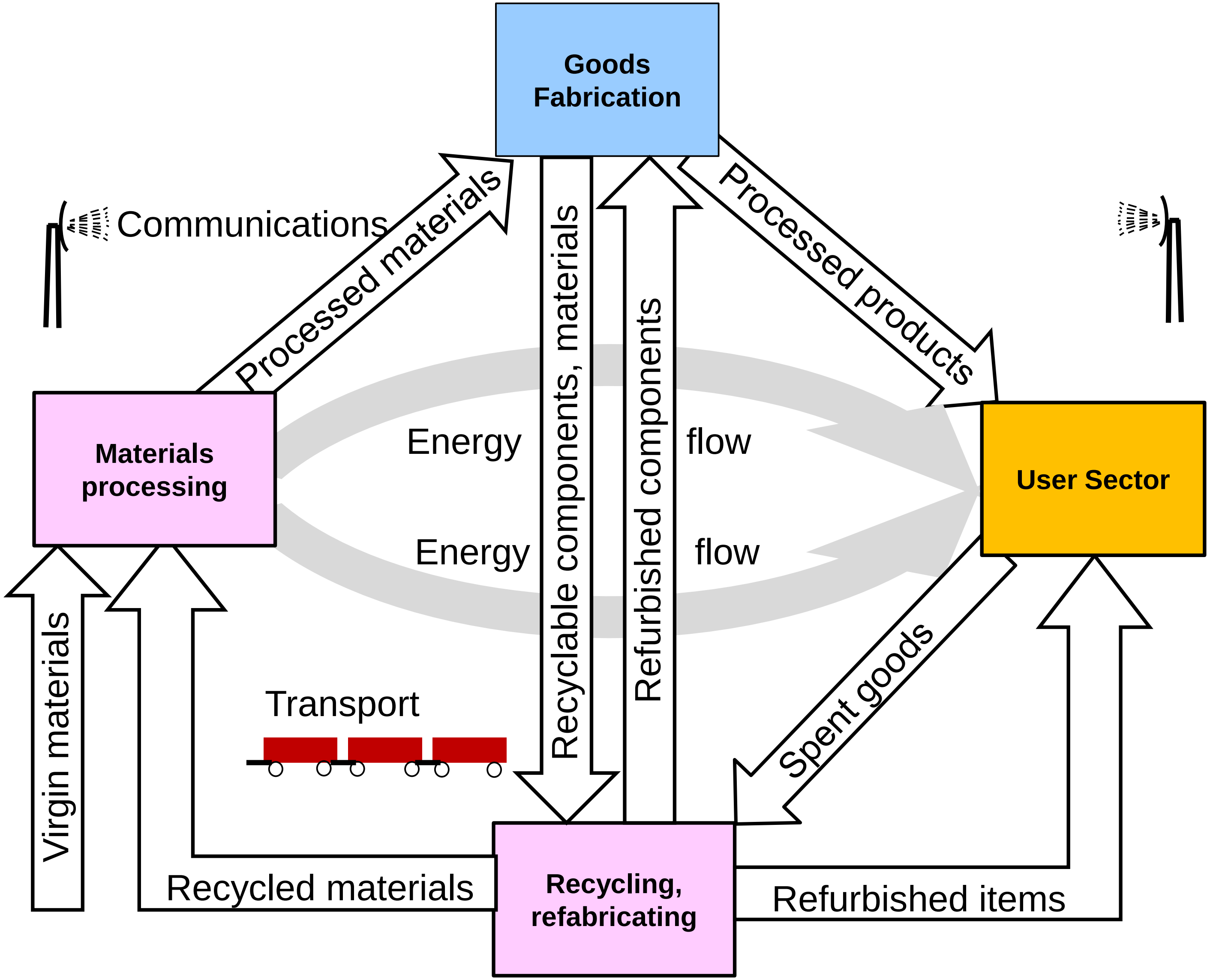
Anthroposphere

Sink for:
Wastes
&
Emissions

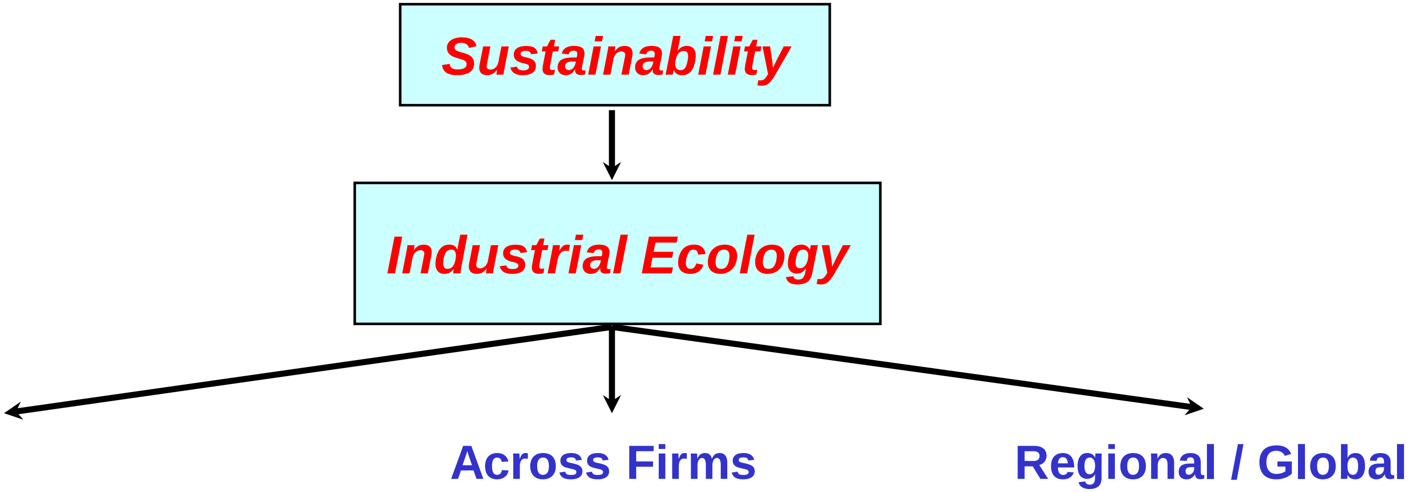
Ecosphere

Industrial production and consumption systems use the environment as **source** of resources and **sink** for wastes and emissions

Major Components of an Industrial Ecosystem with Material and Energy Flows.



Industrial Ecology Operates at 3 Levels.



Sustainability

Industrial Ecology

Firms

- design for environment
- pollution prevention
- eco-efficiency
- green accounting

Across Firms

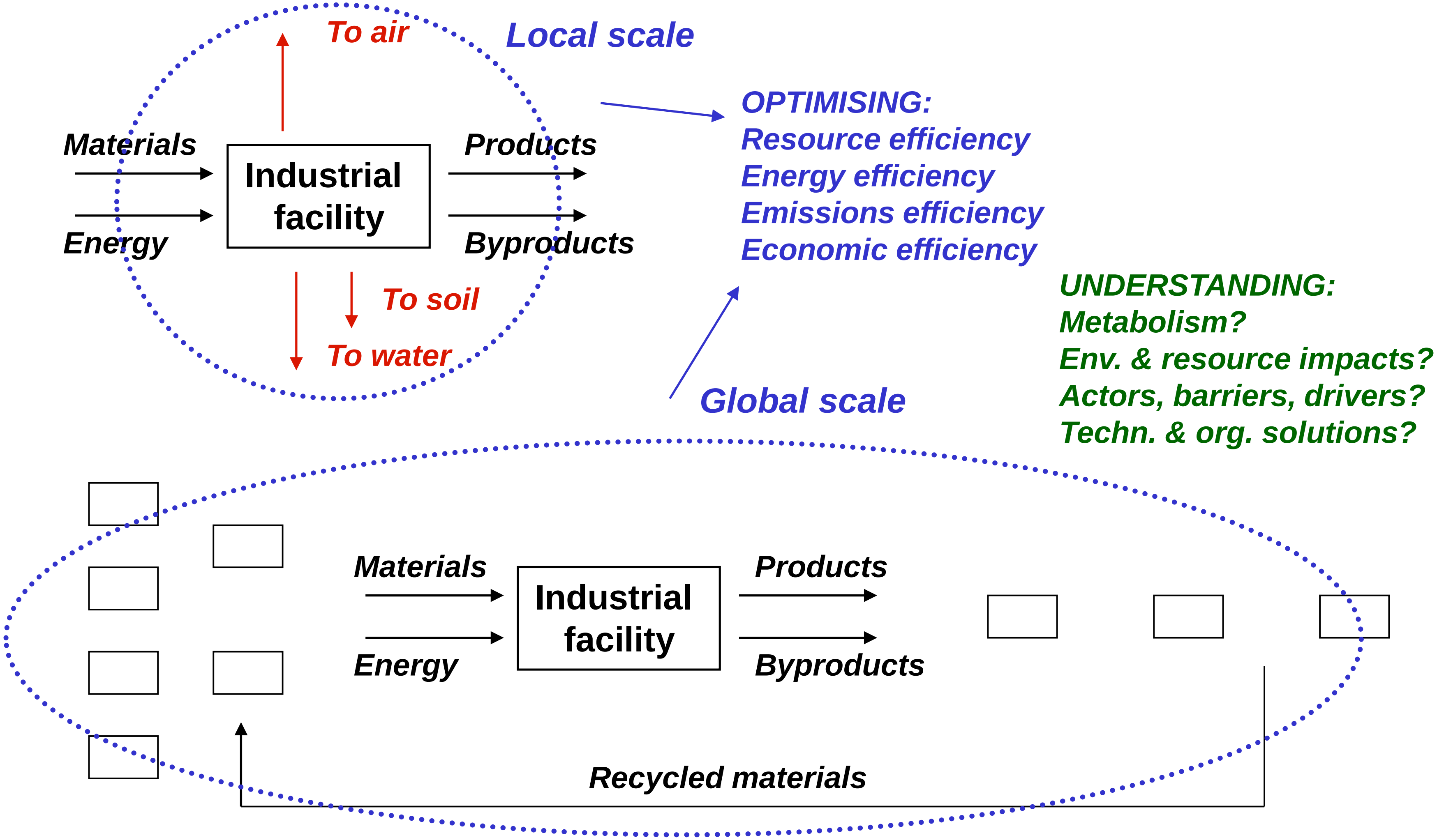
- industrial symbiosis
- product life-cycles
- industrial sector initiatives

Regional / Global

- budgets and cycles
- materials and energy flow studies (industrial metabolism)

At all levels, industrial ecology aims to provide tools and knowledge for analysis and design towards more sustainable solutions.

Industrial Ecology – a Systems View.



To air

Local scale

Materials

Industrial facility

Products

Energy

Byproducts

To soil

To water

OPTIMISING:
Resource efficiency
Energy efficiency
Emissions efficiency
Economic efficiency

UNDERSTANDING:
Metabolism?
Env. & resource impacts?
Actors, barriers, drivers?
Techn. & org. solutions?

Global scale

Materials

Industrial facility

Products

Energy

Byproducts

Recycled materials

H. Brattebø, 2004

Main Six Elements of Industrial Ecology.

- Industrial Ecosystems — Fostering cooperation among various industries whereby the waste of one production process becomes the feedstock for another.
- Balancing industrial input and output to the constraints of natural systems — Identifying ways that industry can safely interface with nature, in terms of location, intensity, and timing, and developing indicators for real-time monitoring.
- Dematerialization of industrial output — Striving to decrease materials and energy intensity in industrial production.
- Improving the efficiency of industrial processes — Re-designing production processes and patterns for maximum conservation of resources.
- Development of renewable energy supplies for industrial production — Creating a worldwide energy system that functions as an integral part of industrial eco-systems.
- Adoption of new national and international economic development policies — Integrating economic and environmental accounting in policy options.

Goal of Industrial Ecology.

	Atmosphere	Hydrosphere	Geosphere	Biosphere
Fossil Fuel combustion	Emission of partially combusted hydrocarbons and nitrogen oxides cause photochemical oxidants; acid precipitation caused by emissions of sulfur oxides; greenhouse warming	Water pollution from acid mine water, petroleum production byproduct brines, acid precipitation,	Disturbance of land from coal mining	Indirect effects
Industrial manufacturing and processing	Emissions of gases, vapors, and particles, greenhouse gases, acid gases, particles	Pollution, limited water supplies in danger	Solid and hazardous waste from extractive industries	Distribution of toxic substances.
Crop Production	Greenhouse gases due to deforestation	Water used for irrigation, water returned to hydrosphere has high salinity, contamination by fertilizers, herbicides	Topsoil can be lost from water and wind erosion	Entire ecosystems be destroyed and replaces, loss of species or diversity cultivation of limitec strains of crops
Livestock production	Animals produce greenhouse gas methane due to methane-producing bacteria in their digestive systems	Large quantities of water are required, nitrogen wastes from manure and urine cause nitrate contamination of groundwater, large amounts of oxygen-consuming wastes contaminate surface water.	Destruction of land (i.e. rain forests) to provide food for livestock, overgrazing has caused land deterior.	Loss of species diversity ie cloning.

Souce: Inustrial Ecology: Environmental Chemistry and Hazardous Waste

Environmental Accounting Techniques.

Classifying physical economy environmental accounting techniques.

The variations among the techniques:

- the system extent as the container of the driving forces behind material and sometimes energy flows
- system boundaries of the metabolic pathways
- level of detail
- level of aggregation of human induced material and energy flow

Environmental Accounting Techniques (2).

Between the numerous proposed, the more relevant are:

- Total Material Requirement and Output
- Substance or Material Flow Analysis
- Physical Input-Output Tables
- Substance Flow Analysis
- Ecological Footprint Analysis
- Environmental Space
- Material Intensity per Unit Service
- **Life-Cycle Assessment**
- Sustainable Process Index
- Levels of Recycling

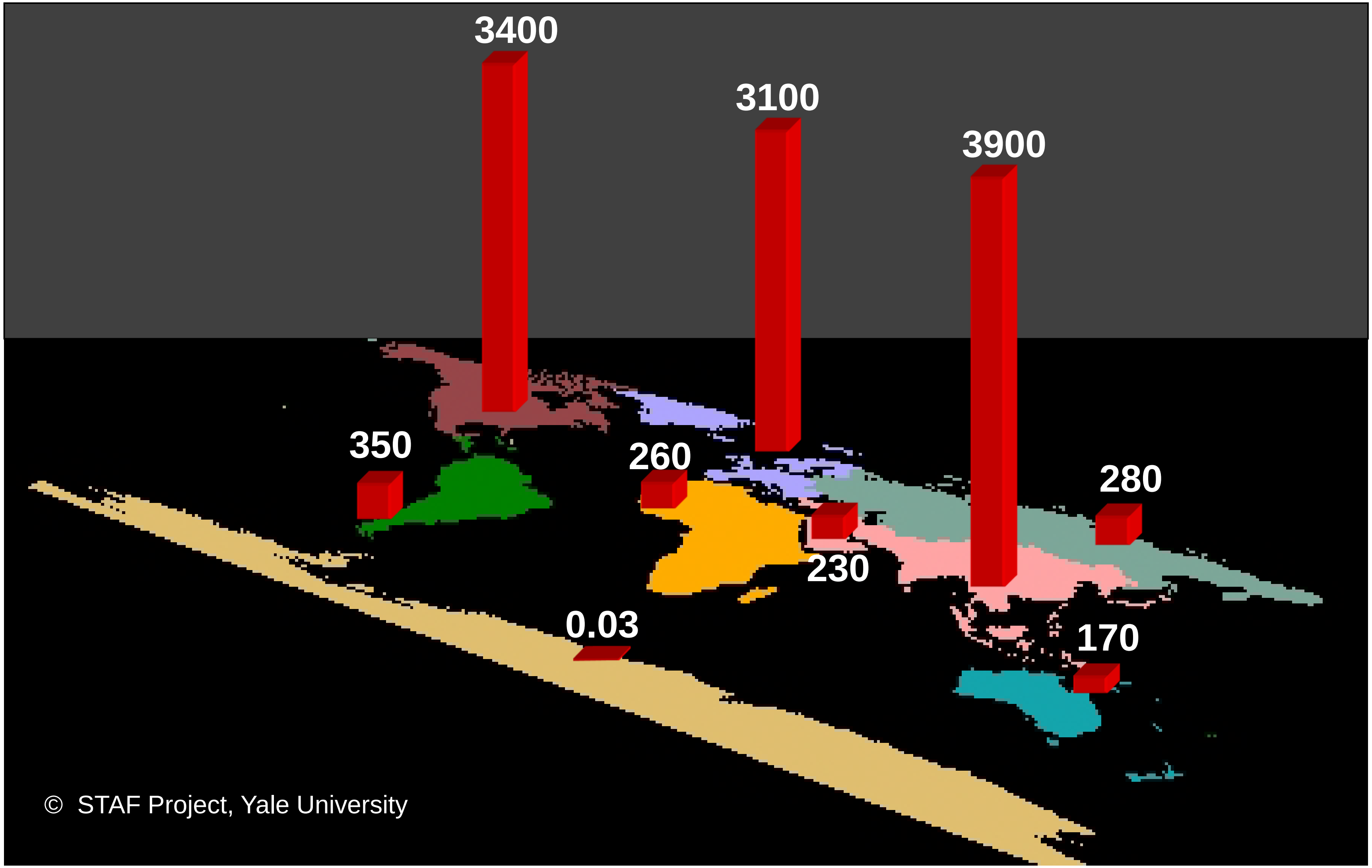
Environmental Accounting Techniques (3).

Total Material Requirement and Output (TMR, TMRO)

Quantifies the physical exchange of aggregated material flows between national economies and the environment.

- **Inputs**: domestic resource extraction
- **Outputs**: domestic releases to the environment and exports.

Copper Entering Use (10^9 g Cu/y in 1994).



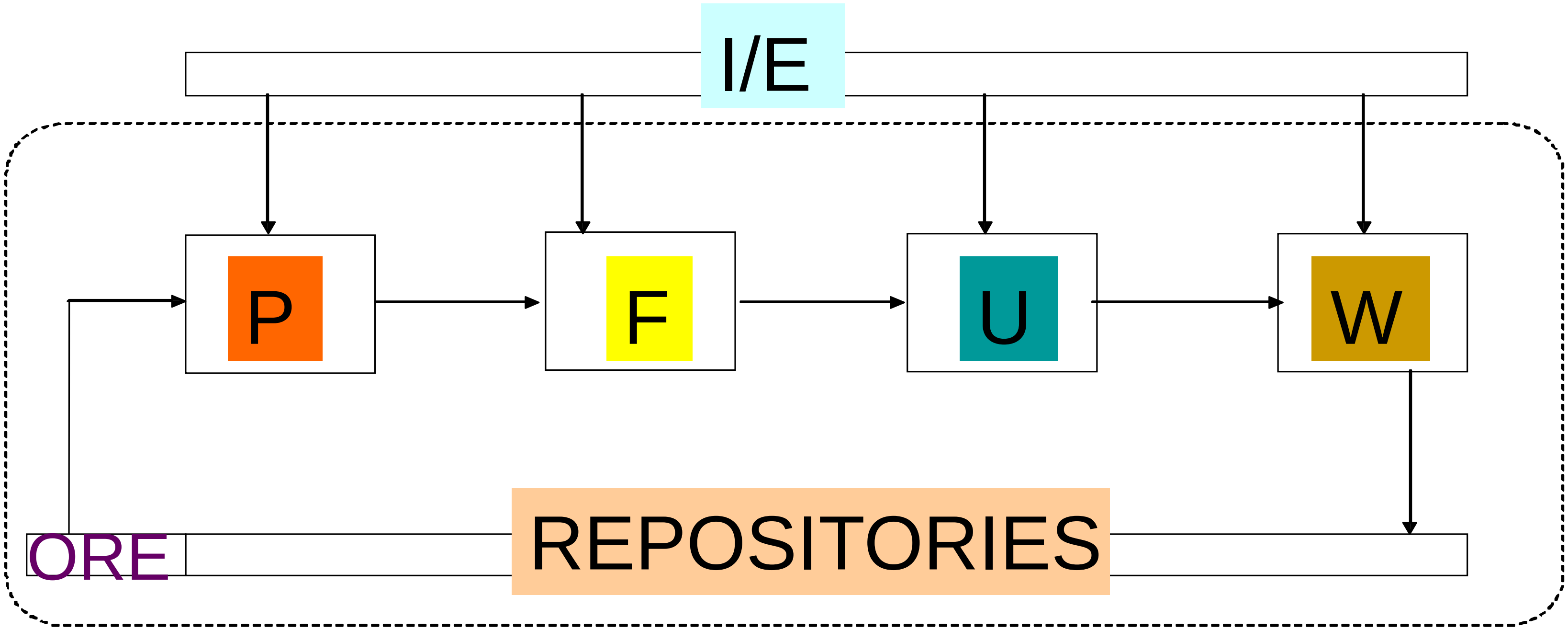
© STAF Project, Yale University

Environmental Accounting Techniques (4).

Physical Input-Output Tables (PIOT)

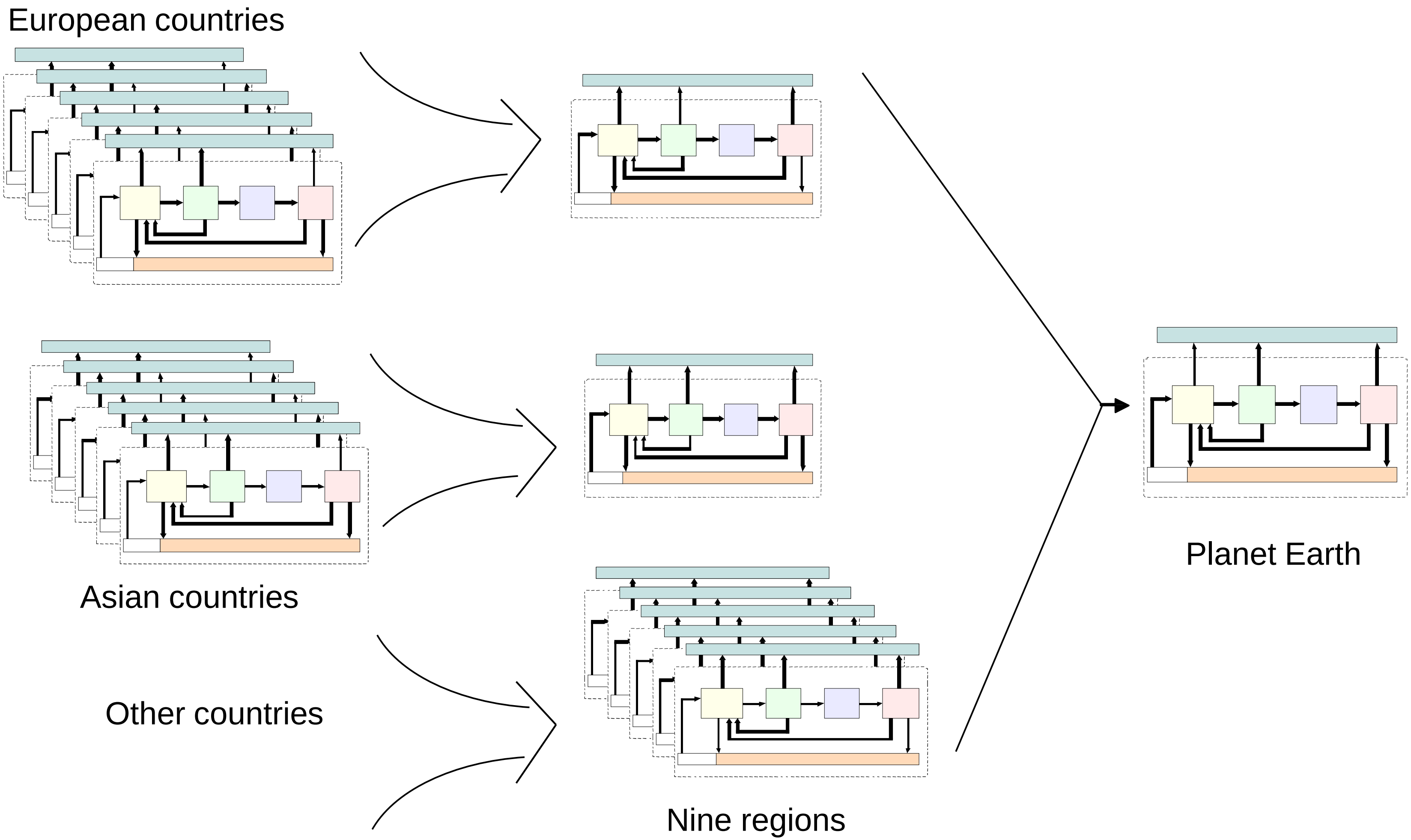
- Traces how natural resources enter, are processed, moved around the economy, used, and returned to the natural environment as residuals.
- Has the ability to evaluate the cumulative environmental burden because of its exhaustive physical coverage of the movement.

The Stocks and Flows Approach.



I/E = Import/Export
P = Production
F = Fabrication & Manufacturing,
U = Use
W = Waste management

Building Multilevel Material Cycles - Available: Cu Zn, Ag, Ni, Fe, Sn, Cr, Pb, W.



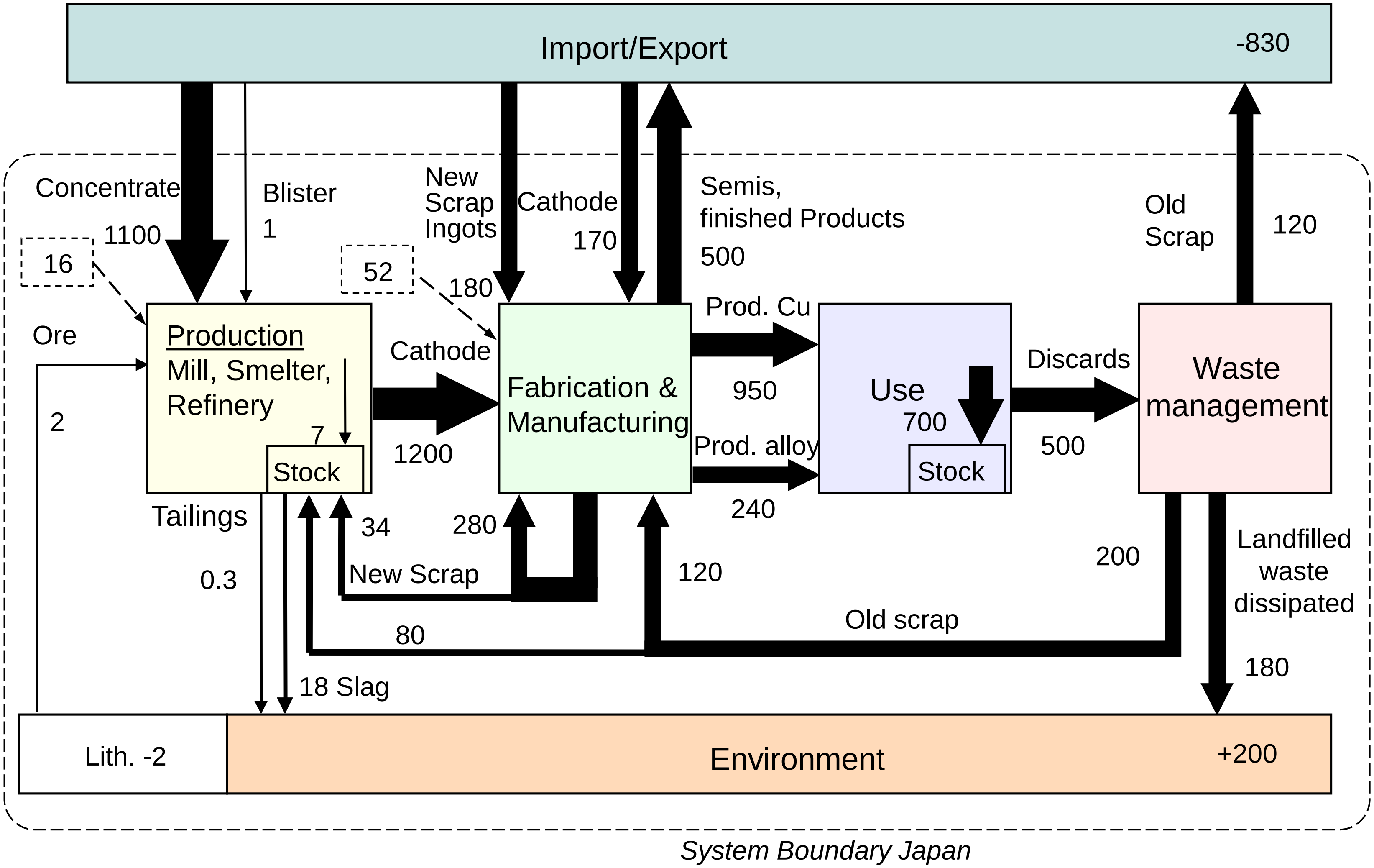
H. Brattebe 2004

Environmental Accounting Techniques (5).

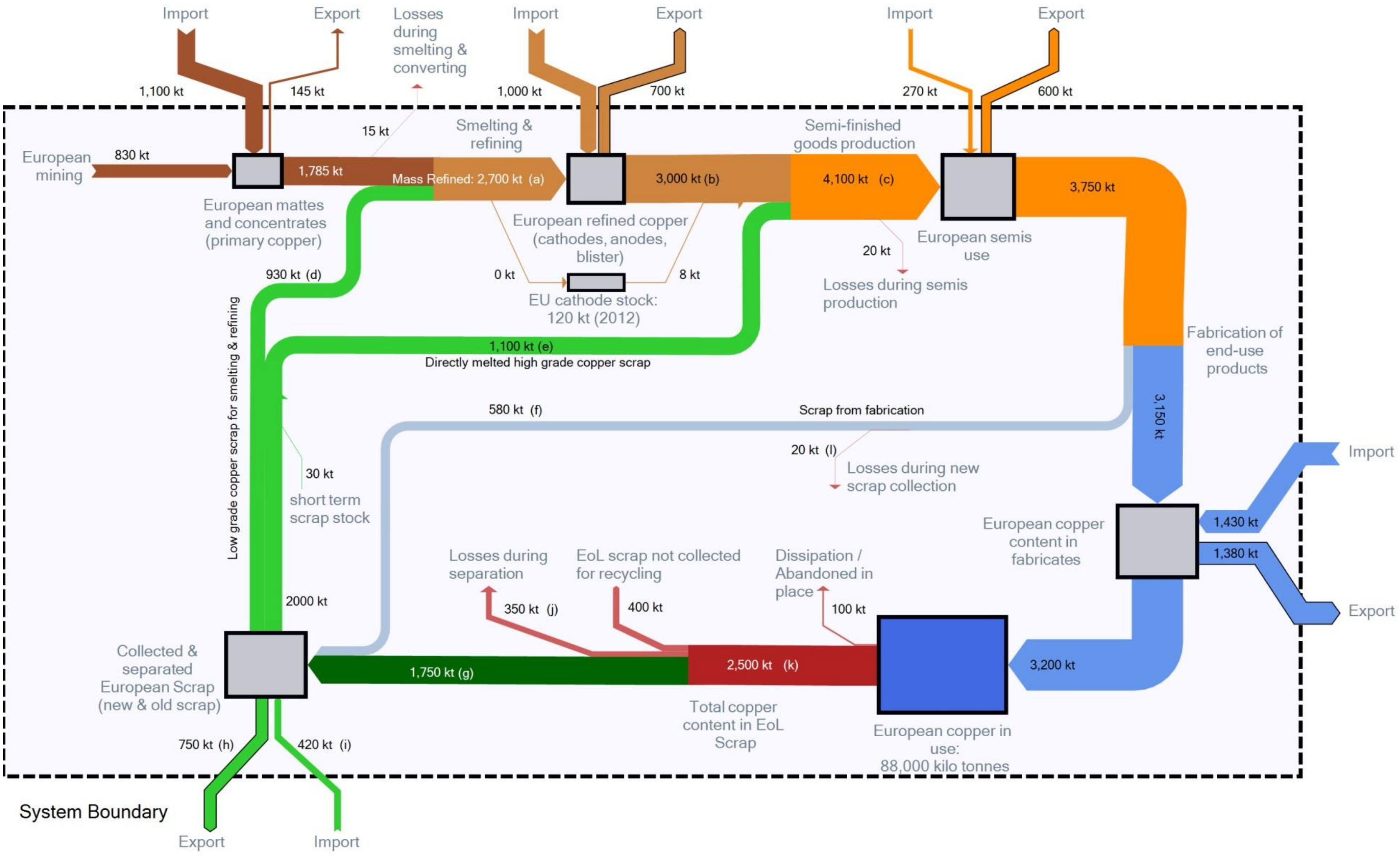
Substance or Material Flow Analysis (SFA, MFA)

- Focuses on just one material through the metabolism of a relatively extensive predetermined geographic region.

Copper Cycle Japan:
One Year Stocks and Flows, 1990-2000 (kt).



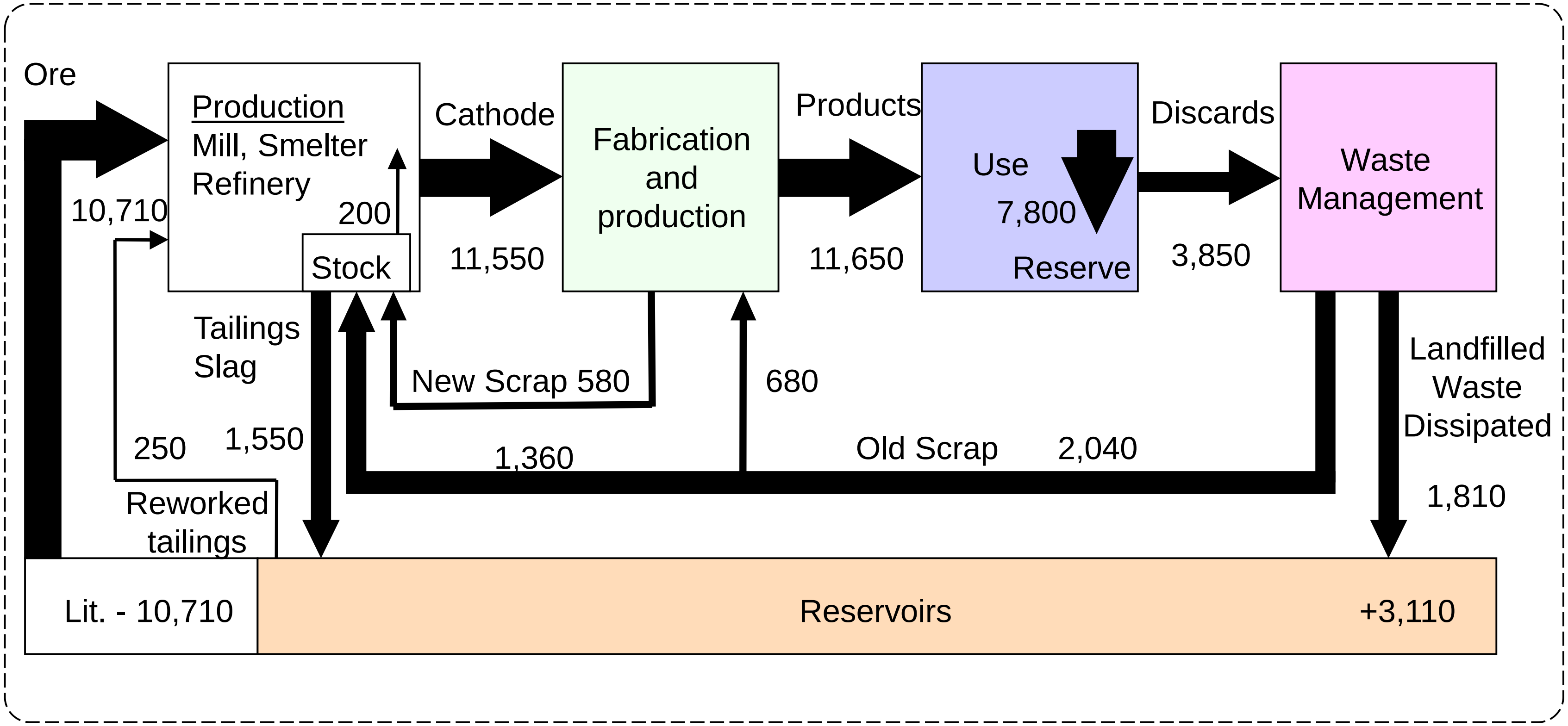
European Copper Stocks and Flows (kt/y – 2012).



Source: Fraunhofer ISI

The Global Copper Cycle, 1990-2000 (kt/y).

Cu



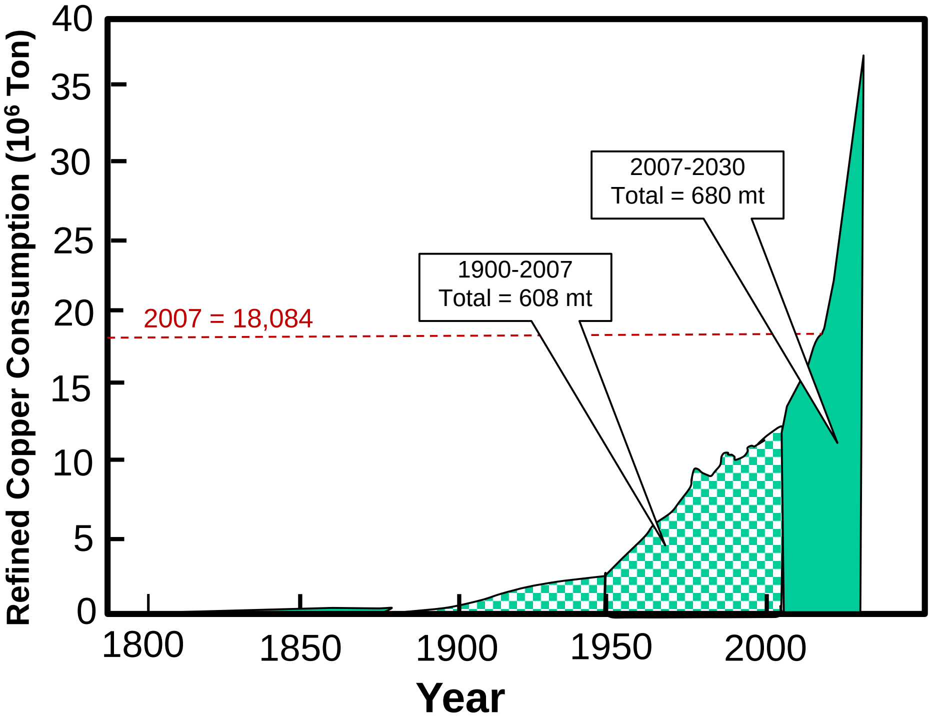
System Boundary (Closed System): "STAF World"

Copper Year Flows in Last two Centuries.

Copper is mainly used for electrical and hydraulic circuits → represents a good measure of a vital standard material.

Until 2000 (2015):

- 10 (13) *kg* pro capita for highly developed nations
- 0.6 (6) *kg* pro capita in China
- 0.2 (4) *kg* pro capita in India

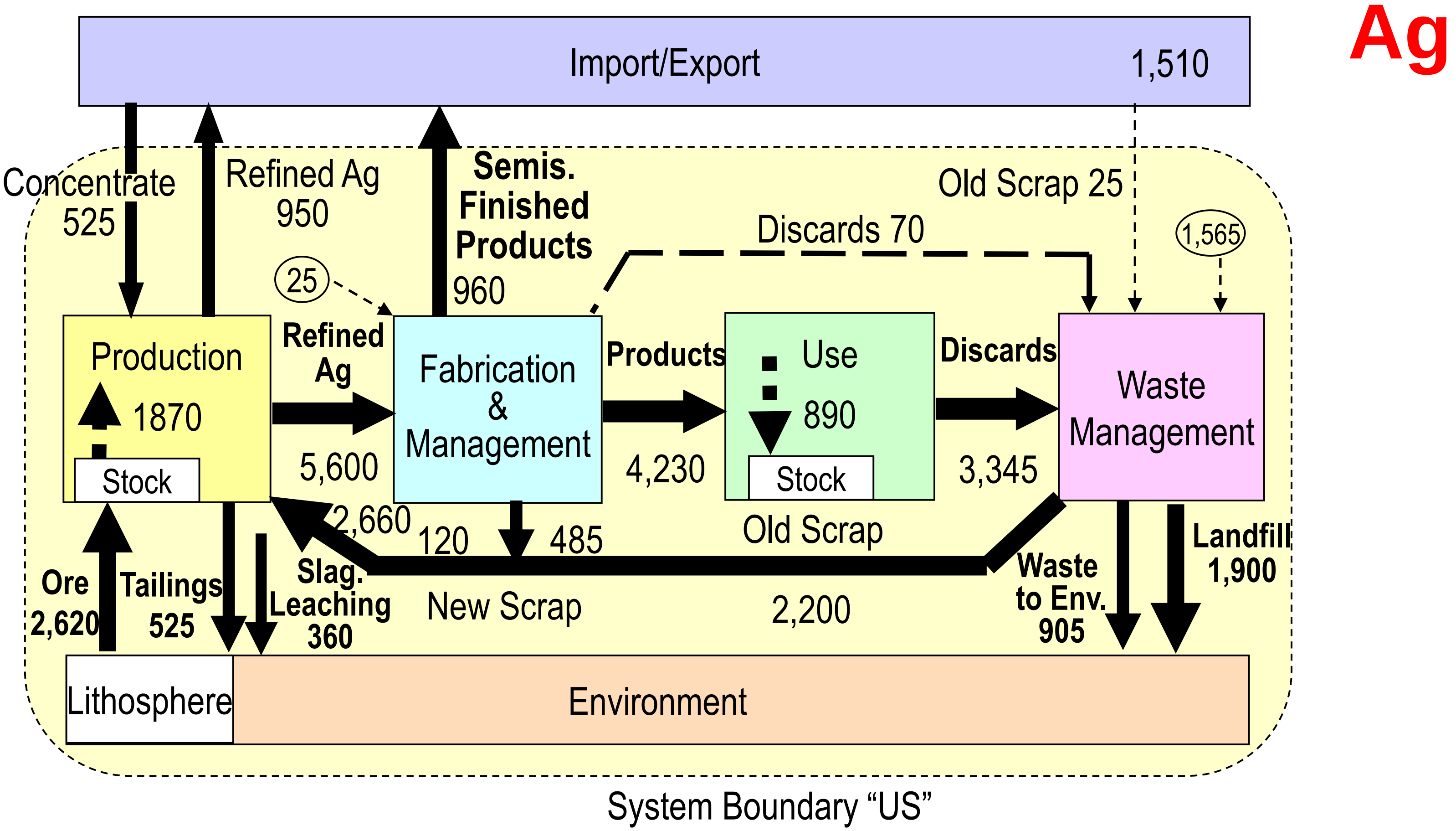


Copper Prices - 45 Year Historical Chart.

Source: https://www.macrotrends.net/1476/copper-prices-historical-chart-data

1 pound = 0.45359237 kilograms

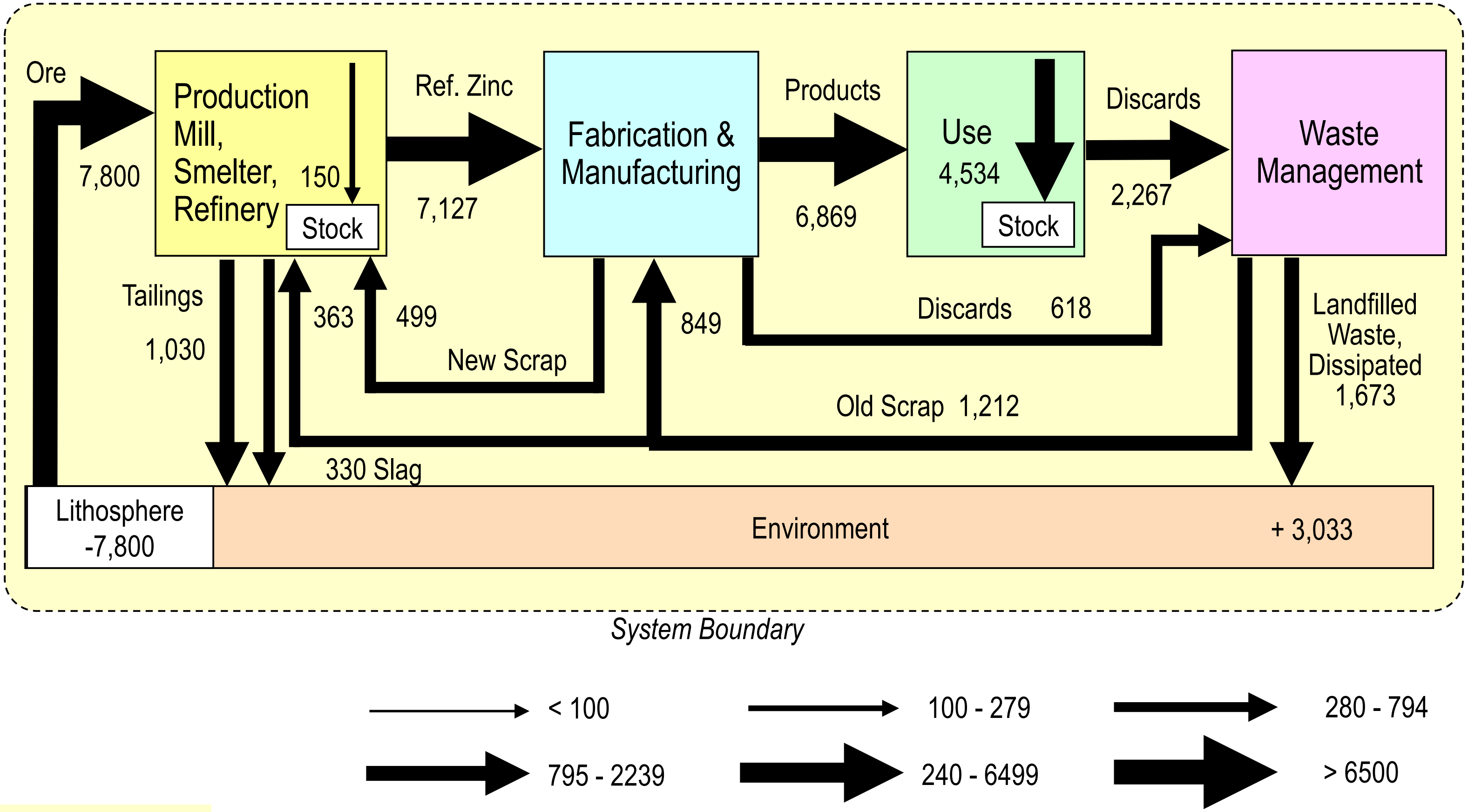
The US Global Silver Cycle, 1990-2000 (Mg/y).



All Results are in *Mg/y* of silver (1*Mg* = 1 *tonne*). Dashed lines indicate less reliable data; numbers in ovals are closure errors in the mass balance. STAF, Yale University

The Global Zinc Cycle, 2000-2007 (kt/y).

Zn



Scale: kt Zn/yr.

STAF, Yale University

Known Reserves of Selected Elements.

Element	**Reserves (10^9 *kg*)**	**Lifetime (*y*)**	**Locations of major reserves**
Al	20,000	220	Australia, Brazil, Guinea
Fe	66,000	120	Australia, Canada, Russia
Mn	800	100	Russia, Gabon, S. Africa
Cr	400	100	Russia, S. Africa, Zimbabwe
Cu	300	36	Chile, Russia, USA, Zaire
Zn	150	21	Australia, Canada, USA
Pb	71	20	Australia, Canada, USA, Russia
Ni	47	55	Canada, Russia, Cuba, N.Caled.
Sn	5	28	Brazil, China, Indonesia, Malaysia
U	2.8	58	Australia, Russia, S. Africa, USA

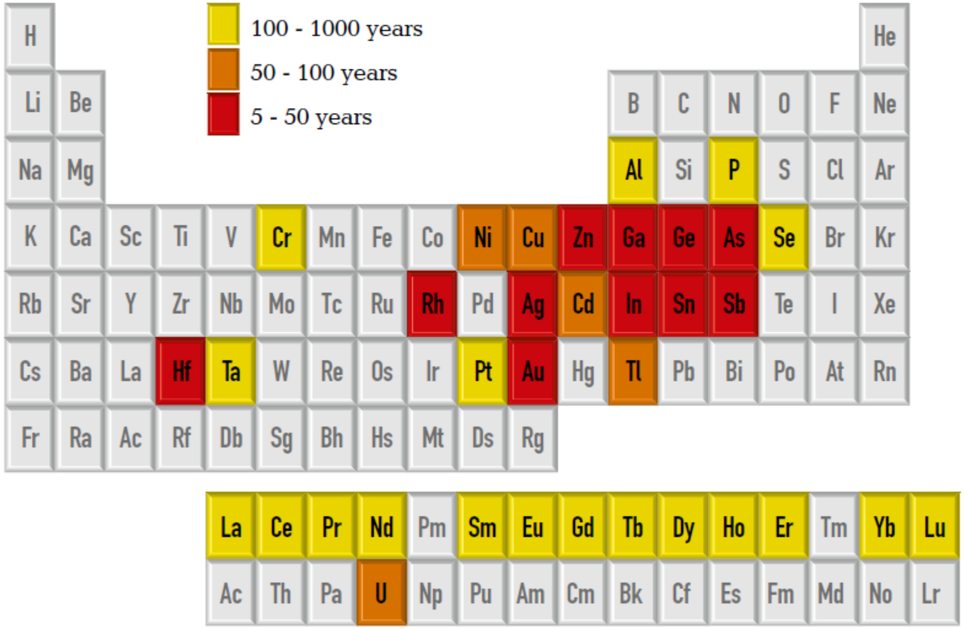
Elemental Sustainability: Towards the Total Recovery of Scarce Elements.

Some modern so-called low-carbon technologies are actually broadening concerns over future elemental sustainability for a wide range of elements.

To address rapidly depleting metal sources, such as indium and silver, we need to be more innovative in recovery technologies that essentially turn waste into a resource.

A multi-disciplinary blend of chemistry, engineering and biotechnology is required to realise this ambition.

Number of years remaining of rare and precious metals if consumption and disposal continues at present rate.



🟨 100 - 1000 years
🟧 50 - 100 years
🟥 5 - 50 years

H																	He	
Li	Be											B	C	N	O	F	Ne	
Na	Mg											Al 🟨	Si	P 🟨	S	Cl	Ar	
K	Ca	Sc	Ti	V	Cr 🟨	Mn	Fe	Co	Ni 🟧	Cu 🟧	Zn 🟥	Ga 🟥	Ge 🟥	As 🟥	Se 🟨	Br	Kr	
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh 🟥	Pd	Ag 🟥	Cd 🟧	In 🟥	Sn 🟥	Sb 🟥	Te	I	Xe	
Cs	Ba	La	Hf 🟥	Ta 🟨	W	Re	Os	Ir	Pt 🟨	Au 🟥	Hg	Tl 🟧	Pb	Bi	Po	At	Rn	
Fr	Ra	Ac	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg								
				La 🟨	Ce 🟨	Pr 🟨	Nd 🟨	Pm	Sm 🟨	Eu 🟨	Gd 🟨	Tb 🟨	Dy 🟨	Ho 🟨	Er 🟨	Tm	Yb 🟨	Lu 🟨
				Ac	Th	Pa	U 🟧	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

Source: Research Agenda for Process Intensification Towards a Sustainable World of 2050, (2011). www.ispt.nl

Environmental Accounting Techniques (6).

Ecological Footprint Analysis (EFA)

- An indicator of the sustainability of the human economy in relation to the earth's remaining natural capacity to supply resources.

- Converts material and energy flows into the land area required to produce the resources used in these activities, and compares the required areas to the available ones.

Environmental Accounting Techniques (7).

Environmental Space (ES)

- Compares resource demand with available environmental space and sustainability limits. These limits are compared to per capita use levels.

Environmental Accounting Techniques (8).

Material Intensity per Unit Service (MIPS)

- Involves the identification of all primary material and energy requirement of a specific product, example: the car.
- Links required input to goods as functional units, example: passenger-kilometres yielded by a car. The result is a material intensity unit.

Environmental Accounting Techniques (9).

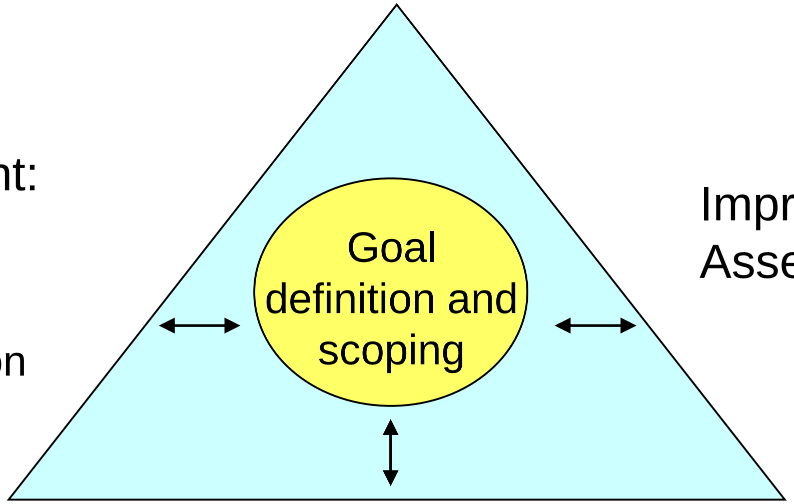
Sustainable Process Index (SPI)

- Calculates the total land area required by any process, technology, or other economic activity to sustainably provide natural material and energy resource flows and maintain waste assimilation.

- The aim is to assess the consistency of a process with its sustainability limits.

Environmental Accounting Techniques (10).

Life Cycle Analysis (LCA):



Impact Assessment:

- ecological health
- human health
- resource depletion

Goal definition and scoping

Improvement Assessment

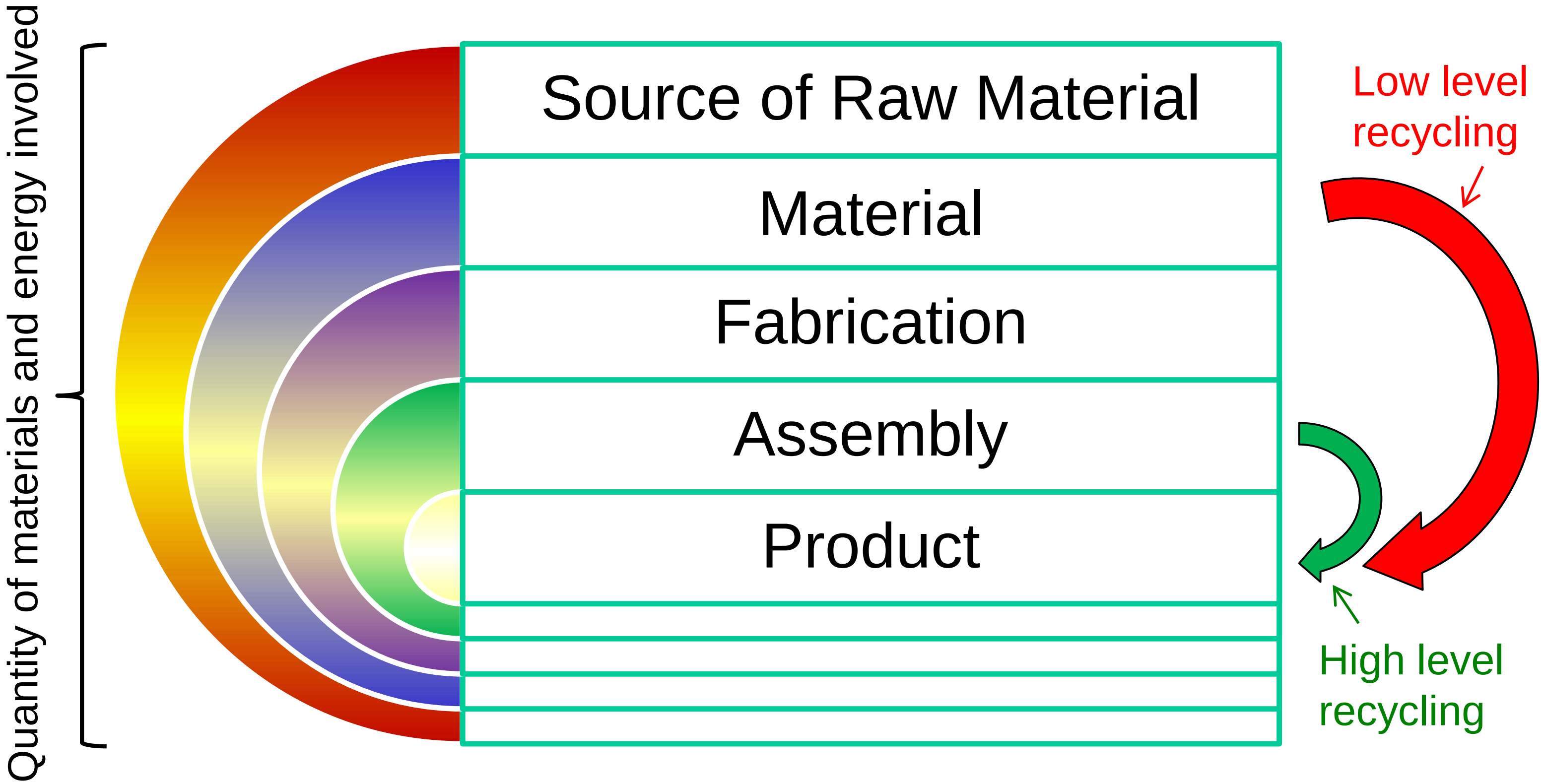
Inventory Analysis:

- material and energy consumption
- manufacturing
- use
- waste management

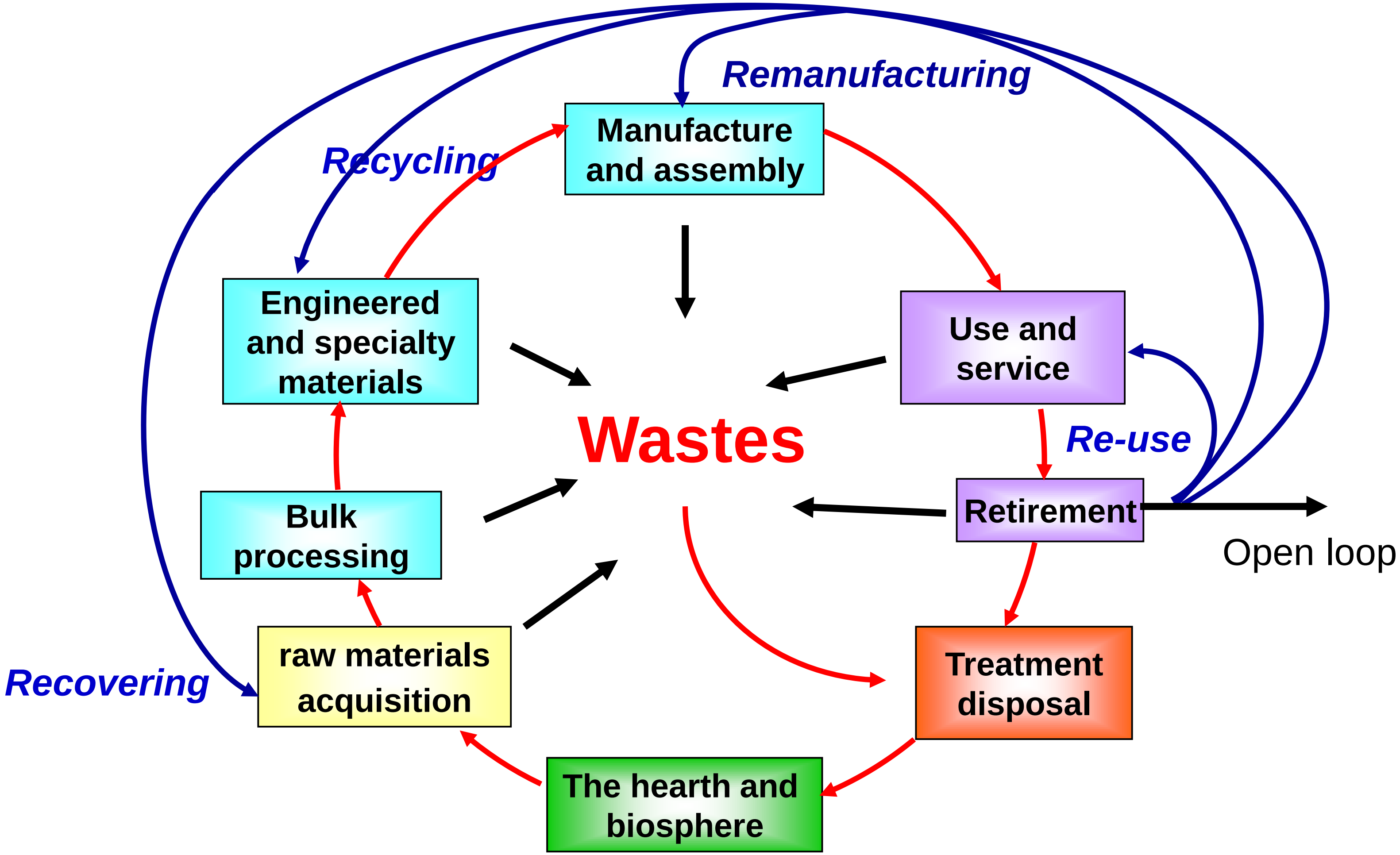
See the specific chapter

Guidelines for Life Cycle Assessment: A code of practice, F Consoli et al, 1993 Society of Environmental Toxicology and Chemistry.

Level of Recycling and Embedded Utility.



LCA and Alternatives in Cycle Closure.



Industrial Ecology: DFE e LCD.

Life cycle design (LCD):

- a systems-oriented approach for designing more ecologically and economically sustainable product systems.

Design for the environment (DfE):

- similar goal but evolved from “design for x” approach (where x = testability, reliability).

DFE: Parameters and Strategies.

ISSUES TO CONSIDER WHEN DEVELOPING ENVIRONMENTAL REQUIREMENTS:

- Materials and Energy
- Ecological Health
- Residuals
- Human Health and Safety

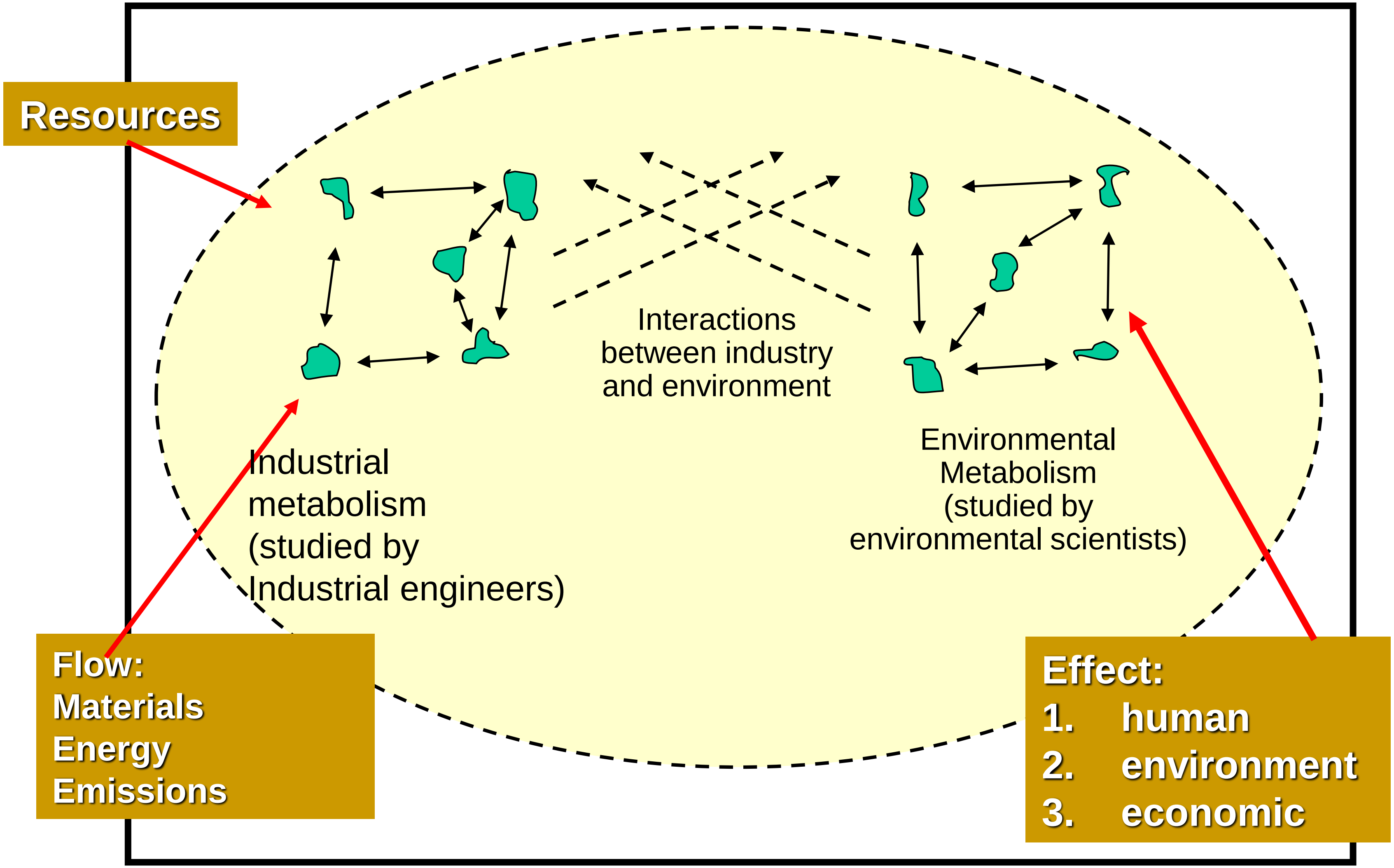
STRATEGIES FOR MEETING ENVIRONMENTAL REQUIREMENTS:

- Product Life Extension
- Material Life Extension
- Material Selection
- Efficient Distribution
- Improved Management Practices

Industrial Ecology: Applications.
Environmental Policy and Regulation.

- IE global view offers an appropriate context for prioritizing risks and identifying points of high leverage for change.
- IE methods, such as industrial metabolism provide means for assessing alternative policy options.
- Organizational design could benefit from IE strategy of learning from the dynamics and principles of ecosystems, particularly their processes of regulation and self regulation.
- IE can assist in policy making and research funding in energy, transportation, agriculture,
- More effective sustainable strategies
- Opening of many business opportunities through demand of new technologies and processes and new applications of old ones.

Elements of Industrial Ecology.



Resources

Interactions between industry and environment

Industrial metabolism (studied by Industrial engineers)

Environmental Metabolism (studied by environmental scientists)

Flow:
Materials
Energy
Emissions

Effect:
1. **human**
2. **environment**
3. **economic**

Source : Graedel & Allenby, 1995

Forms of Eco-Industrial Development (EID).

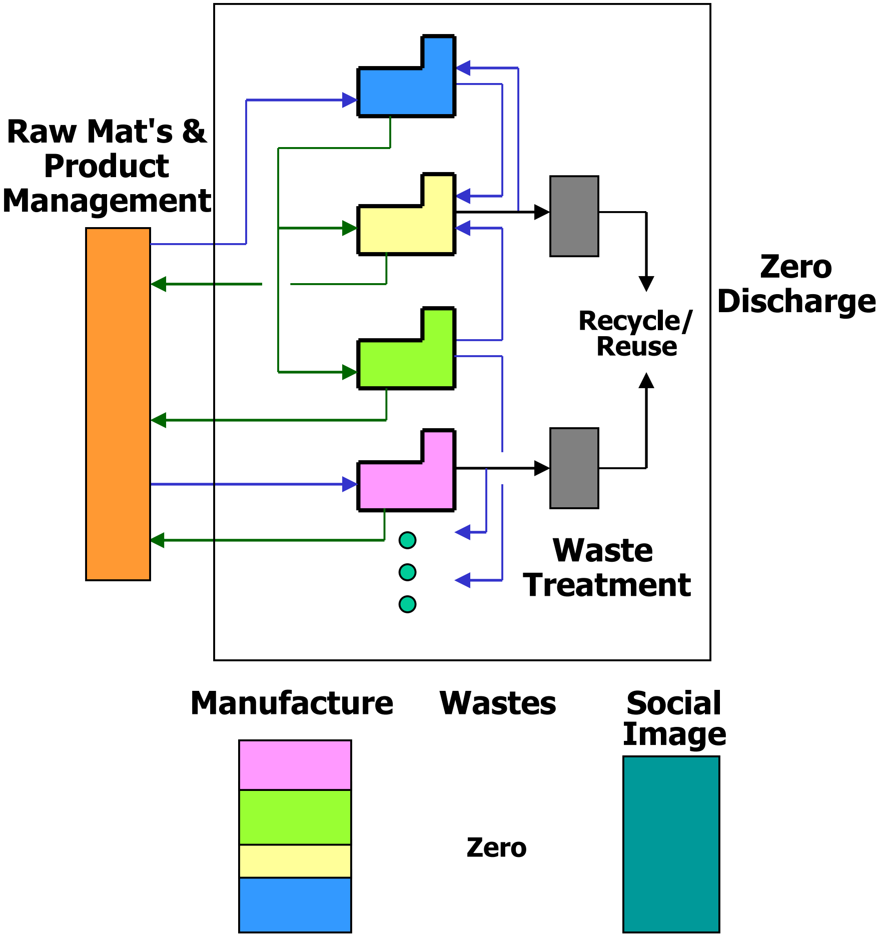
- **Eco-Industrial Parks (EIP)**
  - Co-located businesses
  - “Closed loop” with significant byproducts
  - Continuous environmental and societal improvements

- **Eco-Industrial Networks**
  - Virtual EIPs: Regional waste exchange network
  - Optimize material flow efficiencies and scale economies through resource recovery and exchange
  - EIN can bring scale economies required for developing a byproduct market

Definition of an EIP [Lowe, 2001].

An **eco-industrial park** (EIP) or estate is a community of manufacturing and service businesses *located together on a common property*. Member businesses seek enhanced environmental, economic, and social performance through collaboration in managing environmental and resource issues including information, energy, water, materials, infrastructure, and natural habitat.

By working together, the community of businesses seeks a collective benefit that is greater than the sum of individual benefits each company would realize by only optimizing its individual performance.



EIP Concept

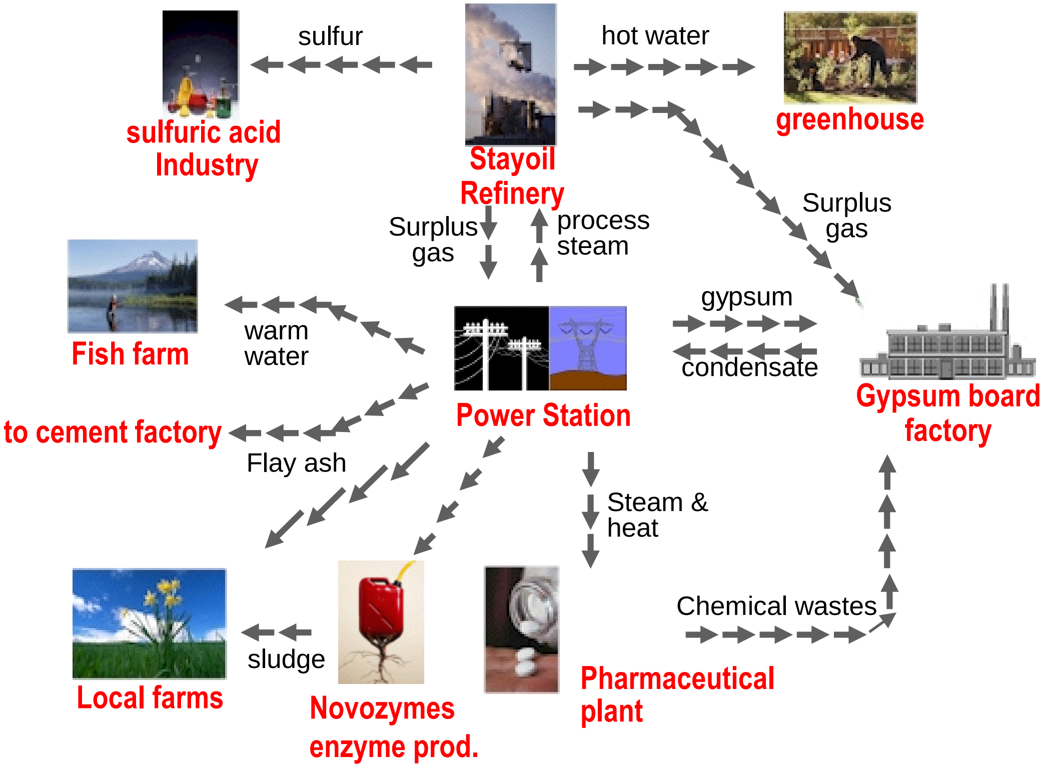
Industrial Ecology : Applications.

Eco-Industrial Parks: Industrial Symbiosis.

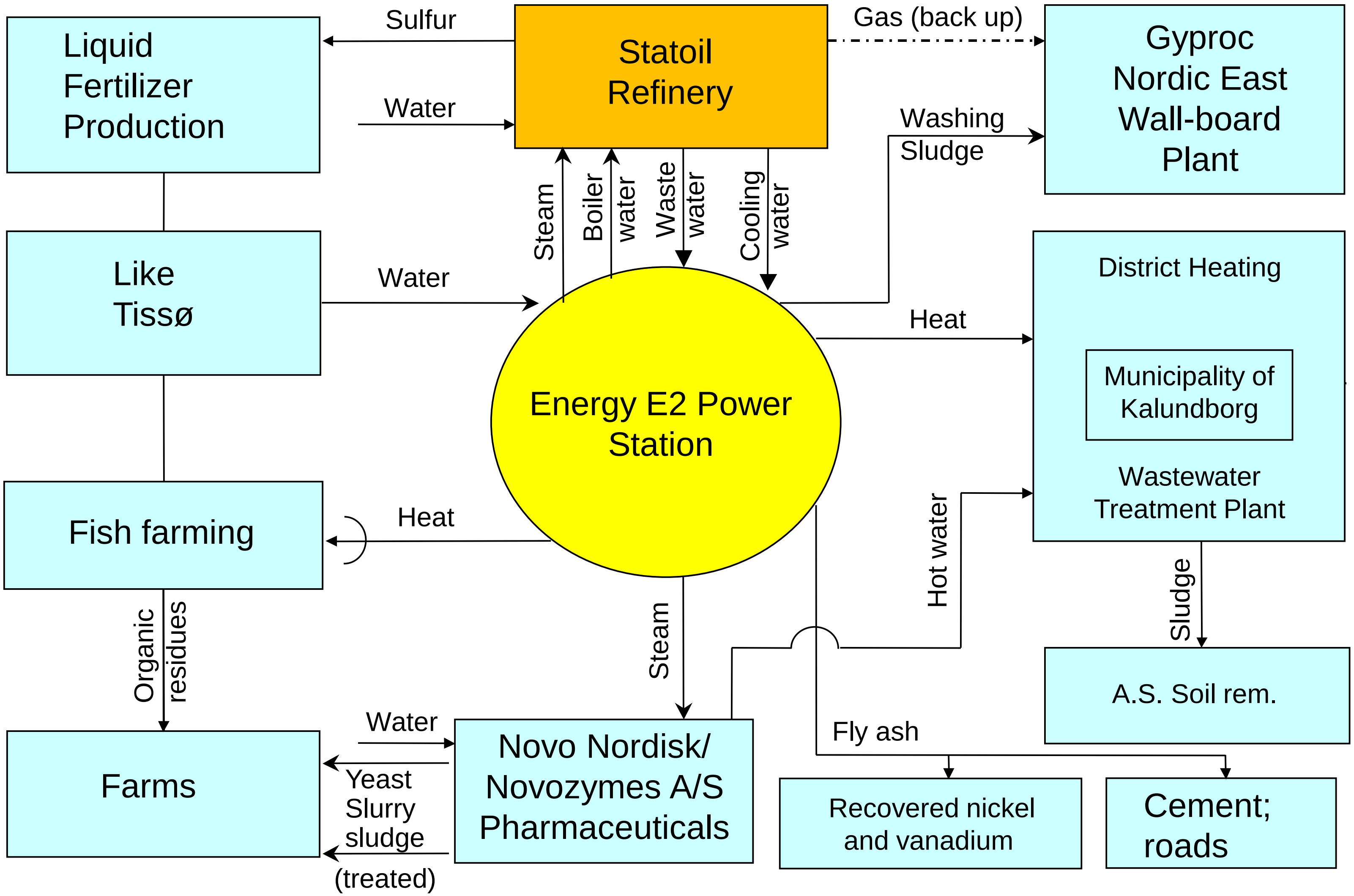
Well- known example of the **Kalundborg park**.

The Kalundborg park involves mainly 6 players:

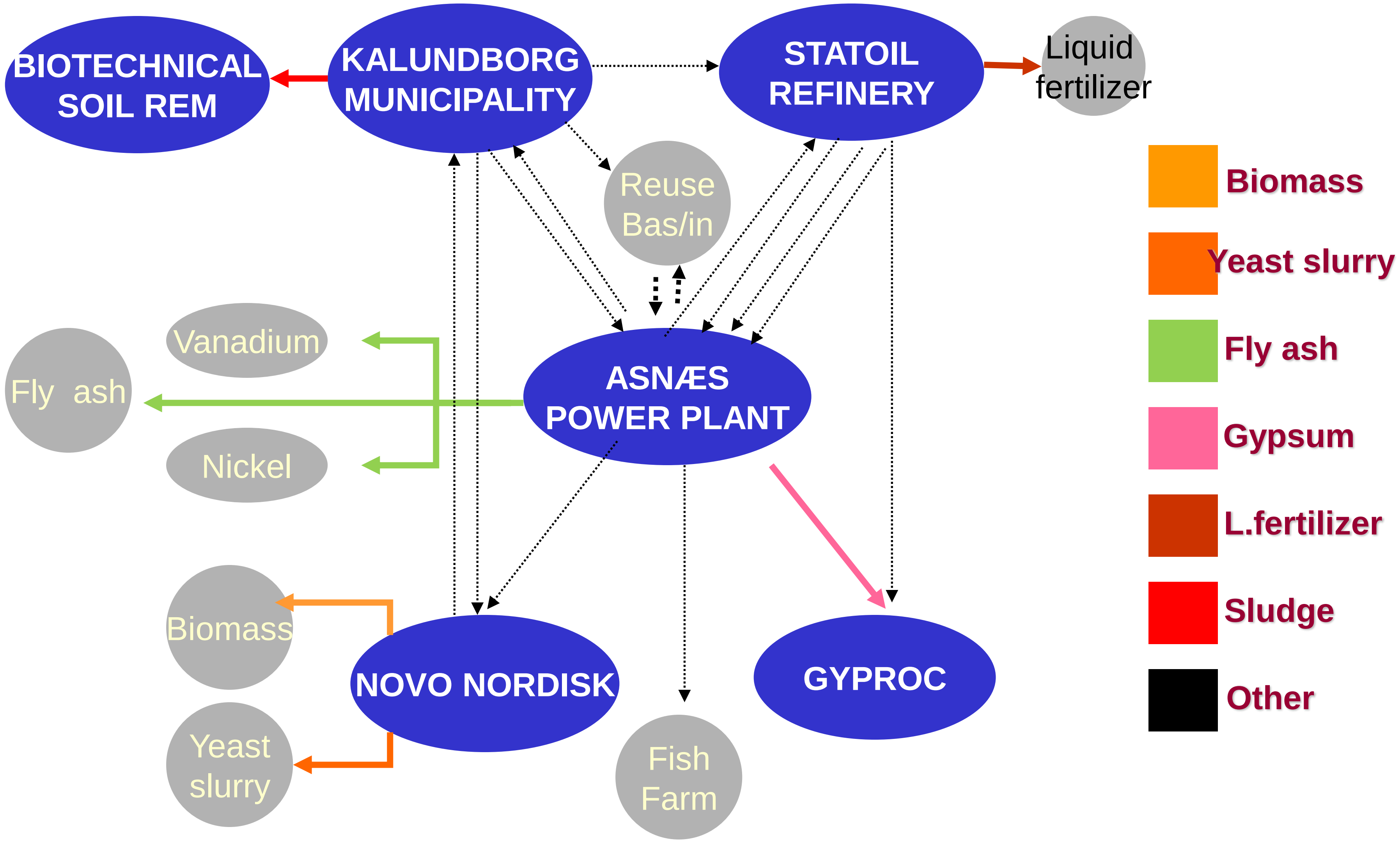
- “Aesnes” power station, coal-fired
- “Statoil” refinery
- “Gyproc”, a plastboard factory
- “Novo Nordisk”, a pharmaceutical firm
- “Novozymes A/S” an enzyme producer
- City water and heat supply



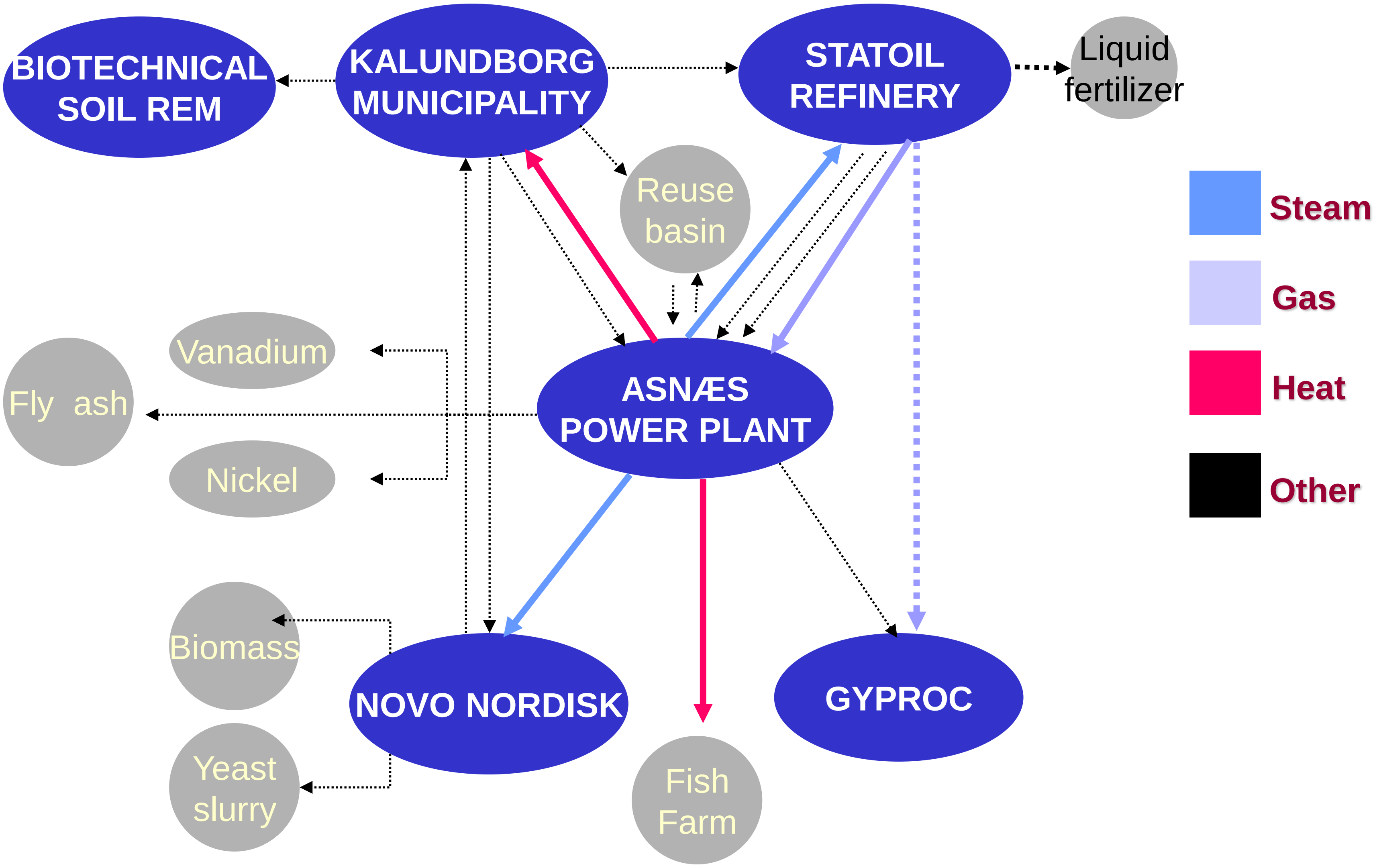
Industrial Symbiosis at Kalundborg (DK).



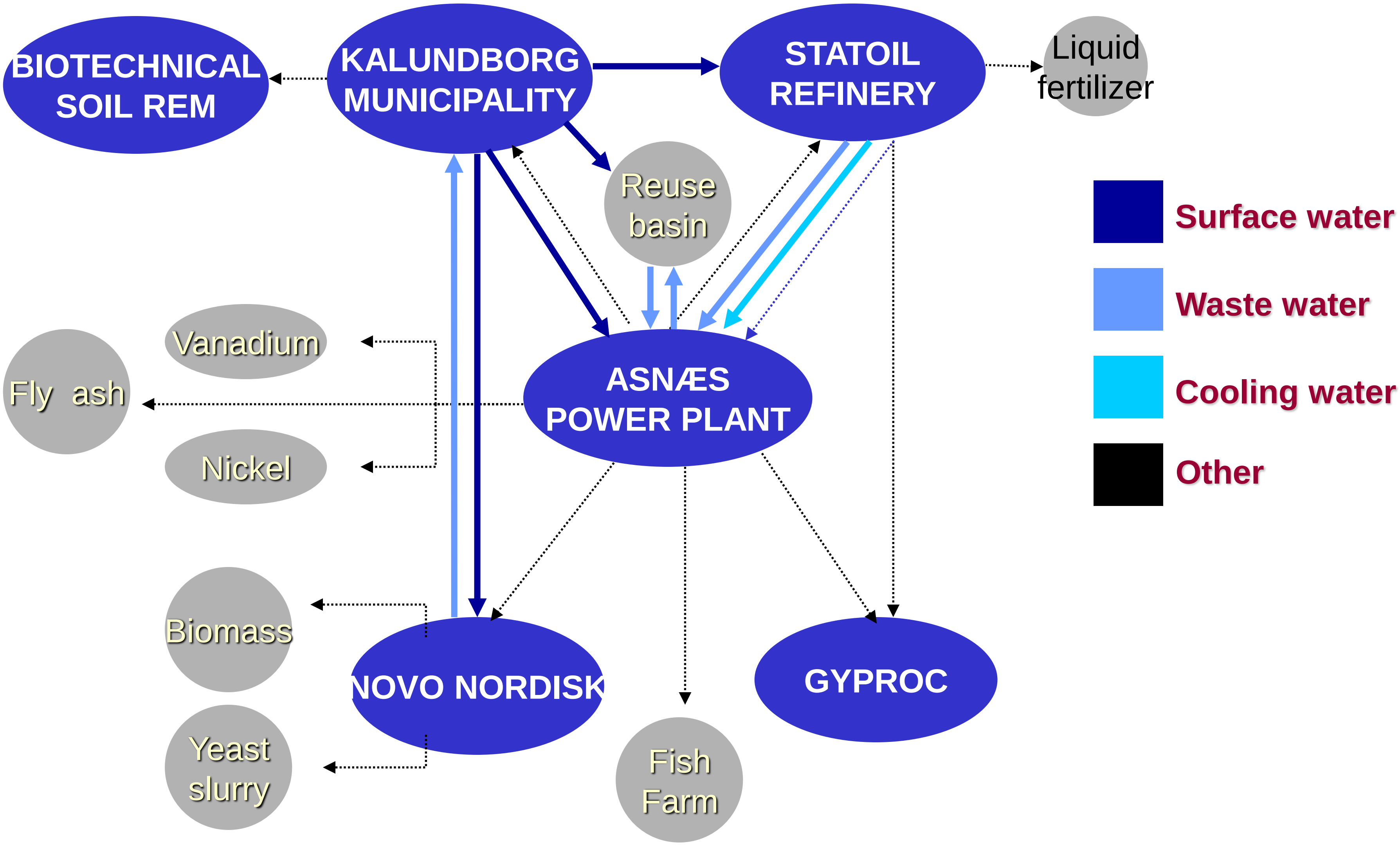
Physical Flows: Waste Exchange.



Physical Flows: Energy Exchanges.



Physical Flows: Water Exchanges.



BIOTECHNICAL SOIL REM

KALUNDBORG MUNICIPALITY

STATOIL REFINERY

Liquid fertilizer

Reuse basin

Vanadium

Fly ash

Nickel

ASNÆS POWER PLANT

Biomass

NOVO NORDISK

Yeast slurry

Fish Farm

GYPROC

🟦 Surface water

🟦 Waste water

🟦 Cooling water

⬛ Other

What Resources can be Shared through Industrial Symbiosis?

Physical flows

- Energy
- Water
- Waste/recovery/recycling/substitution
- Transportation

Other matters

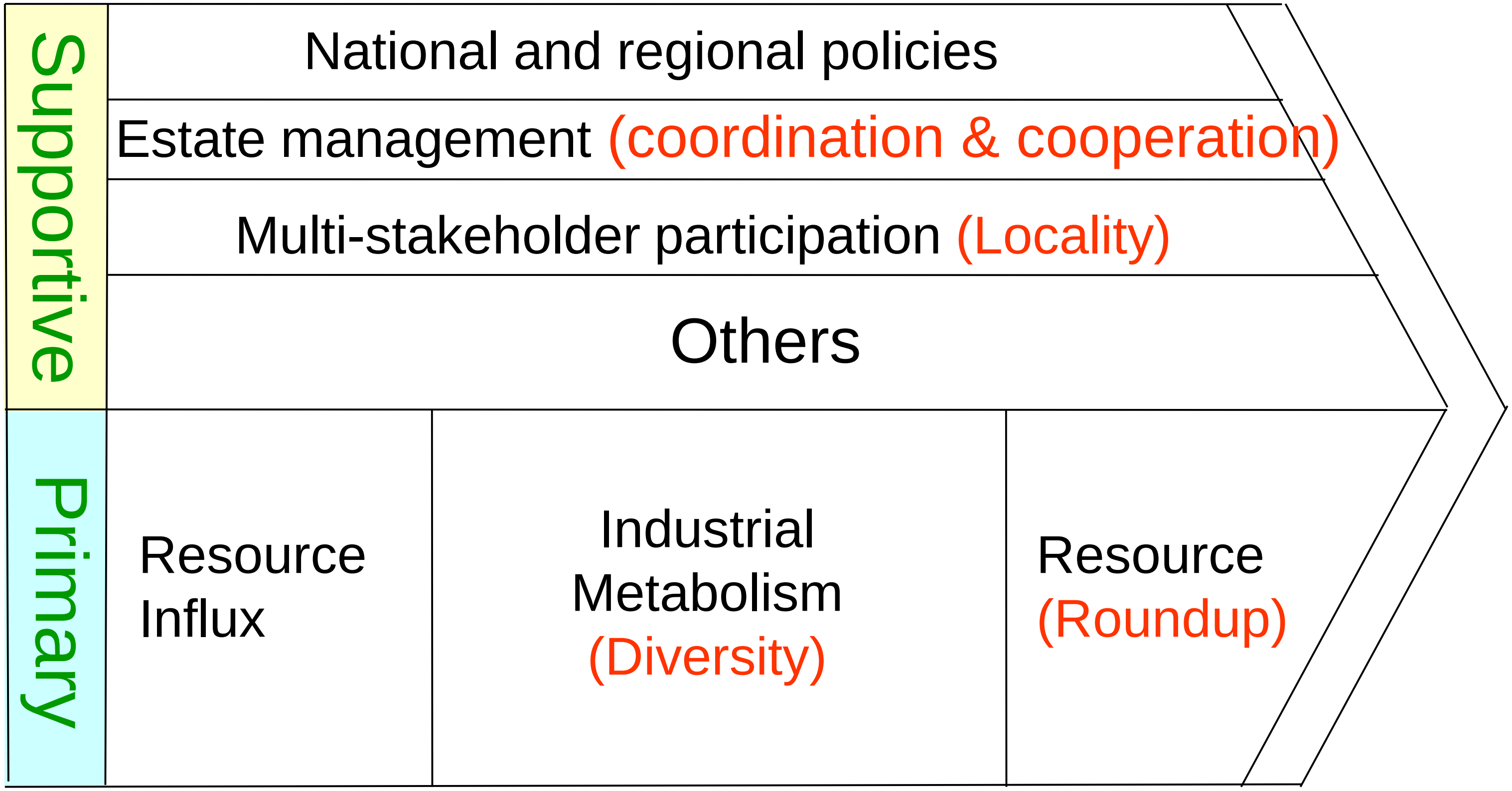
- Information
- Training
- Regulatory functions
- Marketing

Components.

- Primary: Interaction - **Industrial Metabolism**
  - *Resource optimization*: energy/water/material flow (closing the loop, green chemistry, renewable energy, resource cascading)
  - *Product and system design* (efficiency and effectiveness, built environment design such as green architecture, wetland preservation, landscape ecology)
  - *Information management* (effectiveness)

- Supportive: Inter-relationship among the elements in the industrial system **- Industrial Symbiosis**
  - *Stakeholders participation and communications* (industry, government, citizen, NPO, academia, researchers, etc.) – policies and management, economy and finance, human resources, education, research and development, training, marketing, regulatory functions ...
  - *Accounting system, Shared infrastructure, utility, and services*

Value Chain and the 4 IE Principles.



Supportive

National and regional policies

Estate management (coordination & cooperation)

Multi-stakeholder participation (Locality)

Others

Primary

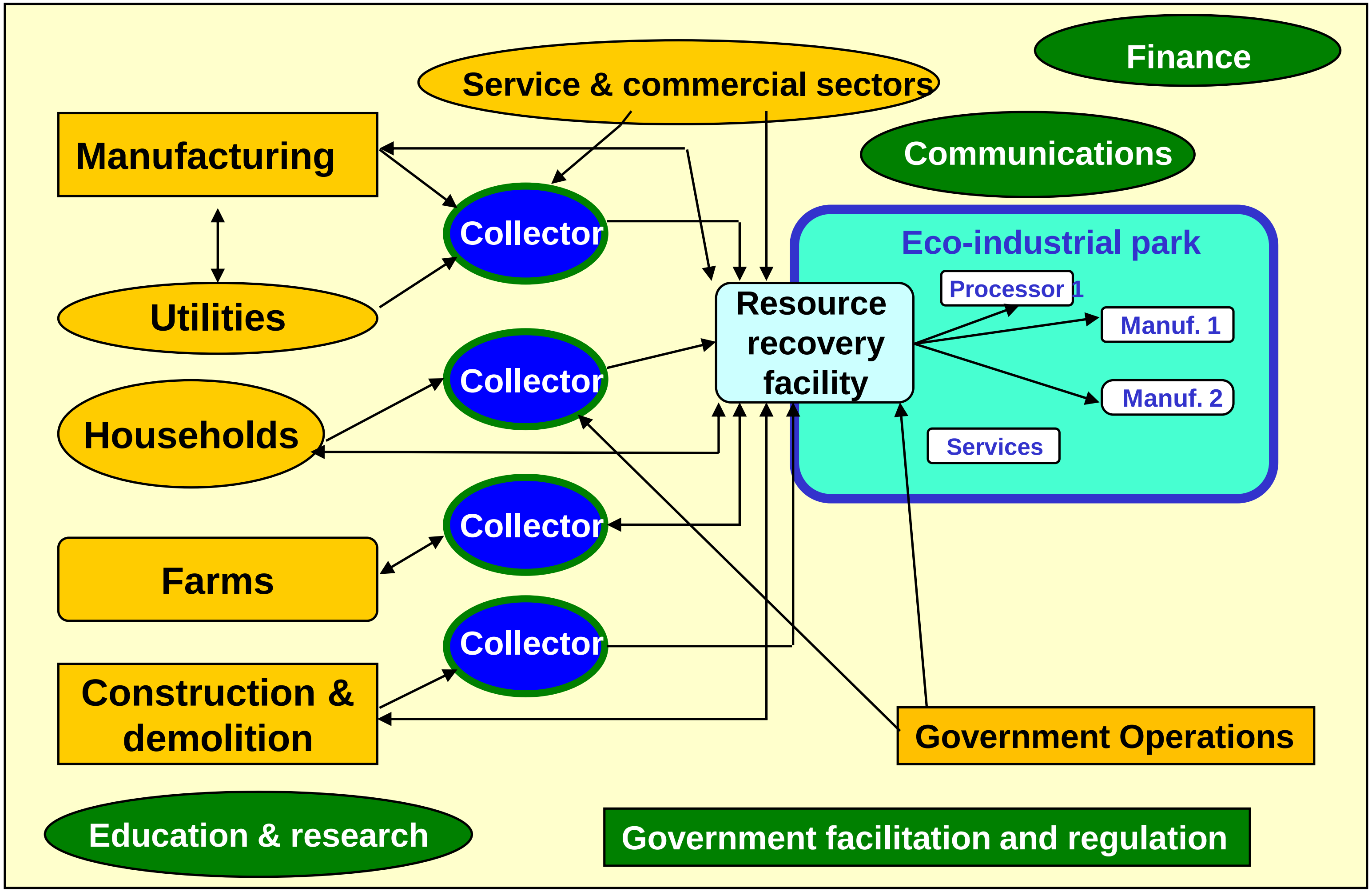
Resource Influx

Industrial Metabolism (Diversity)

Resource (Roundup)

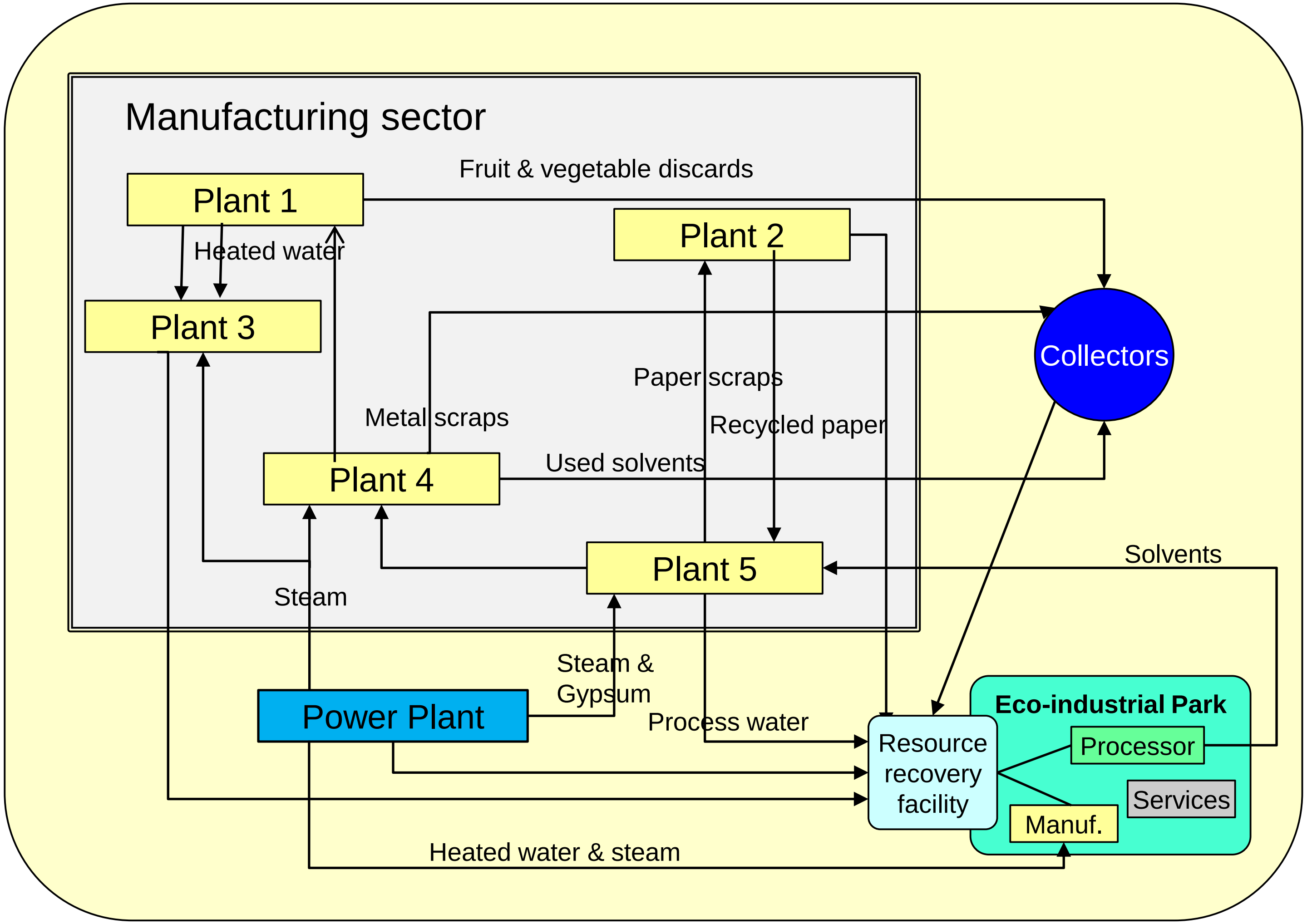
"Creating By-Product Resource Exchanges for Eco-Industrial Parks",
Journal of Cleaner Production, Volume 4, Number 4, an industrial ecology special issue,
Elsevier, Oxford.

Integrated Management of Wastes.

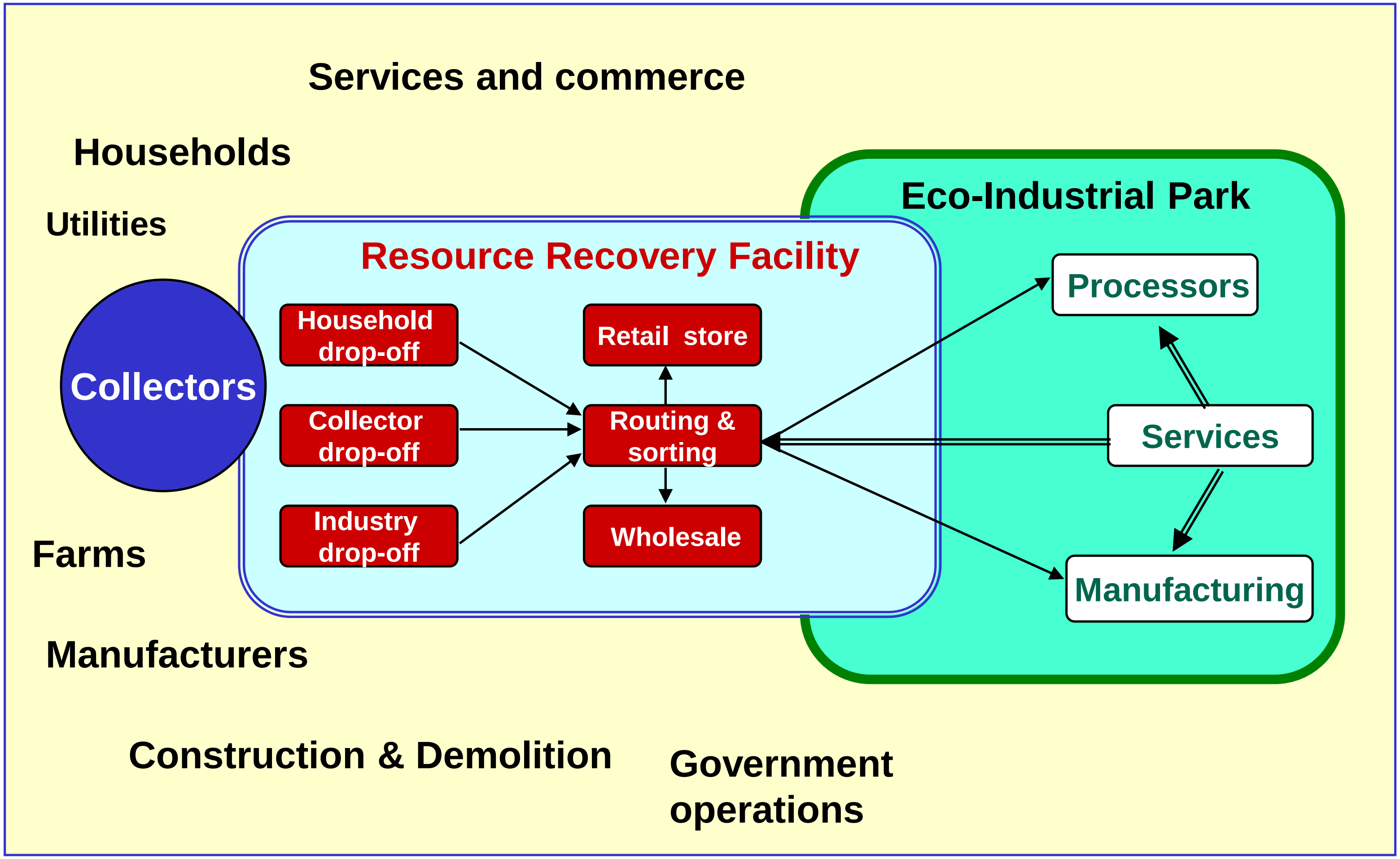


http://www.indigodev.com/Eipresrecov.html

An EIP Serves Regional Manufacturing.

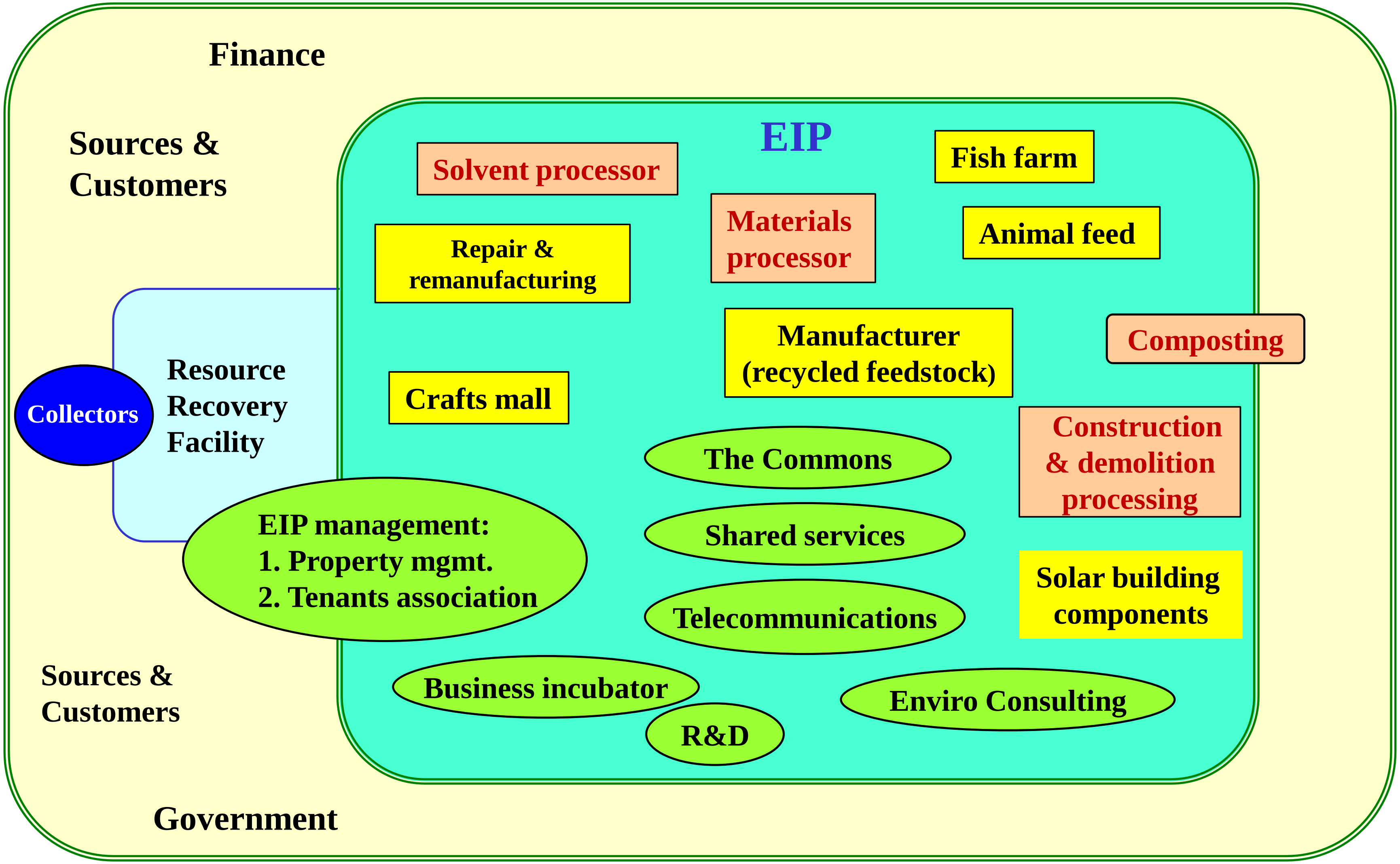


Resource Recovery as Hub to EIP.



Collection companies may be part of the resource recovery facility and EIP or independent.

Inside the Eco-Industrial Park (EIP).



A conceptual model, not a map

Urban Ore's Twelve Master Categories of Discards.

paper	plant debris	putrescibles
ceramics	soils	wood
metal	glass	plastic
chemicals	textiles	reusable goods

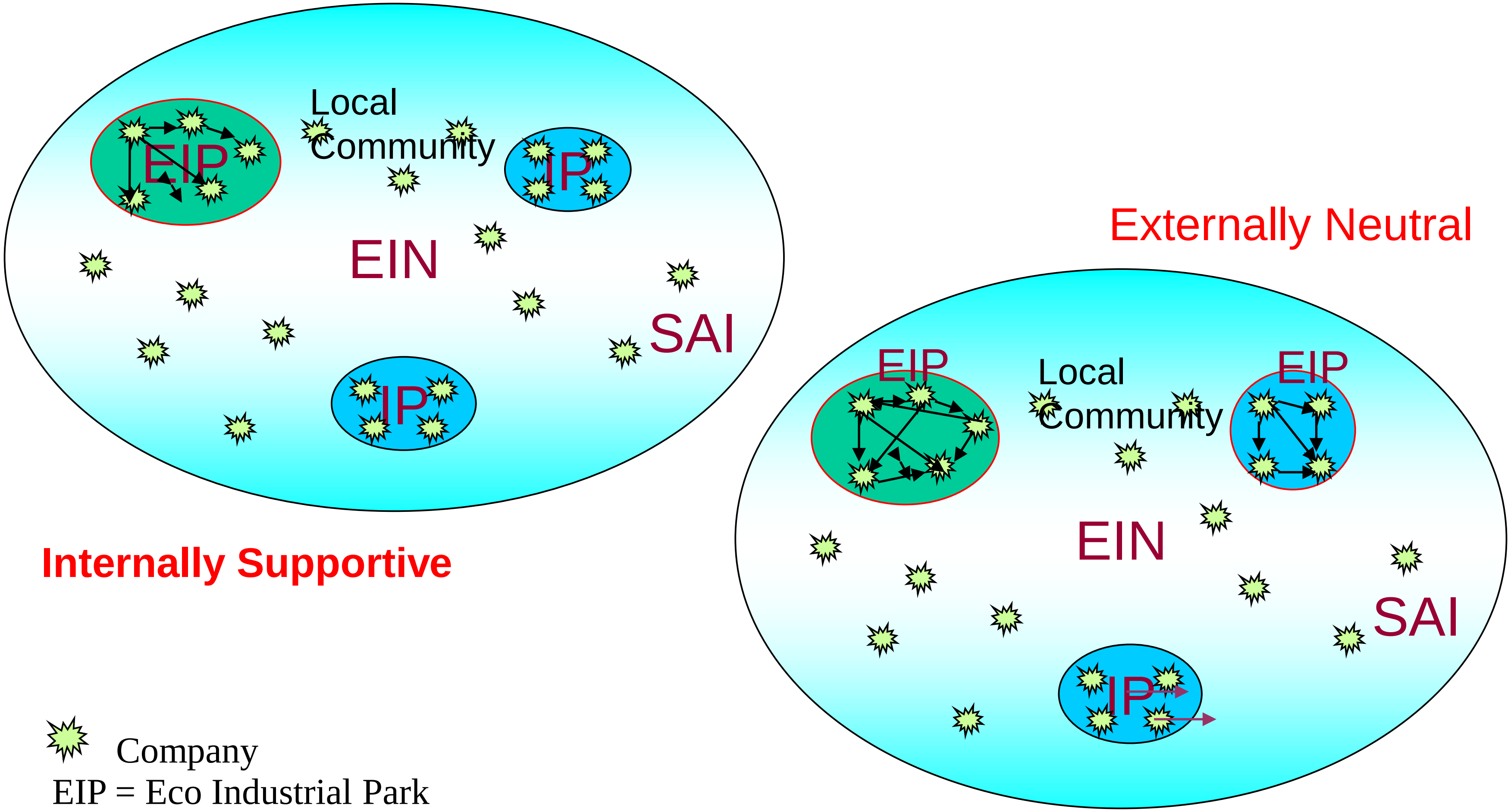
Service voids in any of these categories (or their subcategories) may indicate business development opportunities. Sometimes an existing business may be able to expand to recover a particular material or class of materials. An asphalt company, for instance, might profitably expand to handle concrete and asphalt construction and demolition debris, providing it with a recycled feedstock. With some materials, research will be necessary to find technologies ready for commercial application or firms that have demonstrated proprietary technologies which may be available for licensing.

Filling service voids effectively requires exploration of different technical and business options to find the ones that provide the highest value reuse that is economically feasible.

Potential Areas of Action Program.

Quality of Life/Community Connections Integrating Work and Recreation Cooperative education Opportunities Volunteer and Community programs Involvement in Regional planning	**Marketing** Green Labeling Accessing Green Markets Joint Promotions (e.g. advertising, trade shows) Joint Ventures Recruiting Value Added Companies	**Materials** Common Buying Customer/Supplier Relations By-Product Connections Creating New Material Markets
Information/Communications Systems Internal Communications External Information Exchange Monitoring Systems Computer Compatibility Joint Management Information System for Park Management	**Transportation** Shared Commuting Shared Shipping Common Vehicle Maintenance Alternative Packaging Intra-Park Transportation Integrated Logistics	**Environment, Health and Safety** Accident Prevention Emergency Response Waste Minimization Multi-media Planning Design for Environment Shared Environmental Information Systems Joint Regulatory Commit
Production Process Pollution Prevention Scrap Reduction and Re-use Production Design Common Subcontractors Common Equipment Technology Sharing Integration	**Human Resources** Human Resources Recruiting Joint Benefit Packages Wellness Programs Common Needs (payroll, maintenance, security) Training and Integrated Logistics	**Energy** Green Buildings Energy Auditing Cogeneration Spin-off Energy Firms Alternative Fuels

EID (Eco-Industrial Development) Stages.



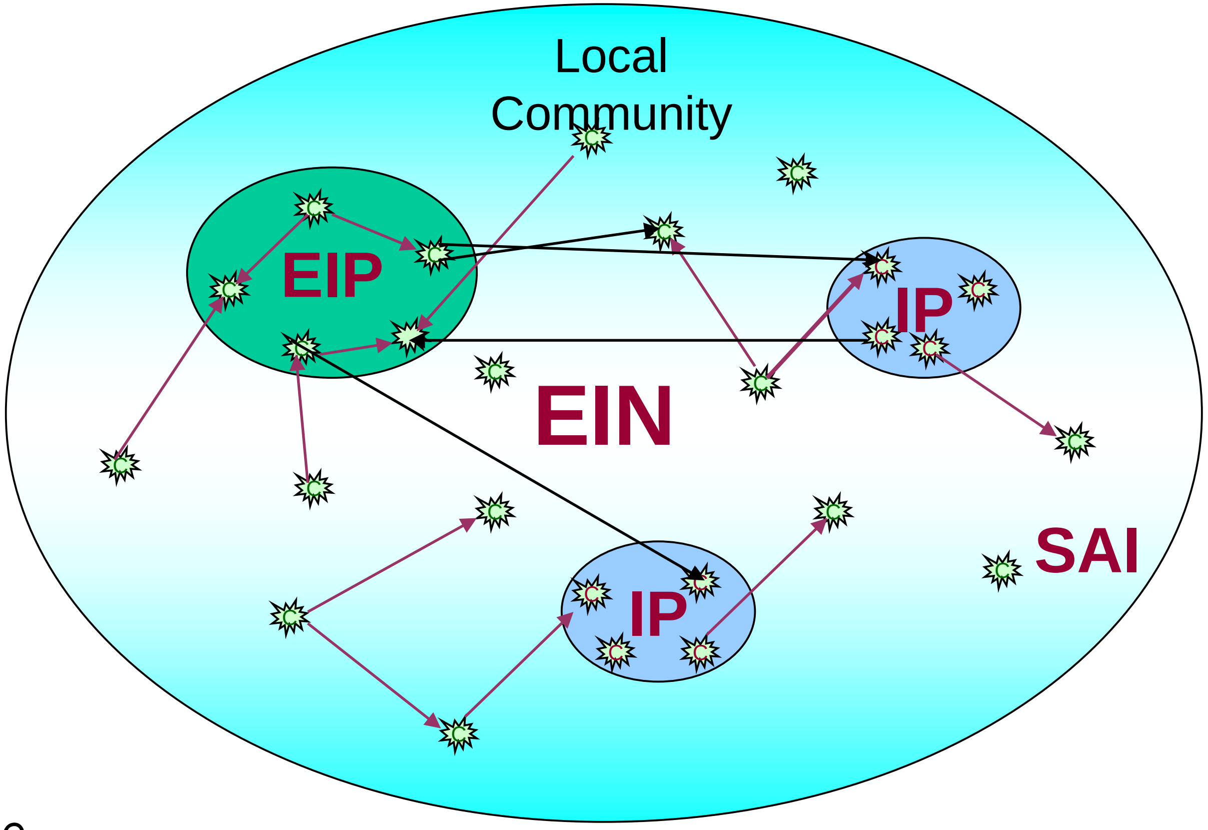
Internally Supportive

Externally Neutral

✸ Company
EIP = Eco Industrial Park
EIN = Eco Industrial Network
IP = Conventional Industrial Park
SAI = Stand Alone Industry

→ + by-product exchanges

EID Stage: Externally Supportive.



Company

EIP = eco-industrial park

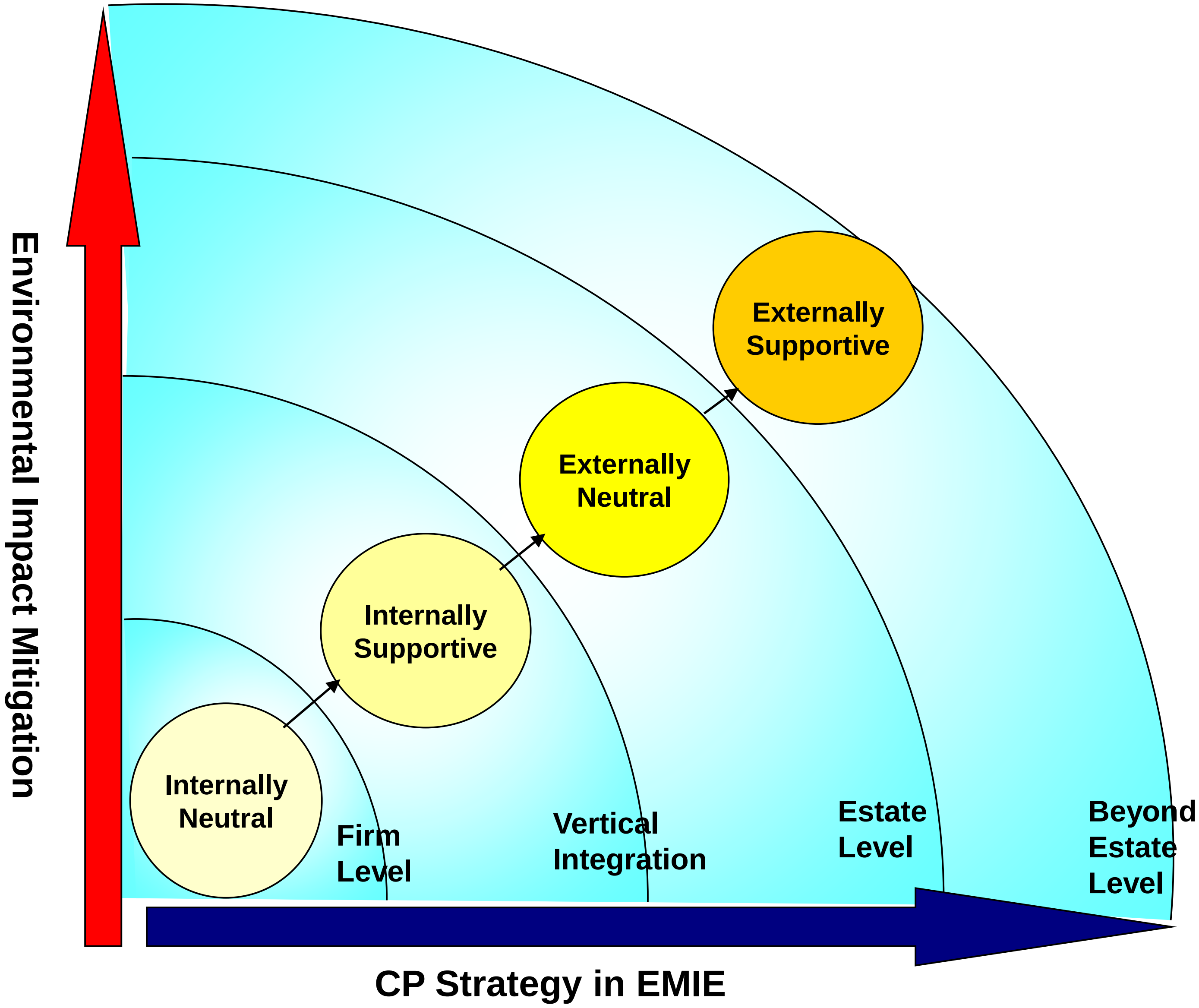
EIN = eco-industrial network

IP = conventional industrial park

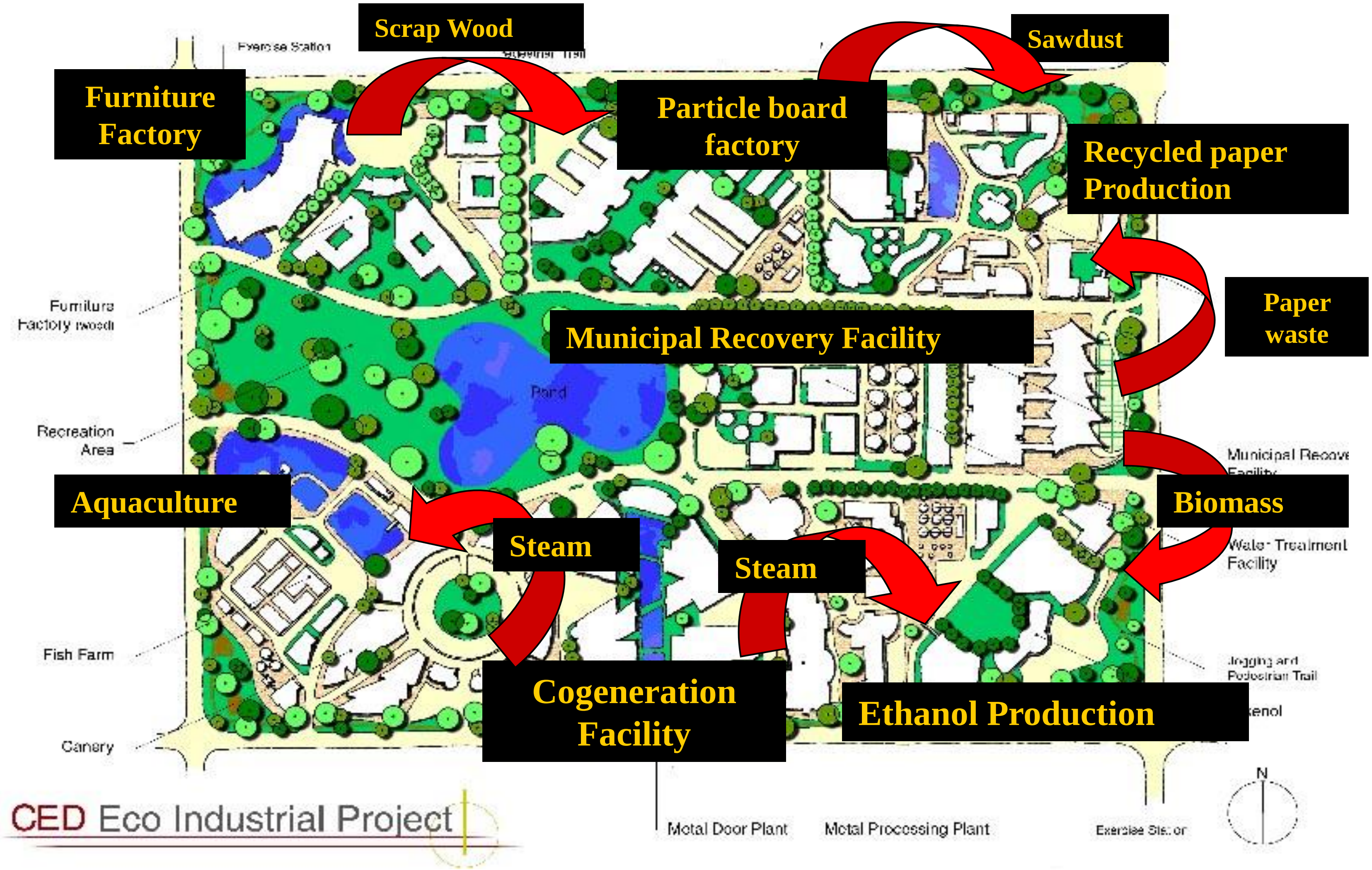
SAI = Stand Alone Industry

→ + by-product exchanges

EID Stages.


Environmental Impact Mitigation
Internally Neutral
Internally Supportive
Externally Neutral
Externally Supportive
Firm Level
Vertical Integration
Estate Level
Beyond Estate Level
CP Strategy in EMIE

Exchange of Biological By-products.



Scrap Wood

Furniture Factory

Particle board factory

Sawdust

Recycled paper Production

Paper waste

Municipal Recovery Facility

Biomass

Aquaculture

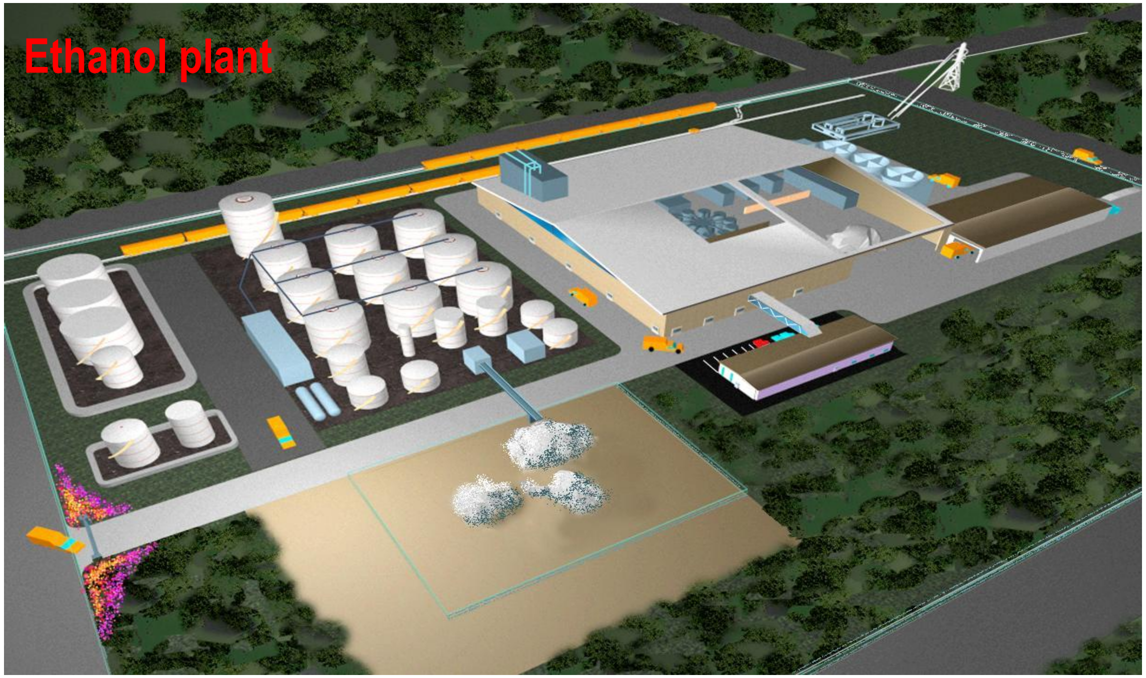
Steam

Steam

Cogeneration Facility

Ethanol Production

Exchange of Biological By-products (2).



Ethanol By-products:

- Lignin
- Gypsum
- Yeast

Potential Structures for exchange:

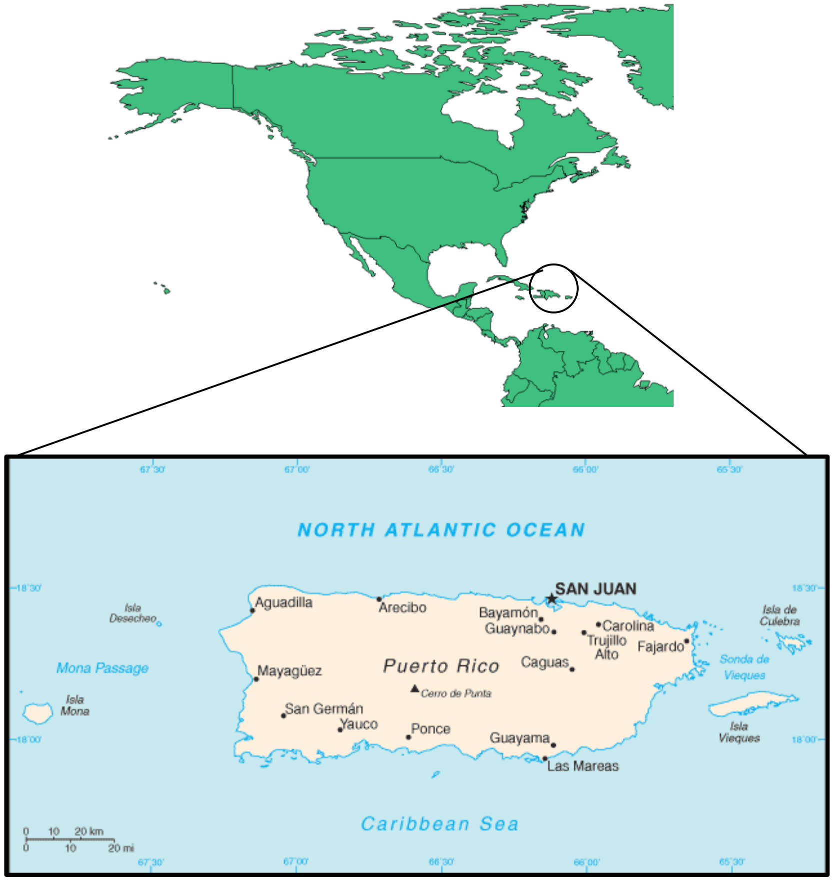
- Wallboard Manufacturer
- Animal feed supplier

Main Inputs:

- Agricultural residues or wood wastes
- Sulfuric acid
- Steam from a Co-generation facility

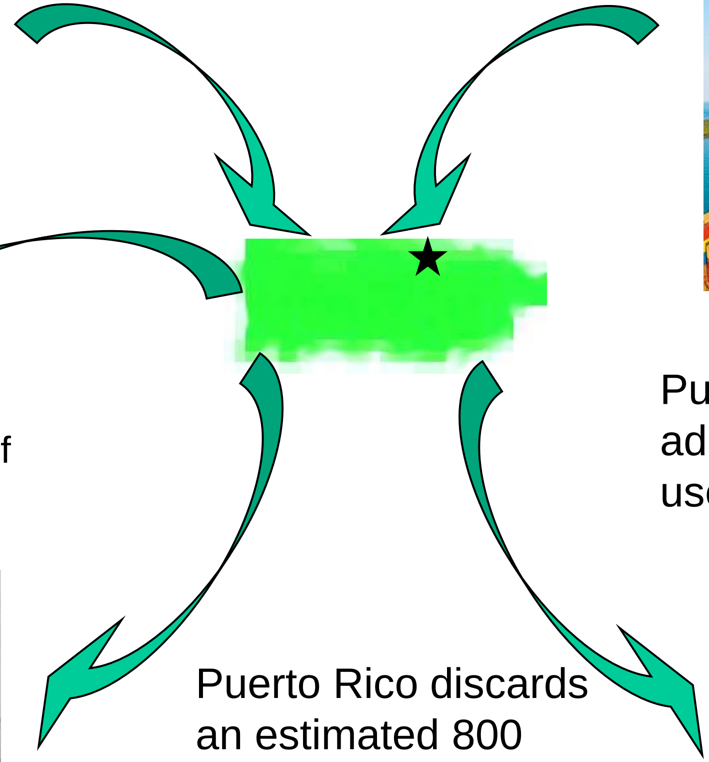
Industrial Symbiosis in Puerto Rico.

- Puerto Rico has intensive industry and significant environmental problems
- How may industrial symbiosis give directions for environmental and economic improvements?
- Projects centered around
  - Cogeneration power plant and chemical industry cluster
  - Pharmaceutical cluster
  - Electronic industry cluster
  - Food industry cluster
  - Regional waste recycling versus import/export



Tension of Environment and Economy

- Mismatch of material flows.



Puerto Rico imports an estimated 400 tons/week of recycled glass for glass manufacturing

Puerto Rico imports some 500 tons/day of used boxboard for cardboard manufacturing

Puerto Rico discards an estimated 1000 tons/week of recyclable glass

Puerto Rico has exported an additional 200 tons/day of used boxboard to Venezuela

Puerto Rico discards an estimated 800 tons/day of recyclable boxboard

Industrial Ecology : Applications.

Dematerialization.

Dematerialization:

- a process that over time offers an obvious path to achieve greater environmental and economic efficiency, the provision of equal units of function (or, more broadly, quality of life) using less material.

Decarbonization:

- decreasing carbon content in fuel.

Implementing Eco-Industrial Network Development.

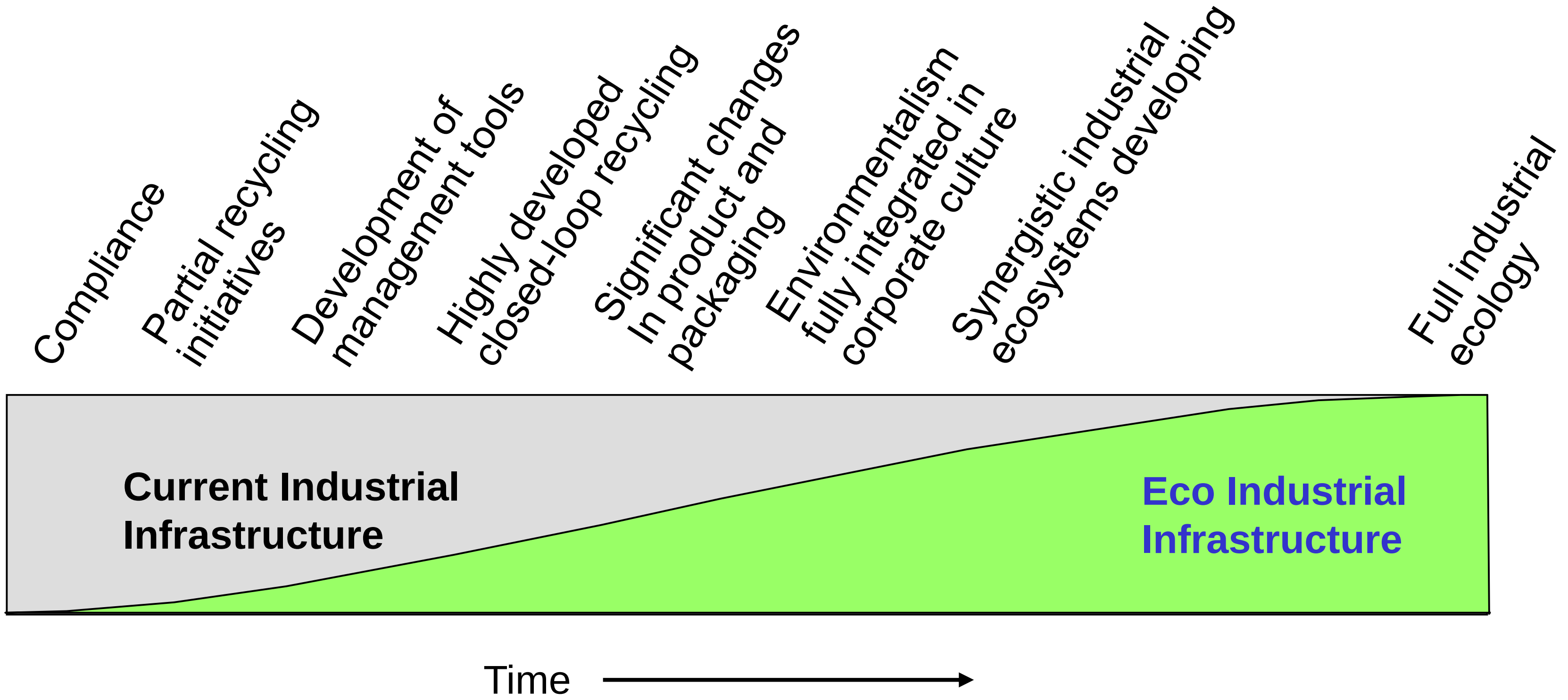
- Different approaches:
  - Top down approach
  - Bottom up approach
- Top Down Approaches:
  - WBCSD (World Business Council for Sustainable Development)*
  - Upfront fee to participate
  - Focused primarily on by-product synergies and facility research
  - Small number of large players, can be separated by great distances (300km)
  - Projects driven by the need to stay competitive, attract new investment – must compete for capital internally
  - Performance based approach
  - Mixed success/hard to maintain – low hanging fruit

*www.wbcsd.org/home.aspx

Implementing Eco-Industrial Network Development (2).

- Different approaches:
  - Top down approach
  - Bottom up approach
- Bottom up Approaches:
  - Communities want strategic edge to stay viable - enhance business retention & investment – protect tax base
  - Larger number of players, such as SMEs, can cluster for new investment.
  - May also include Greenfield or Brownfield development
  - Broader range of issues, such as human resource development, transportation, land use planning, green buildings, etc.
  - Broader ROI considerations may include public dimension, such as land fill life expectancy, water supply and treatment infrastructure, etc.
  - Shared emergency response & training capacity.

The Future of IE.

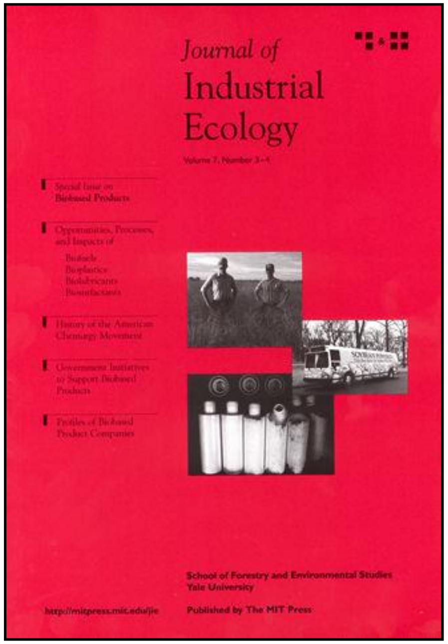


IE research profile

Publications in the Journal of Industrial Ecology.

Distribution of papers per topic: (2000-2003)

- 53 % on Quantitative Environmental Systems Analysis
  (methodology development + applications)
  Half of those related to LCA and hybrid-LCA
- 15 % on Waste Management system evaluation
  (including recycling and Industrial Symbiosis)
- 10 % on production and product design/development
- 8 % on e-commerce, ICT and service industry
- 7 % on conceptual issues
- 6 % on management (corporate and governmental)
- 2 % on other issues



Journal of
Industrial
Ecology

Volume 7, Number 3–4

Special Issue on
Biobased Products

Opportunities, Processes,
and Impacts of
Biofuels
Bioplastics
Biolubricants
Biosurfactants

History of the American
Chemurgy Movement

Government Initiatives
to Support Biobased
Products

Profiles of Biobased
Product Companies

School of Forestry and Environmental Studies
Yale University

http://mitpress.mit.edu/jie

Published by The MIT Press

http://mitpress.mit.edu/jie/bio-based

Conclusions.

Summarizing, IE is a complex and quite challenging discipline with several quantification issues which, however, aims to reach the following objectives:

- Improving the metabolic pathways of industrial processes and materials use
- Creating loop-closing industrial systems
- Dematerializing industrial output
- Systematizing patterns of energy use
- Balancing industrial input and output to natural ecosystem capacity
- Aligning policy to conform with long-term industrial system evolution
- Creating new action-coordinating structures, communicative linkages, and information.

IE Literature.

Eco-Industrial Park Handbook for Asian Developing Countries

Ernest Lowe produced this new and revised edition of the Eco-Industrial Park Handbook under a contract with the Asian Development Bank. It is available as MS Word 97 files. This page is set up for both Internet Explorer and Netscape. With Netscape you can download the files directly. With Explorer the file first displays in the browser and then you can save it.

Cover and Table of Contents 29 kb http://www.indigodev.com/ADBHBCoverToC.doc

Preface and acknowledgements 36 kb http://www.indigodev.com/ADBHBPreface.doc

Executive Summary 74 kb http://indigodev.com/ADBHBExecSum.doc

Chapter 1 Introduction 96 kb http://www.indigodev.com/ADBHBCh1Intro.doc

Chapter 2 Foundations for EIP Development 87 kb http://www.Indigodev.com/ADBHBCh2Foundations.doc

Chapter 3 EIPs and Communities 64 kb http://www.indigodev.com/ADBHBCh3Community.doc

Chapter 4 Planning and Development 268 kb http://www.indigodev.com/ADBHBCh4PlngDev.doc

Chapter 5 Financing Eco-Industrial Parks 102 kb http://www.indigodev.com/ADBHBCh5Finance.doc

Chapter 6 The Emerging Sustainable Economy and Themes for EIP Recruitment 351 kb http://www.indigodev.com/ADBHBCH6SusEcon.doc

Chapter 7 Eco-Industrial Policy 95 kb http://www.indigodev.com/ADBHBCh7Policy.doc

Chapter 8 Design Strategies for Eco-Industrial Parks 187 kb http://www.indigodev.com/ADBHBCh8Design.doc

Chapter 9 Construction and Implementation 67 kb http://www.indigodev.com/ADBHBCh9Constr.doc

Chapter 10 Management 261 kb http://www.indigodev.com/ADBHBCh10Mgmt.doc

Chapter 11 Greening Existing Industrial Parks 81 kb http://www.indigodev.com/ABDHandbookCh11Existing.doc

Chapter 12 Creating BPXs 122 kb http://www.indigodev.com/ADBHBCh12BPX.doc

Appendix 1 Cases 261 kb http://www.indigodev.com/ADBHBApxCases.doc

Appendix 2 Supplementary information 192 kb http://www.indigodev.com/ADBHBApx2Suppl.doc

Eco-Industrial Developments in Japan 95 kb http://www.indigodev.com/Eco-JapanDownload.html

Eco-Industrial Photo Gallery 1,499 kb (will take some time)

http://www.is4ie.org//history.html

Industrial Ecology Bibliography.htm