Source Separation and Decentralization in Cities

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Paradigm shift of urban sanitation

- 1st generation: removal of BOD
  - 1960-1990 in developed countries, 1990-2000s in Korea
  - Construction of sewers and centralized wastewater treatment plants
  - Highly subsidized by federal and state agencies
  - Took about 30 yrs for BOD removal from 10% to ~90%

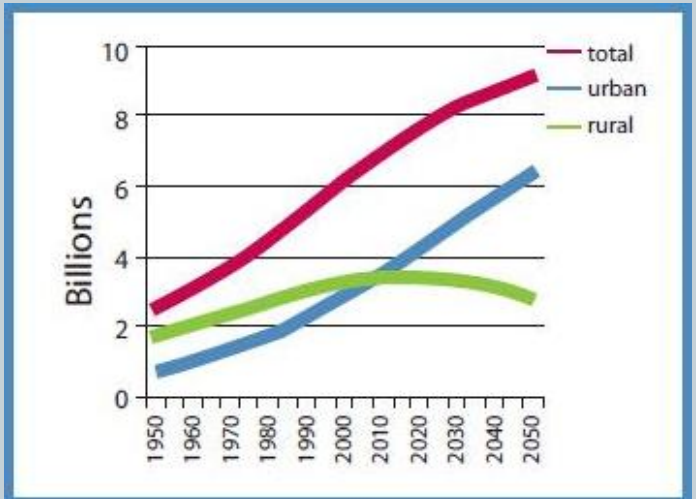
Paradigm shift of urban sanitation

- 2nd generation: improved effluent quality, including nutrient (N, P) removal
  - Significant nutrient problems
  - Still in progress

- **3rd generation: ???**

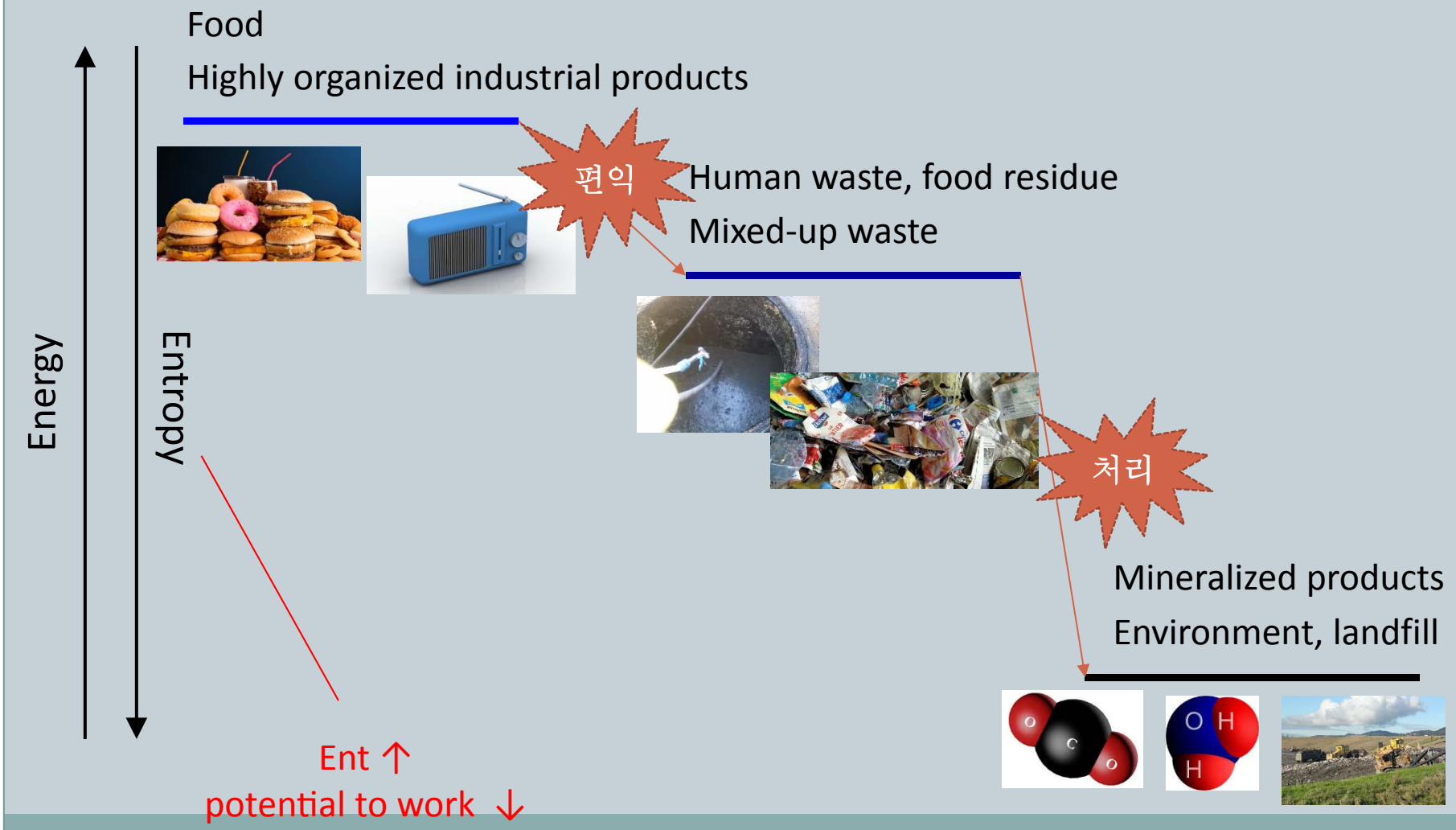
Current issues of urban sanitation

- Rapid urbanization:
  - Most people dwell in urban areas
  - Rapid population growth
  - Projection of population in rapidly growing cities is challenging: overloading sewers
    - Frequent flooding of sewers
    - Permanently active CSOs (combined sewer overflow)
  - Water scarcity problems
  - Sustainability issues



World Population: Urban and Rural 1950–2050
(source: UN Dept of Economic and Social Affairs, 2007)

Current urban metabolism



Current urban metabolism:

wastewater drainage and treatment

Consumers

Energy Resources

WWTP

Energy Resources

Environment

- Drainage (transport)
  - Pipeline & pumping
  - Spend energy & resources to lower elevation (?!)
  - ~70% of total cost for WW management
- Treatment
  - Key process: aerobic biodegradation
  - Spend energy & resources to mineralize organics (?!)
  - >50% of total E for WW treatment spent for aeration

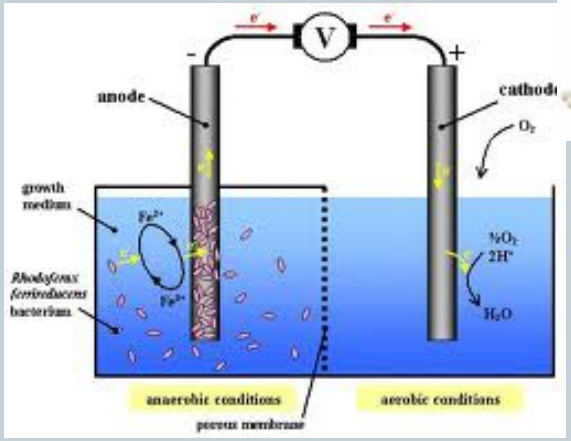
Wastewater: a resource?

- Wastewater = water + nutrients + reduced carbon (chemical energy)

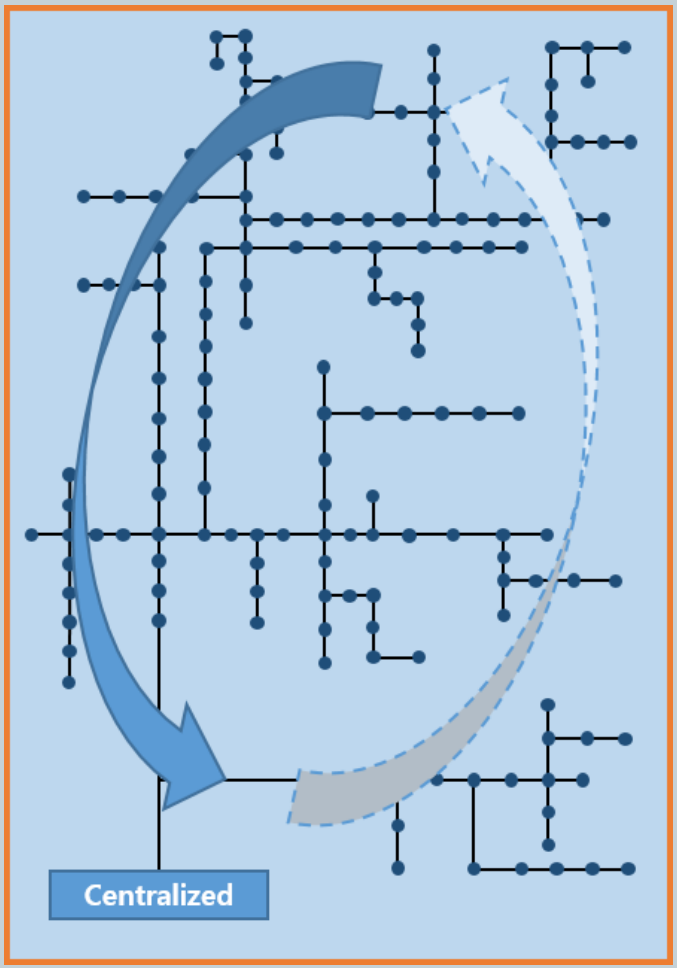
- Wastewater reuse
  - Effective solution in dry regions
    - Reliable water resource
    - Usually cheaper than saltwater desalination
  - Non-potable water reuse: irrigation, toilet water, etc.
  - Potable water reuse: drinking

Wastewater: a resource?

- Resource recovery
  - Energy recovery in the form of CH_4, bio-oil, electricity, etc.
  - Nutrient recovery – use as fertilizer, soil amendments, etc.

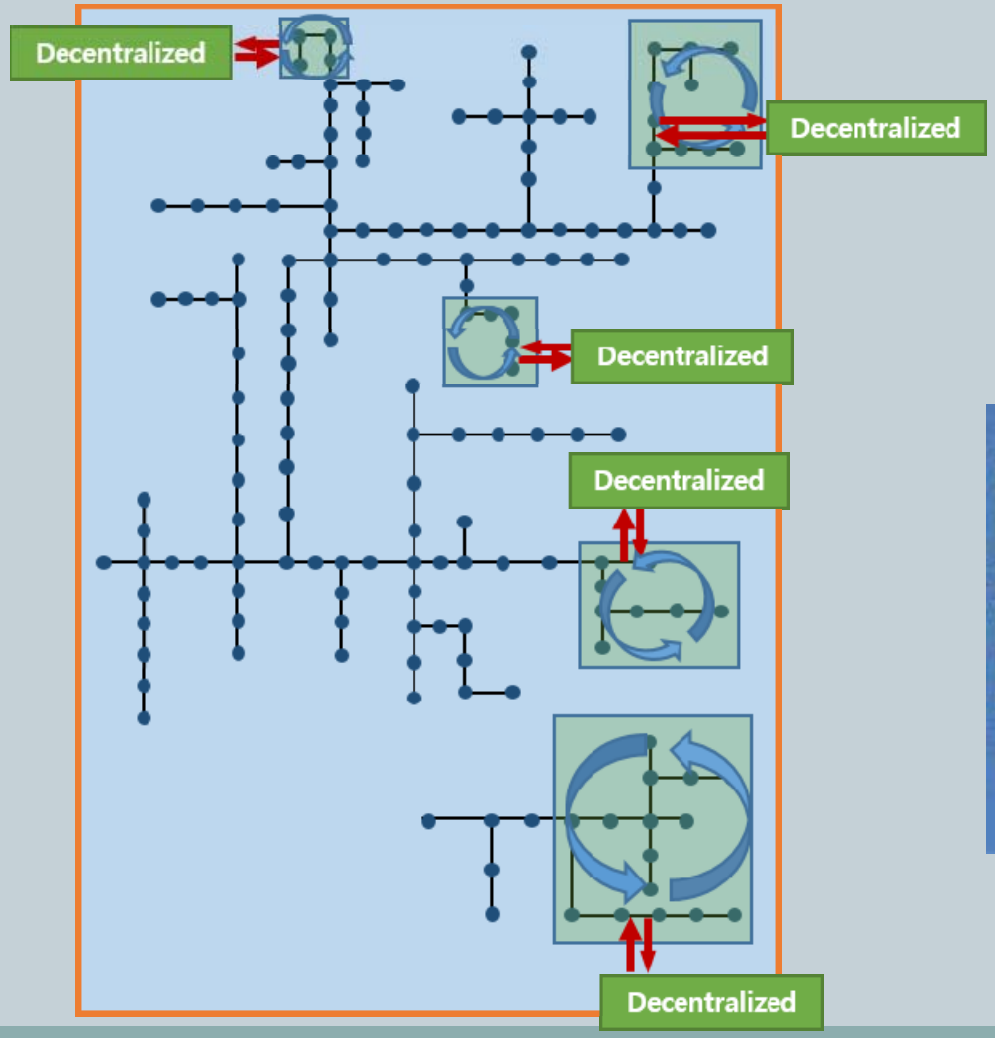


Centralized process

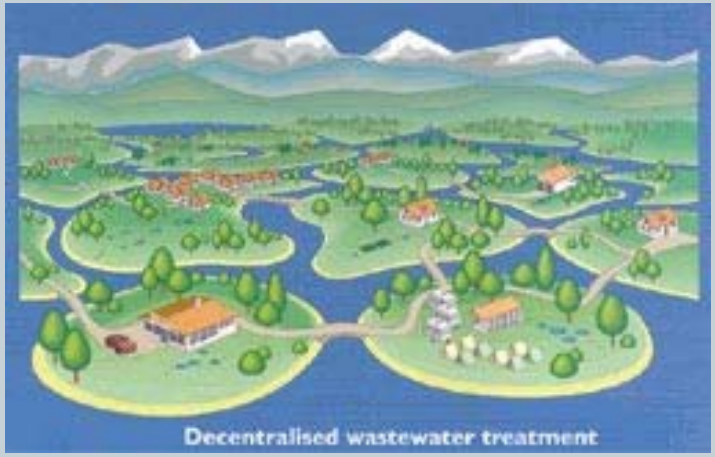


- ~100 tons of wastewater per person is transported over many kilometers a year (by gravity)
- Recovered resources should be transported back uphill!
  - Pipeline installation
  - Pumping and other operational costs
- Cannot give solution to sewer overloading problems

Decentralization



- Treatment and resource recovery at a smaller scale



Decentralization and source separation

- Decentralization requires source separation
  - Mixed-up wastewater contains wide range of pollutants – complicated, advanced technology is needed!
    - High operational cost
    - Inefficient resource recovery
    - Requires well trained & experienced engineers
  - Without source separation, decentralized technology is no more than downscaled advanced treatment plants
- Source separation requires decentralization
  - Transport of source-separated fractions in sewers is almost impossible!

Source separation & decentralization - challenges

- Source separation and decentralization was a common practice in rural areas
- However, there are several challenges to implement source separation and decentralization in urban settings
  - The challenge of acceptance
  - The challenge of transport
  - The challenge of developing treatment processes

The challenge of acceptance

- Most city dwellers are used to “use-and-forget” system

- Owners and decision makers of urban infrastructure are often conservative and risk averse

The challenge of transport

- Decentralized treatment & resource recirculation can result in sedimentation problems of existing sewers!
  - Significant reduction in wastewater quantity
  - Cannot provide sufficient water to flush out sediments in sewers
  - Sediment accumulation (clogging), H_2S production (odor), corrosion problems

The challenge of transport

- Transporting waste streams and residues
  - Wastes and residues produced after treatment
  - Dry residues: can be collected together with solid waste
  - Wastes and residues with water as main constituent
    - Cannot be transported over long distances – suitable handling & collection systems should be developed
    - Transportation process should be hygienic and odorless
    - Decentralized volume reduction and stabilization of wastes is one of the primary research goal!

The challenge of developing treatment processes

- Different concept of the product
  - Centralized treatment – designing large prototype plants, requires on-site construction, no mass production **(civil engineering logic)**
  - Decentralized treatment – building thousands of small identical units **(industrial design and mechanical engineering logic)**

- Significant characteristic differences between decentralized and centralized treatment → totally different technology may be required!

The challenge of developing treatment processes

Table 10.1 Characteristic differences between decentralized and centralized wastewater treatment systems (see also Olsson 2013).

Topic	Properties of decentralized systems	Properties of centralized systems
Waste flow and load	Highly variable, subject to individual events	Variable, but individual events not apparent
Rainwater	Hardly an effect	May define hydraulic design load
Waste composition	Rather homogenous conditions between plants Rather concentrated waste	Different for each plant, subject to individual industries. Rather dilute wastewater.
Frequency of attendance	Irregular, long intervals	Daily to permanent
Cost of intervention	Large	Relatively low
Relative cost of sensors	High	Rather low
Calibration of sensors	Very low frequency and relatively very costly	Costly, but rather frequent
Sensor properties	Must be rugged and reliable, accuracy is of secondary importance, very infrequent maintenance	Must be sensitive, accurate and reliable but may require frequent maintenance
Data transmittance and control system	Due to on-going expansion of the number of systems, elements must be based on an adaptive grid	Typically fixed for one technological cycle
Control software	Highly standardized, but due to application in large numbers also highly optimized	May rely on modular design but adaptation to a specific plant typically required
Required process standardization	Very high, only standardized equipment can be produced in large numbers	Individual plants are typically designed as prototypes
Transport of pollutants and residues	Local extraction of concentrated residues and separate transport	Transported in sewers and extracted in the form of concentrated sludge
Handling of residues	May be centralized. An intermediate form may be transported to a central handling station	Typically occurs at the plant. Only small plants connect to larger ones

The challenge of developing treatment processes

- Need to re-evaluate physicochemical treatment!
  - Centralized treatment – relies on biological treatment
  - But sensitive to variable loads: consistent wastewater quantity & quality required for stable establishment of microorganisms
  - Physicochemical treatment: generally 1st order type reaction at any conditions
  - Available physicochemical techniques
    - Physical adsorption
    - Membrane filtration
    - Chemical precipitation, oxidation, photo- and electro-chemical transformation of pollutants

For the new paradigm

- Thick differently but comprehensively: a “smartphone approach”

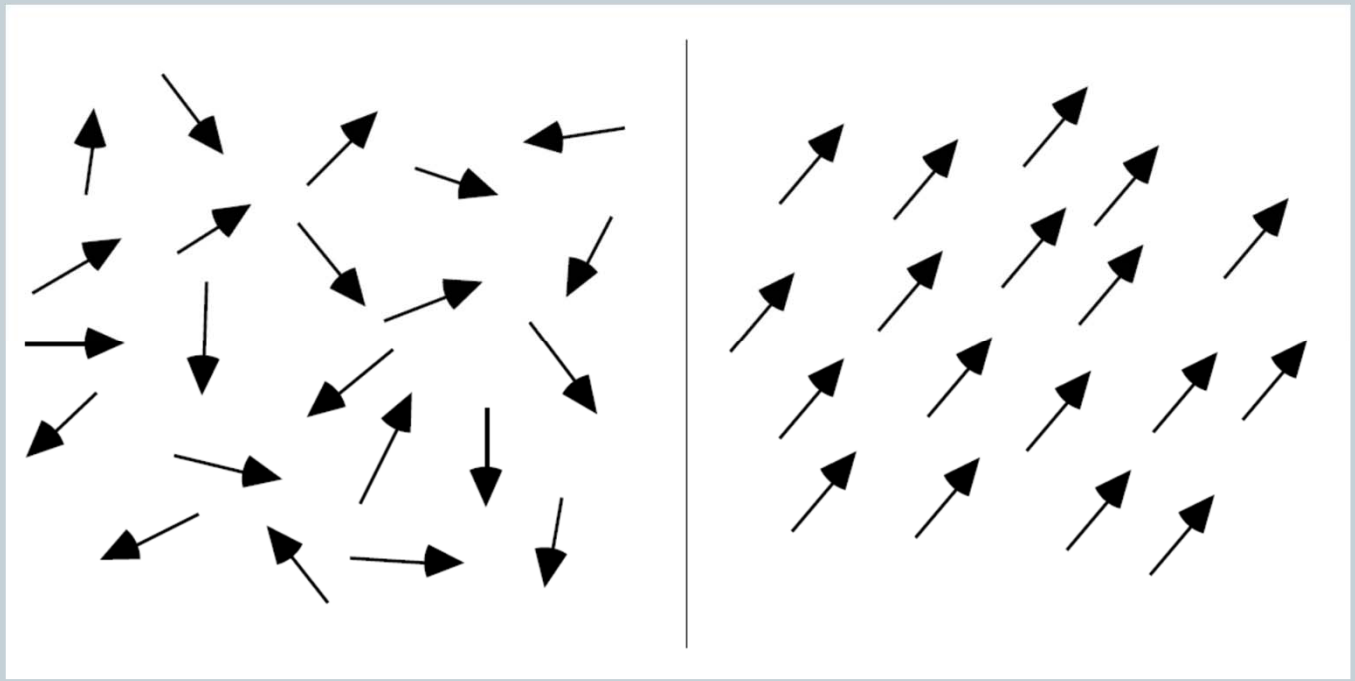
“A smart phone is not a downsized telephone, TV, photo camera, computer, CD player, and so on but a new device which fulfills its tasks on the basis of entirely new technology and with considerably less material and at less cost than all these gadgets together.”

For the new paradigm

- Similarly: decentralized treatment system is not a downsized centralized treatment plants
- We should analyze the problem to be solved as a whole
- For the new urban sanitation, we should consider:
  - awareness by administrators
  - legal requirements
  - rules of trade
  - technology
  - organizations for construction and operation
  - acceptance by engineers, architects and the public
  - economic competitiveness with alternative technologies….

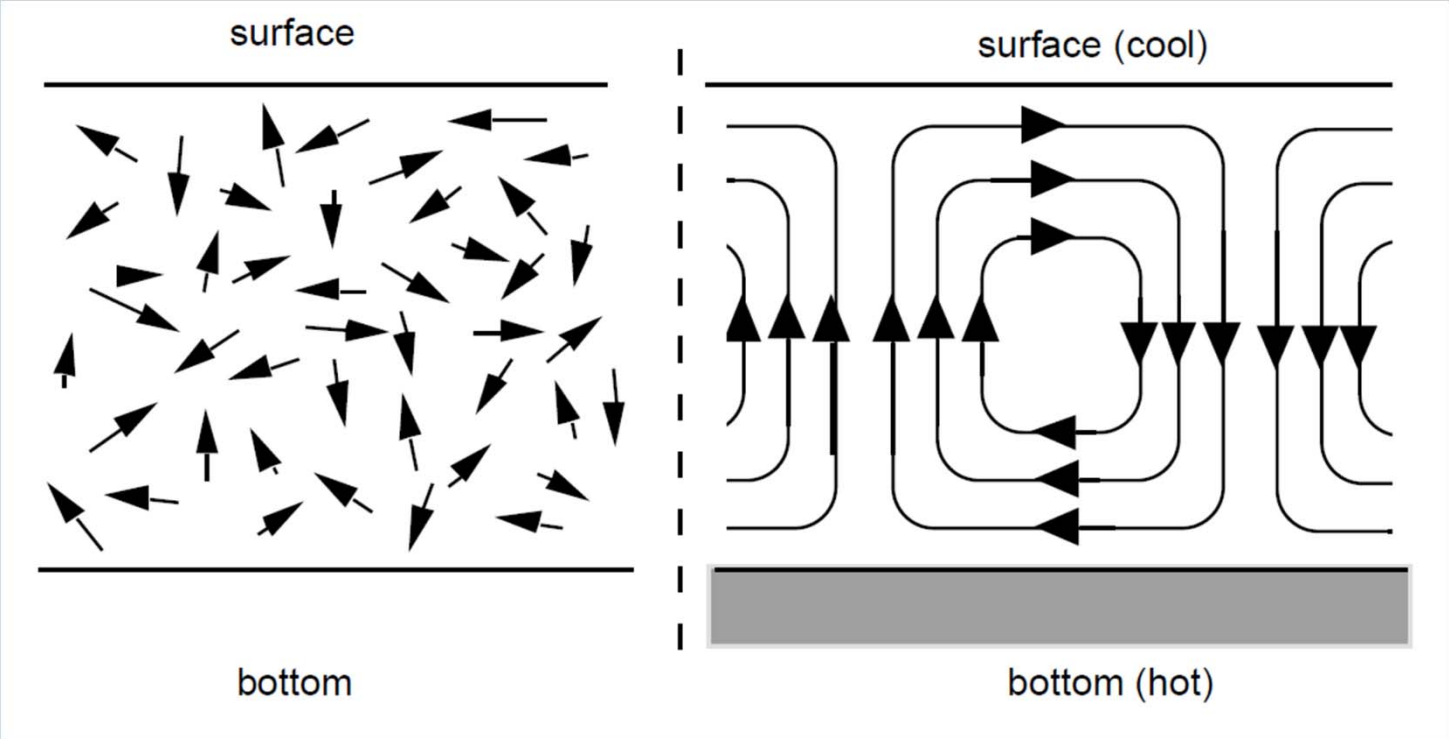
Self-organization

- "A process where some form of overall order arises from local interactions between parts of an initially disordered system"



Disordered arrangement of "spins" Ordered arrangement of "spins": **magnet**

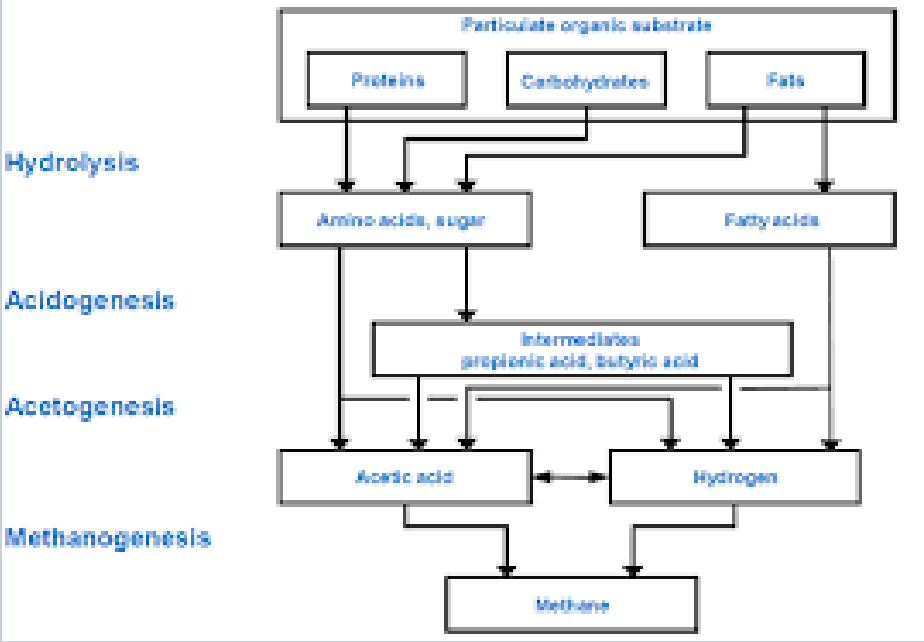
Self-organization



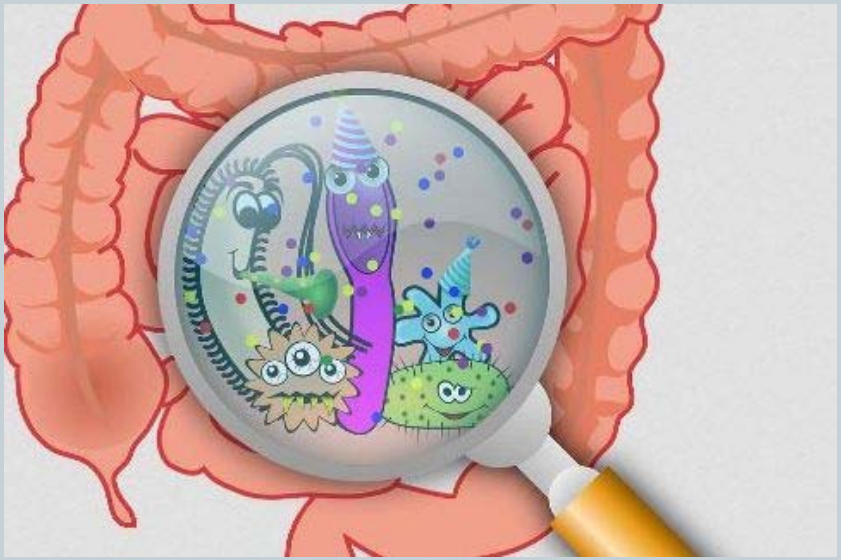
Random movement of water molecules

Ordered movement of water molecules: **“Bénard roll”**

Self-organization of microbial consortia



Anaerobic digestion



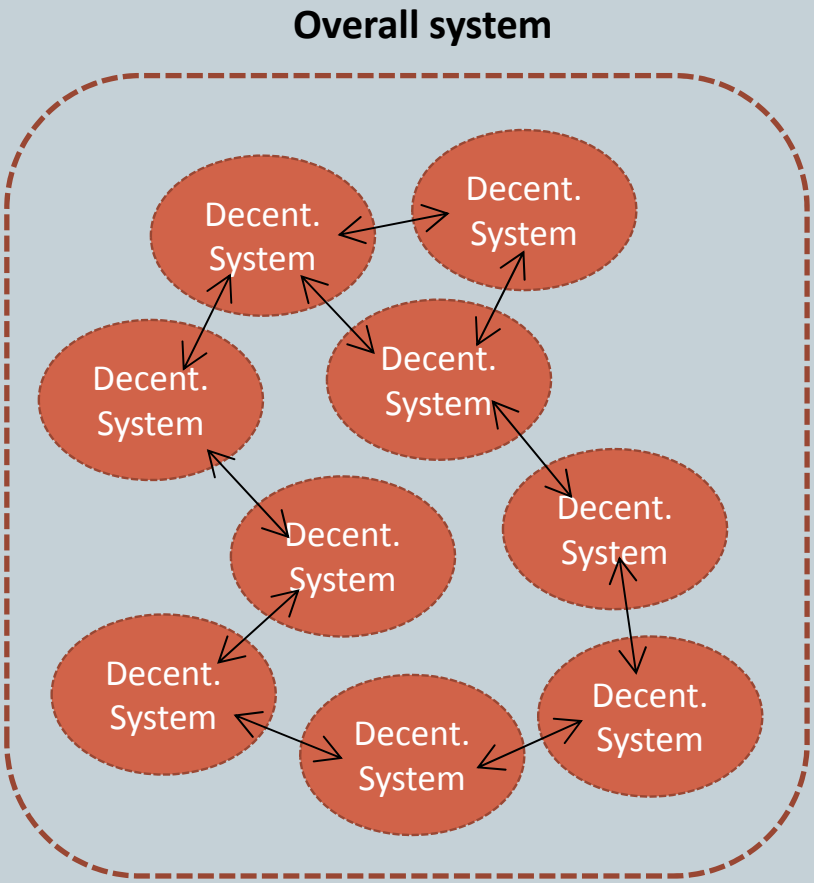
Human digestion system

Characteristics of self-organizing systems

- **Global order from local interactions**
- **Distributed control**
- **Robustness, resilience**
- Non-linearity and feedback
- **Emergence**
- Bifurcation
- Far-from-equilibrium dynamics

(Heylighen, 1999)

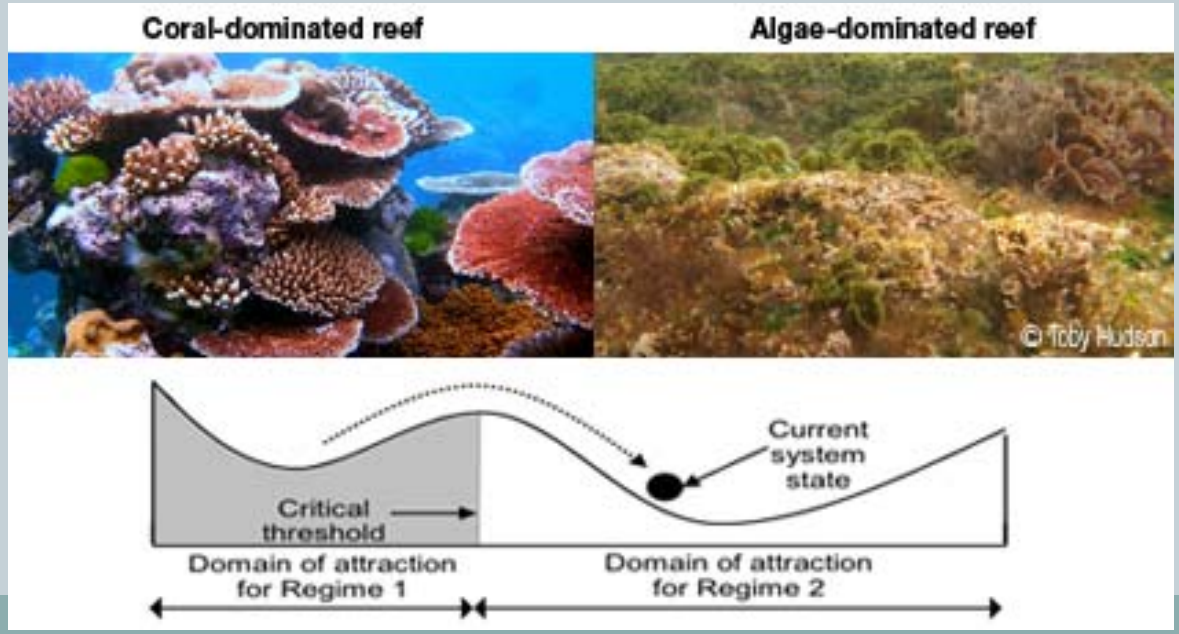
Self-organization at the society level



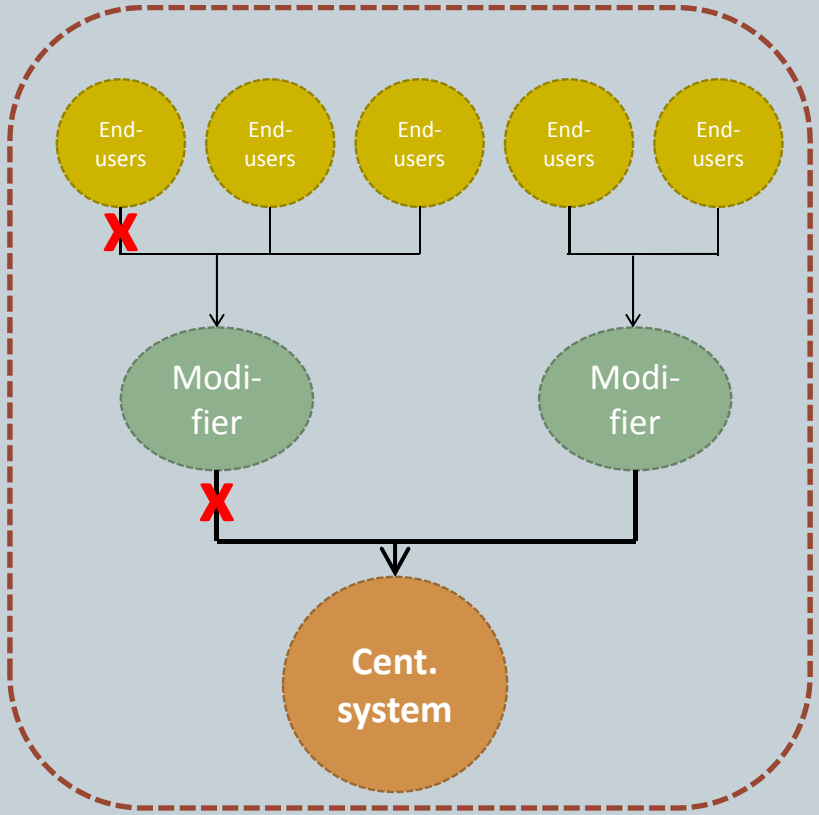
- 분산형 시스템이 상호간에 유기적으로 연결되어 서로의 관계 속에서 각자의 역할을 수행 → 전체 시스템의 목적에 기여
- 각 분산형 시스템 또는 시민 개개인이 생산 및 소비의 주체로서 참여

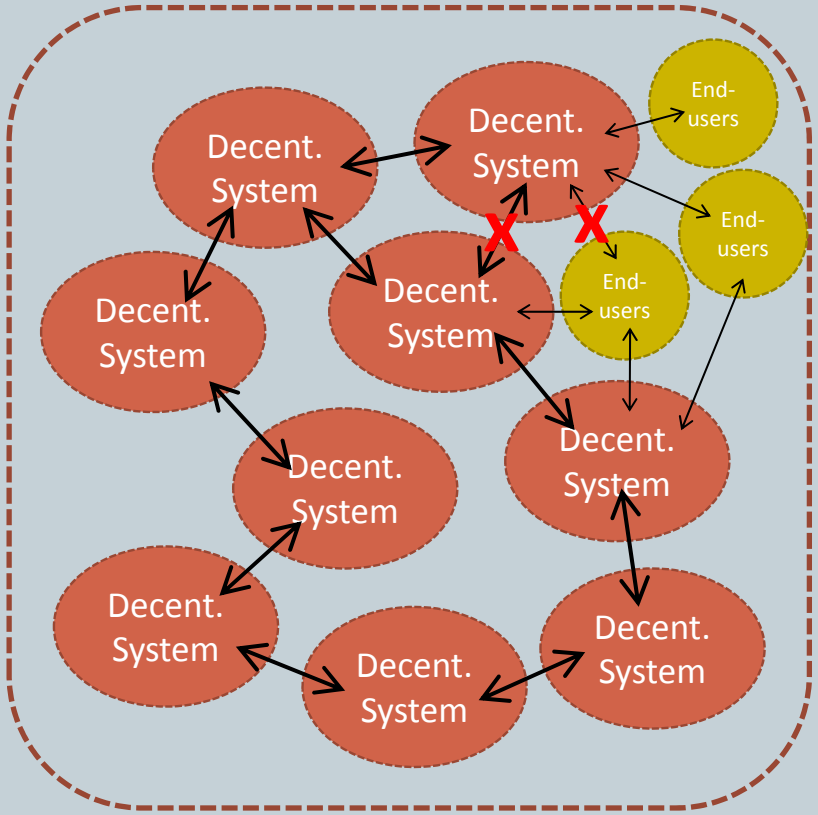
Resilience

- 리질리언스, 회복탄력성, 회복력, …
- “The capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks”

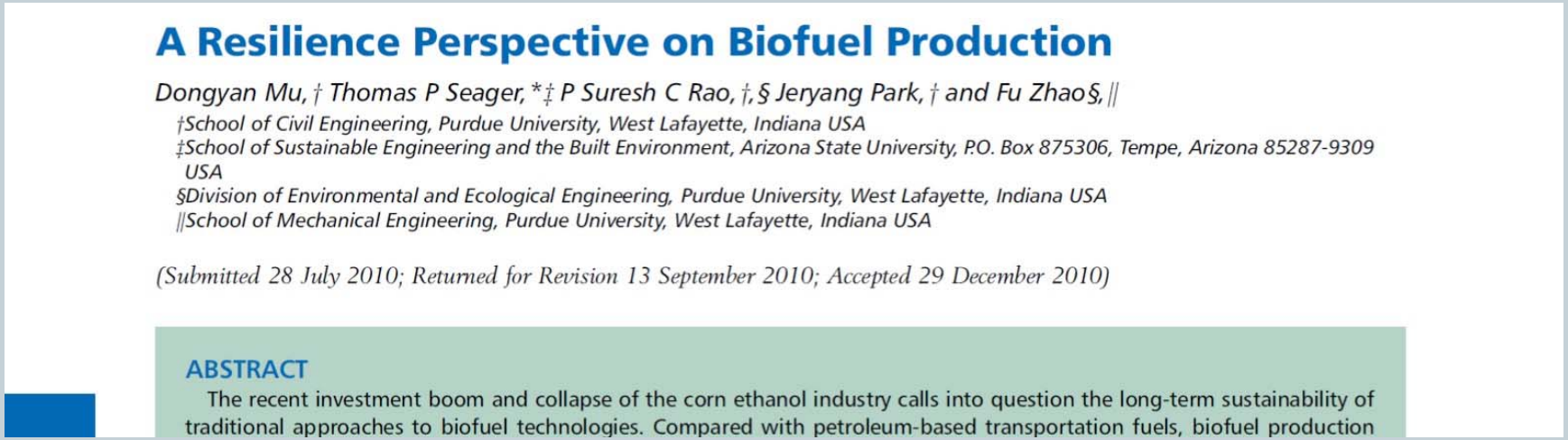


Resilient system?





Resilient thinking – biofuel example



A Resilience Perspective on Biofuel Production

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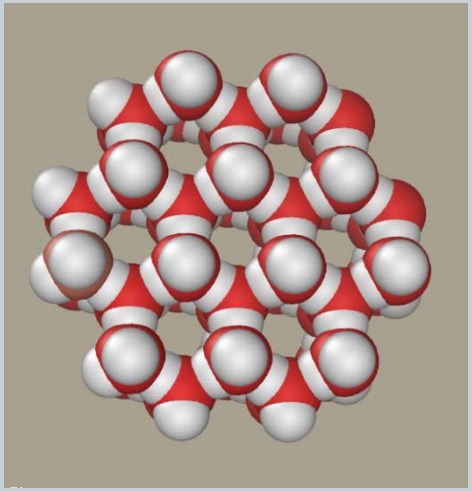
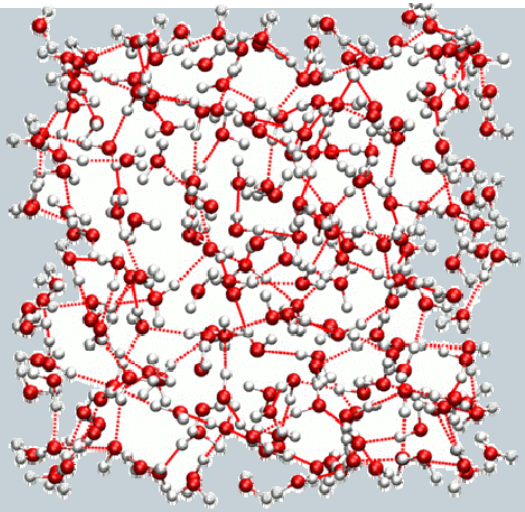
ABSTRACT

The recent investment boom and collapse of the corn ethanol industry calls into question the long-term sustainability of traditional approaches to biofuel technologies. Compared with petroleum-based transportation fuels, biofuel production

- Investment boom for corn ethanol production 2002-2007
- Recent collapse (e.g., bankruptcy of world's one of the largest producer)
- Reducing the diversity in the crop (corn), production process (dry-mill), product (ethanol) and market (energy) resulted in reduced adaptability

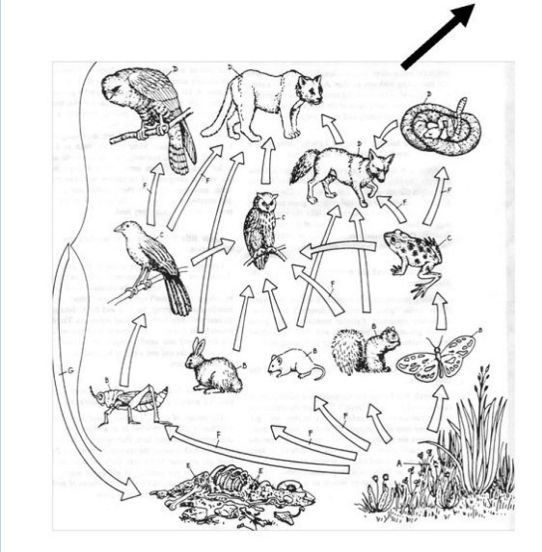
Self-organization – robust or resilient

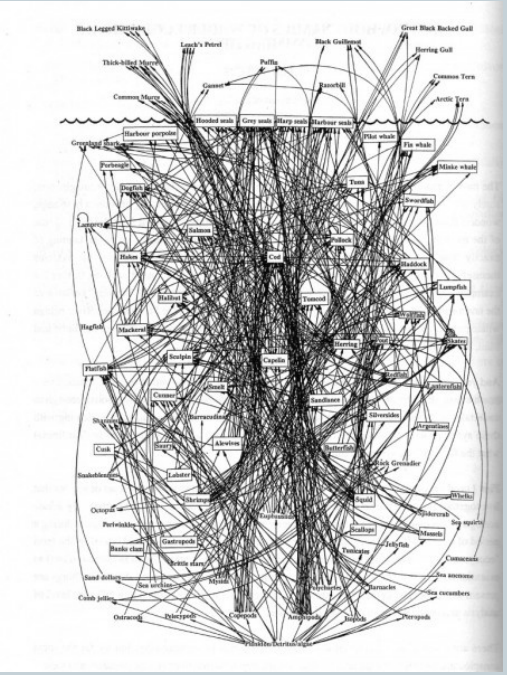




Resilient system

- Resilience is an emergent property of a self-organized system
- Highly resilient systems may have the following characteristics:
  - Diversity of..
    - constituents
    - functions
  - Redundancy in…
    - functions
    - connections





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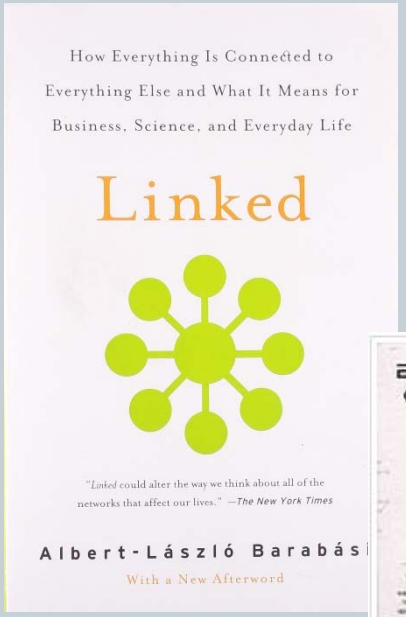

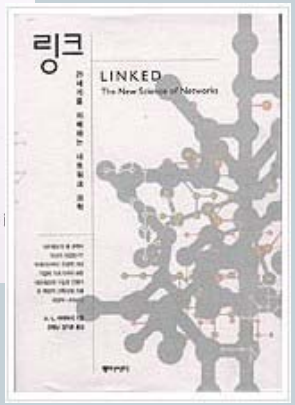

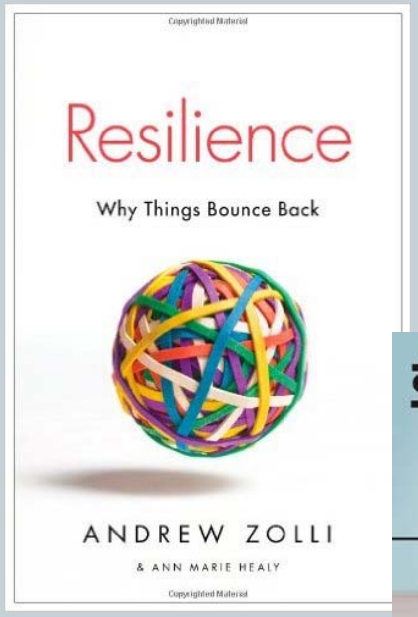

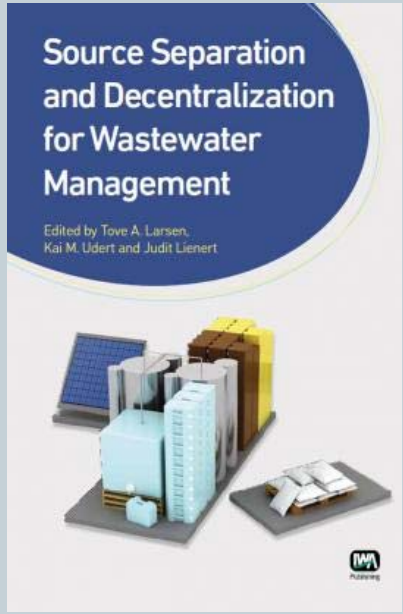

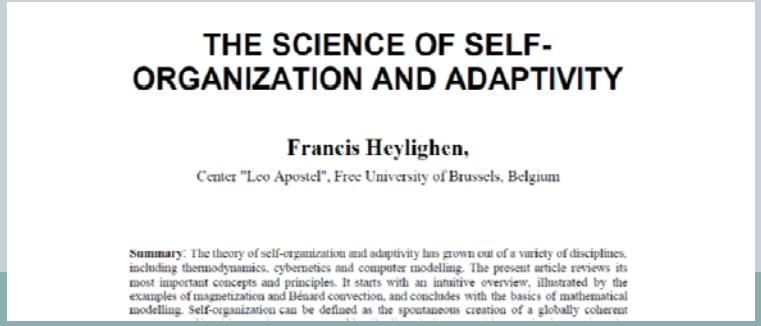

THE SCIENCE OF SELF-ORGANIZATION AND ADAPTIVITY

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Summary: The theory of self-organization and adaptivity has grown out of a variety of disciplines, including thermodynamics, cybernetics and computer modelling. The present article reviews its most important concepts and principles. It starts with an intuitive overview, illustrated by the examples of magnetization and Bénard convection, and concludes with the basics of mathematical modelling. Self-organization can be defined as the spontaneous creation of a globally coherent

Resource recovery from wastes: concept design

Select a type of waste source in urban life. Identify valuable resource(s) that can be recovered. Propose a mechanism for recovering the resources from the waste.

(Multiple methods of recovery can be proposed)

1) Sketch out your concept design.

2) List benefits of this method of recovery.

(e.g. high recovery efficiency, low cost, high load capacity, short recovery time)

3) What would prevent this method from being implemented?

(e.g. costs, public perception, health risks, complexity)

Resource recovery from wastes: concept design

Design Specifications: Decentralized, Industrialized urban society

Possible Waste:

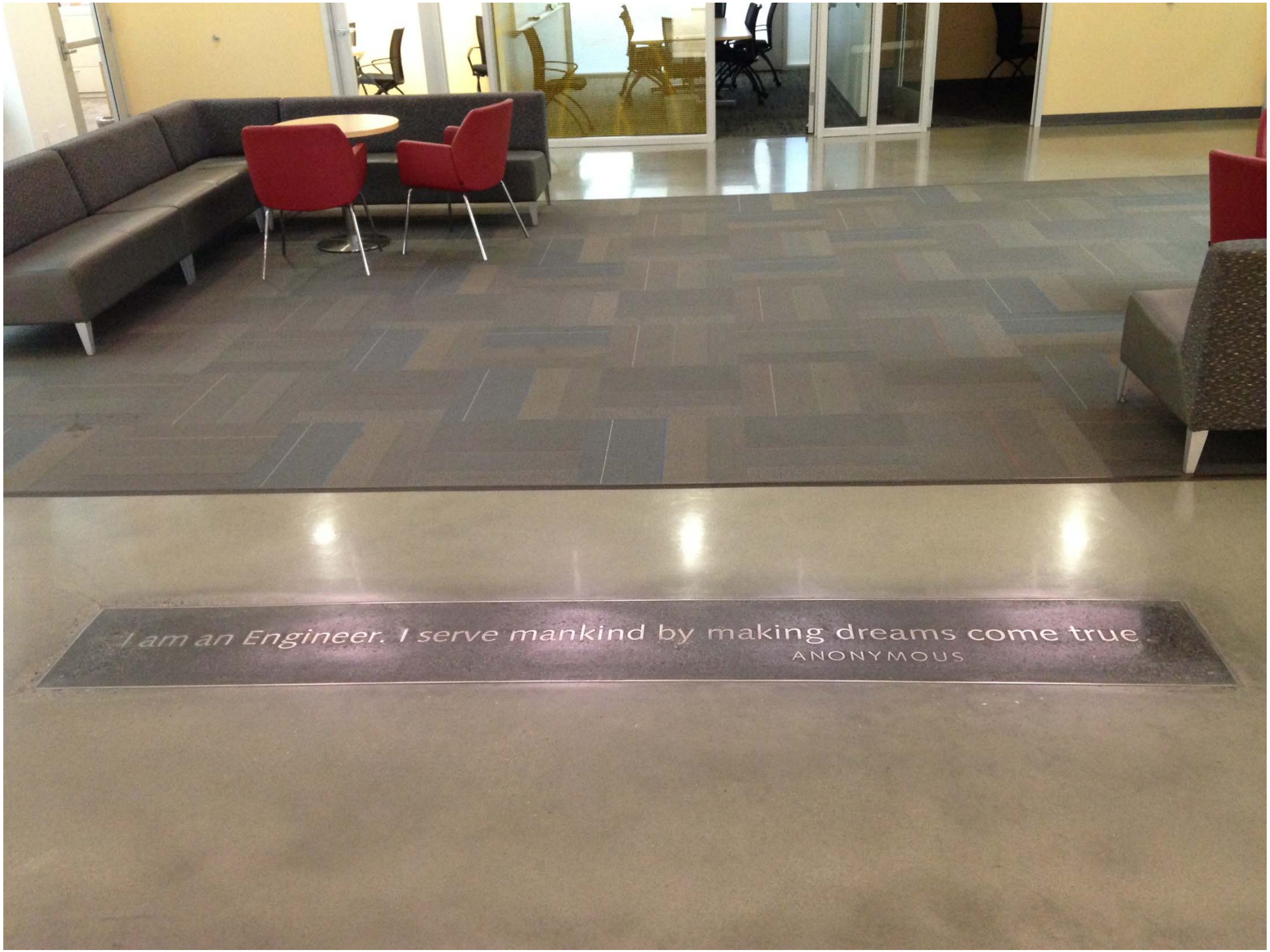
- Toilets
- Dishwashers
- Washing machines
- Showers
- Sinks
- Restaurant/kitchen waste
- Storm water

Possible Resources:

- Nutrients (N, P, trace metals)
- Energy
- Metals
- Heating/cooling capacity
- Water

Takehome messages

- Centralized sewer and wastewater treatment cannot be the global solution to the next-generation urban sanitation problems
- Decentralization should accompany with source separation
- For the implementation of source separation-decentralization in cities, we need new logic, new concept, and new approaches


I am an Engineer. I serve mankind by making dreams come true.
ANONYMOUS