United States Environmental Protection Agency

# Ecological Mimicry and the Design of 21st Century Water Infrastructure

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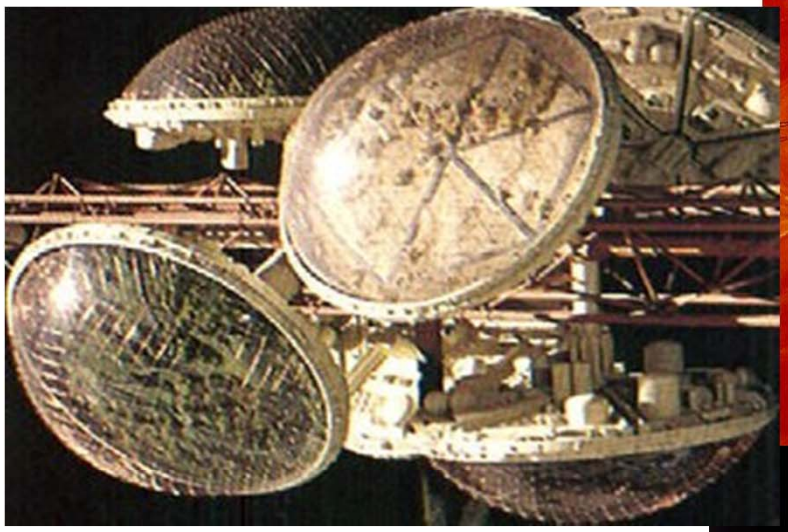
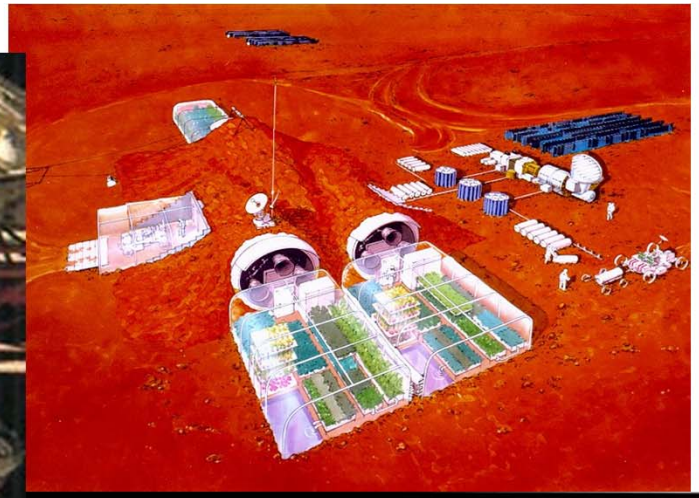
**Office of Research and Development**
National Exposure Research Laboratory

# My Extraterrestrial Bias





"If we knew how to live on Mars, we'd know how to reduce our footprint on Earth. Space colonization is the Rosetta stone for earthly sustainability because it's entirely about living in the absence of ecosystem services. The Moon, Mars and the asteroids are a great experimental laboratory that we're ignoring at our own peril."

*Karl Schroeder*

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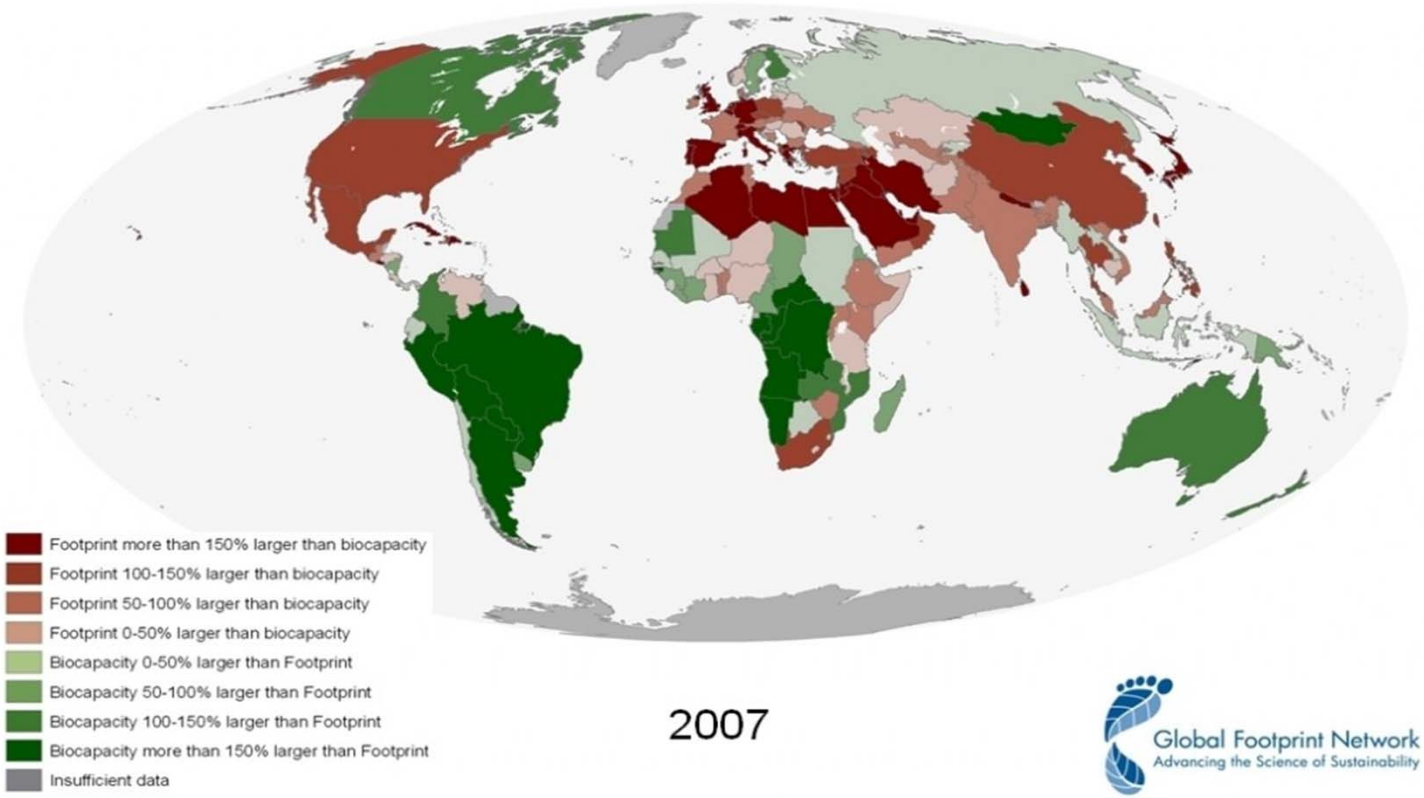
"The river of intellectual progress is not defined purely by the steady flow of good ideas….it follows the topography…carved out by external factors.

….the river may back up for a while, but the dams eventually break."

*The Ghost Map*, Steven Johnson

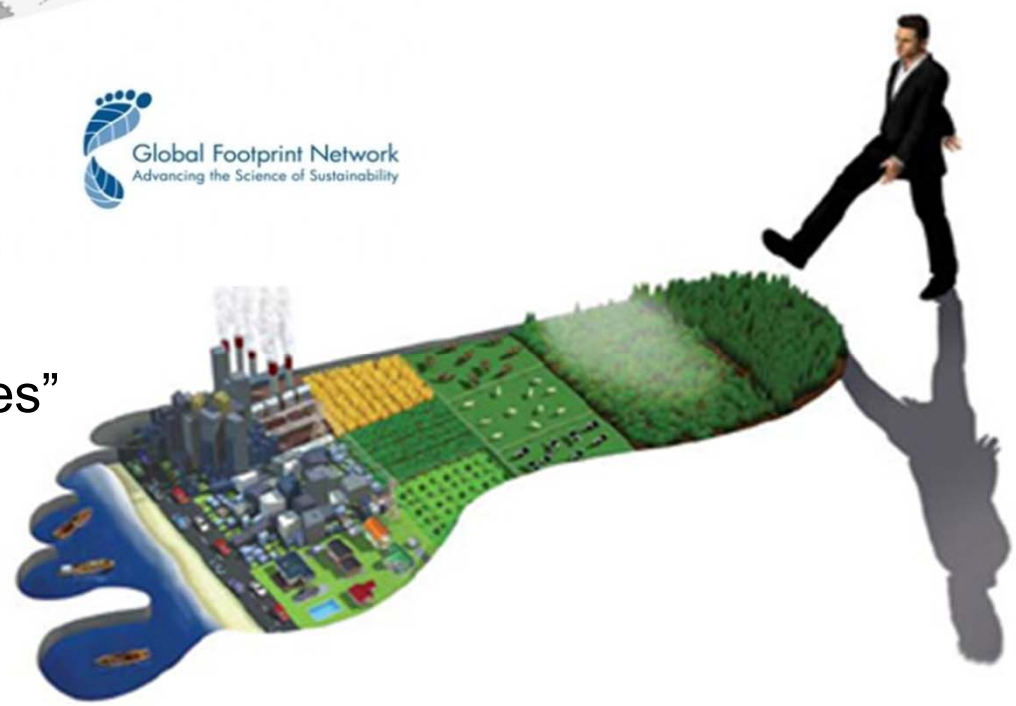
Percent of Earth's Biocapacity Used: 151%




Global Footprint Network
Advancing the Science of Sustainability

Ecological Creditor/Debtor Countries

"Liquidating the Earth's ecological resources"



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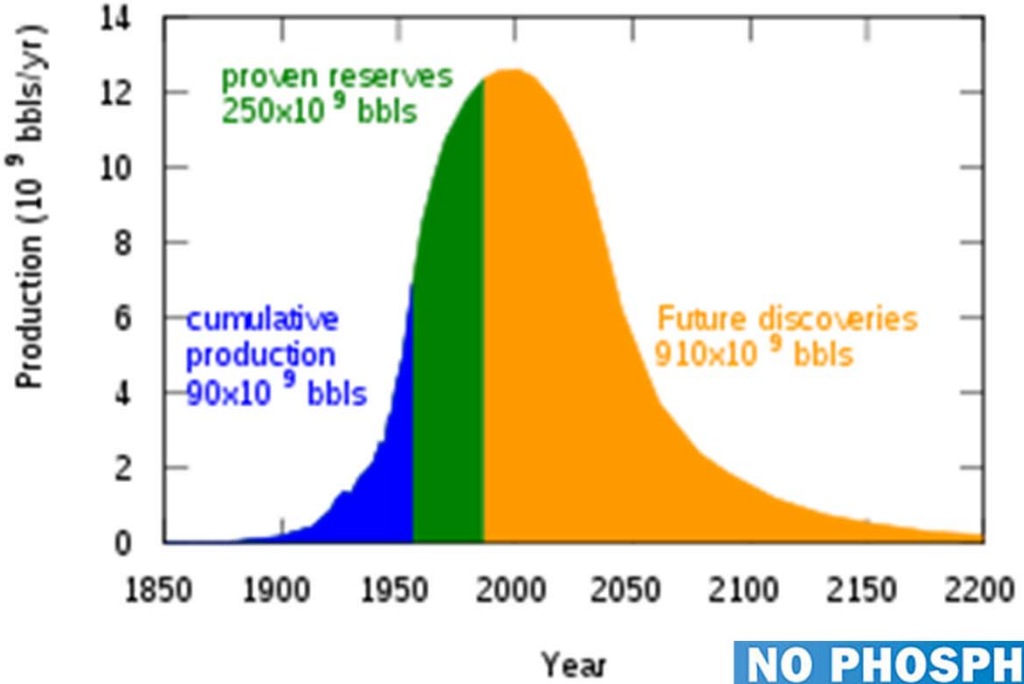
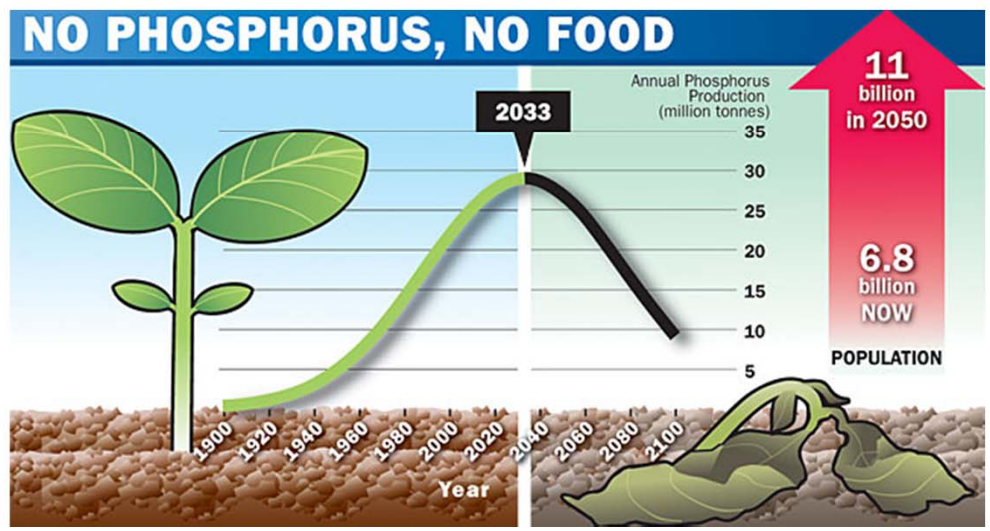
# Peak Oil

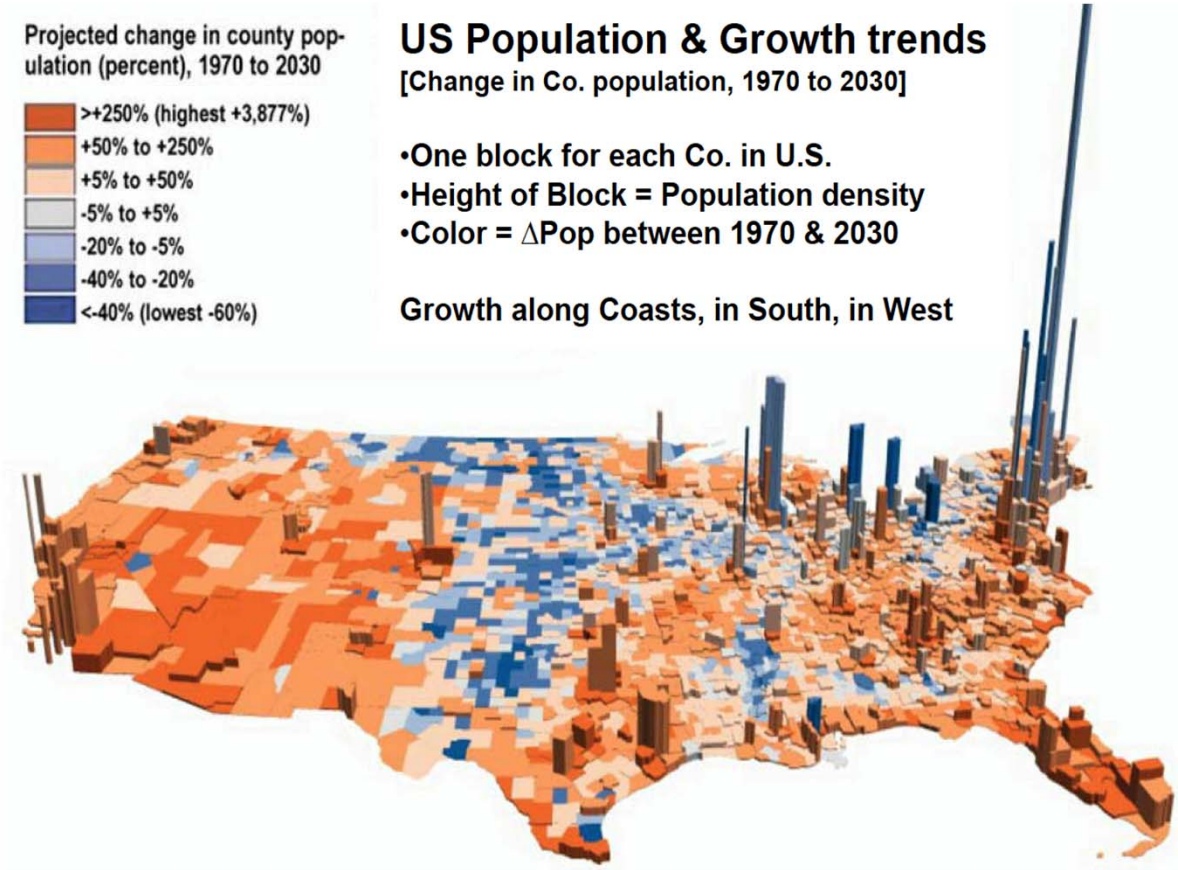


# Our top 10 problems for next 50 years

## (Richard Smalley, Nobel Laureate)

1. Energy
2. **Water**
3. Food
4. Environment
5. Poverty
6. War/terrorism
7. Disease
8. Education
9. Democracy
10. Population



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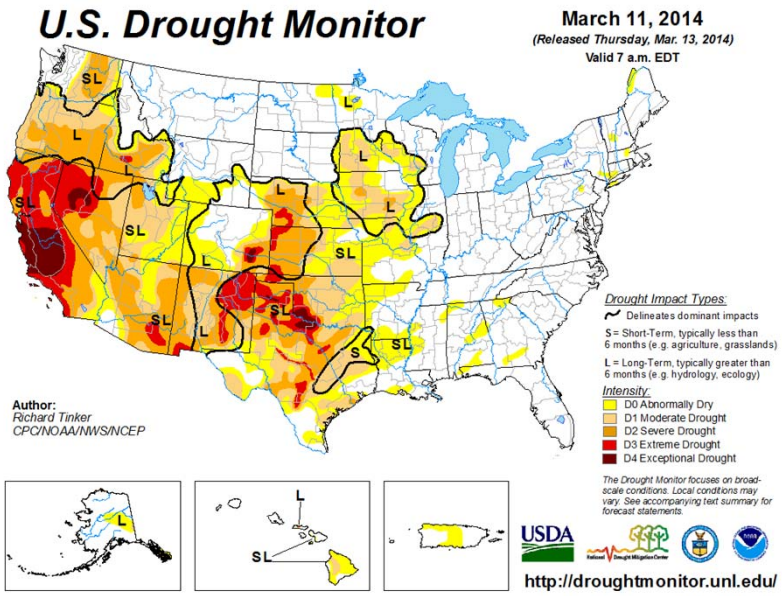
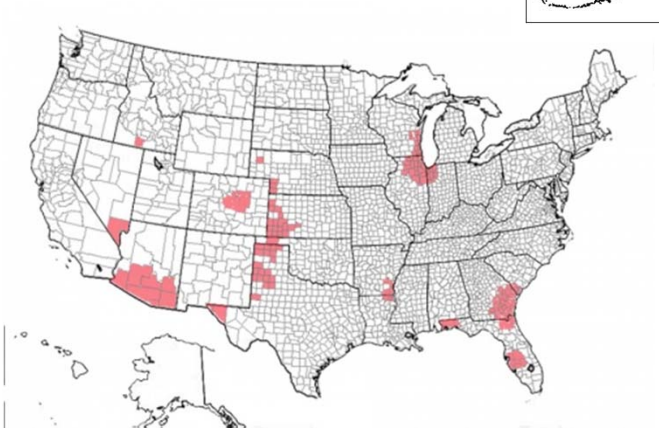
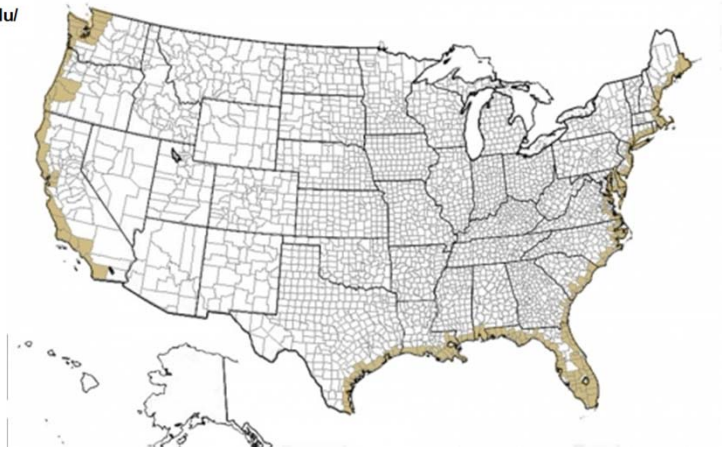



Aquifer Depletion



Saltwater Intrusion into Aquifer



Water services utilize about 3-7% of electricity produced

And the cost of upgrading our degrading water infrastructure will cost an Estimated 1 trillion dollars over the next 15 years.

U. of Illinois WaterCampws (The Center for Advanced Materials for the Purification of Water with Systems)

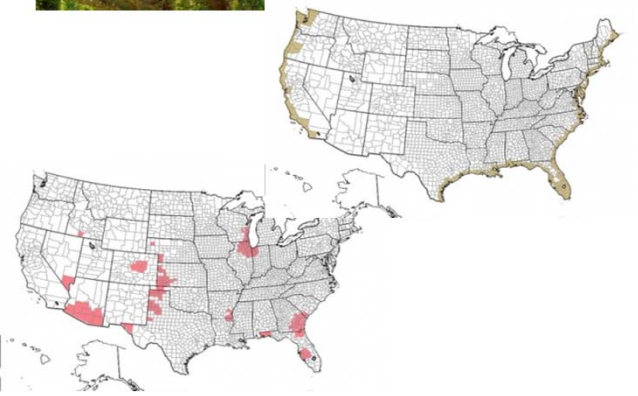
# Human Civilization Has Been Down This Path Before

"But how the world turns. One day, cock of the walk. Next, a feather duster."

Jared Diamond "Collapse"

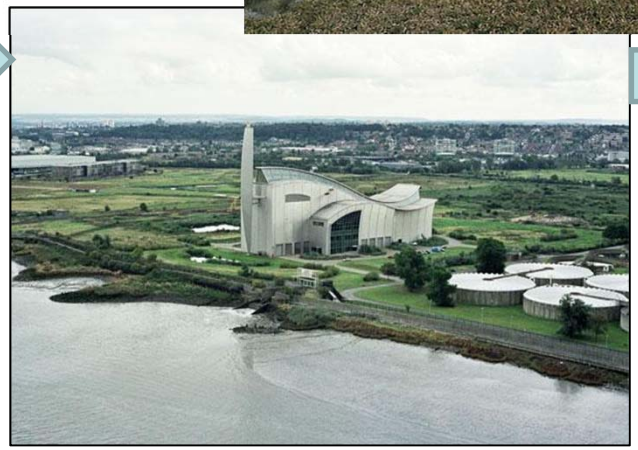
## *Past*

Centralized, 1-way flow



## *Present (emerging)*

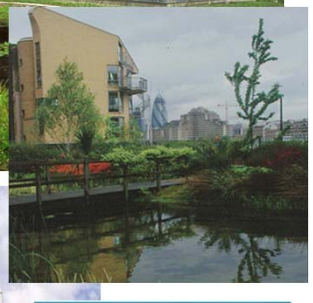
Limit Waste, Efficient

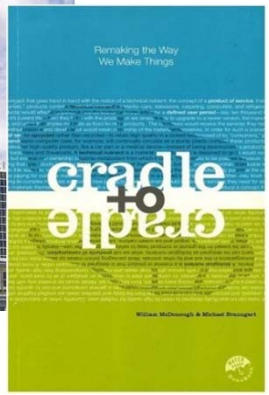


## *Future*

Eliminate concept of waste

Eco-effective, biophillic





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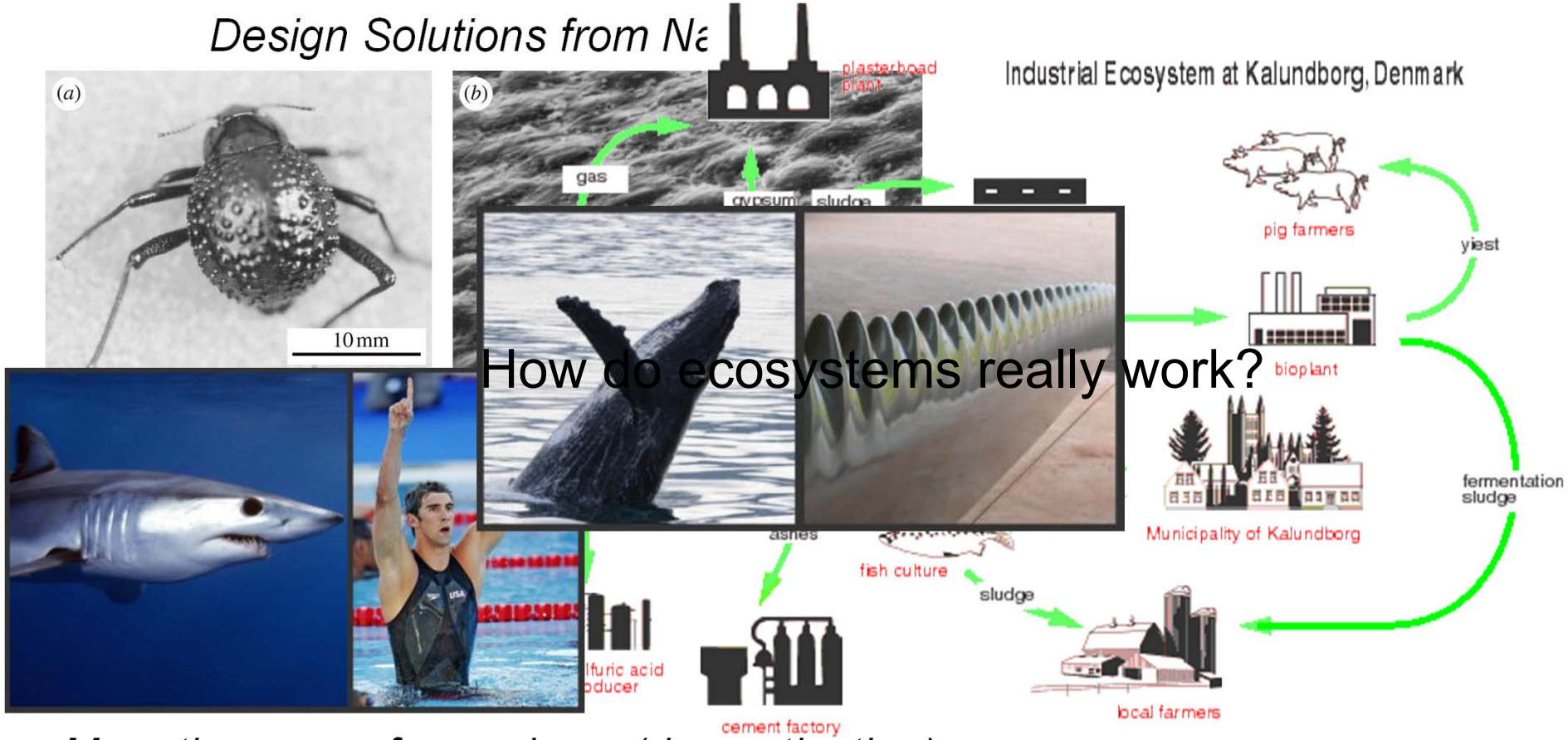
"It is time for designs that are creative, abundant, prosperous, and intelligent from the start…. Quit producing "more efficient engines…that sustain a fundamentally flawed system" . Don't feel good about going less bad

*McDonough and Braungart*

- The intelligence of natural systems should inform human design:
  - *Waste Equals Food*
  - *Use Current Solar Income*
  - *Celebrate Diversity*

# *From Biomimicry to Industrial Ecology to Ecological Mimicry*




*More than use of organisms (domestication)*

*More than linking biological processes*



*Biomimicry 3.8, Janine Benyus*

# So you want to be a regenerative system designer

- What do you mean by regenerative system?
  - processes that restore, renew or revitalize their own sources of energy and materials using systems ecology as a perspective ,
  - sustainable from the point of view that resources are not irreversibly consumed
  - Effective design rather then  simple efficiency

- There is an “easy” part and a “difficult ” part to designing regenerative systems  (from the technical point of view, not necessarily socioeconomic)

  – Easy:  Building *coherent balance* into our systems
    - Coherence: a logical, orderly, and aesthetically consistent relationship of parts. logical or natural connection or consistency

  – Hard:  Developing predictable, self-regenerating systems
    – Minimizing exogenous control

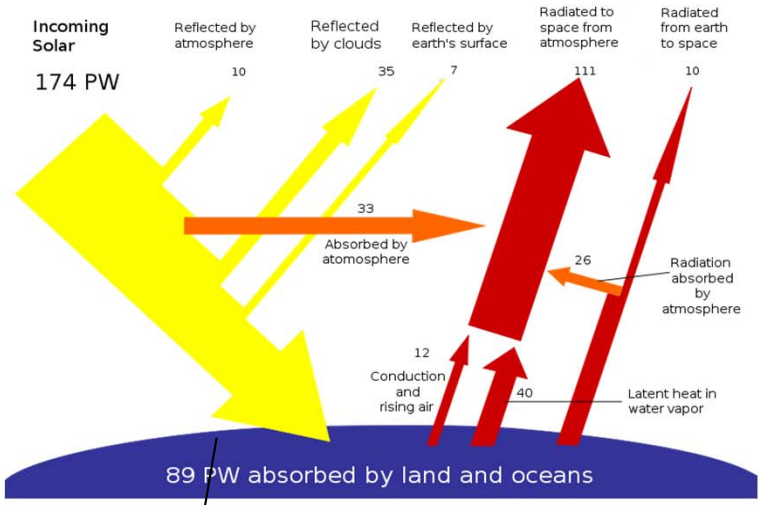
# Water management: a Wicked Problem

- As described by Rittel & Webber (1969 AAAS, 1973*), social problems are ‘wicked’ & beyond reach of science because they are complex, indefinable & lack an objective ‘good’ to aim for;

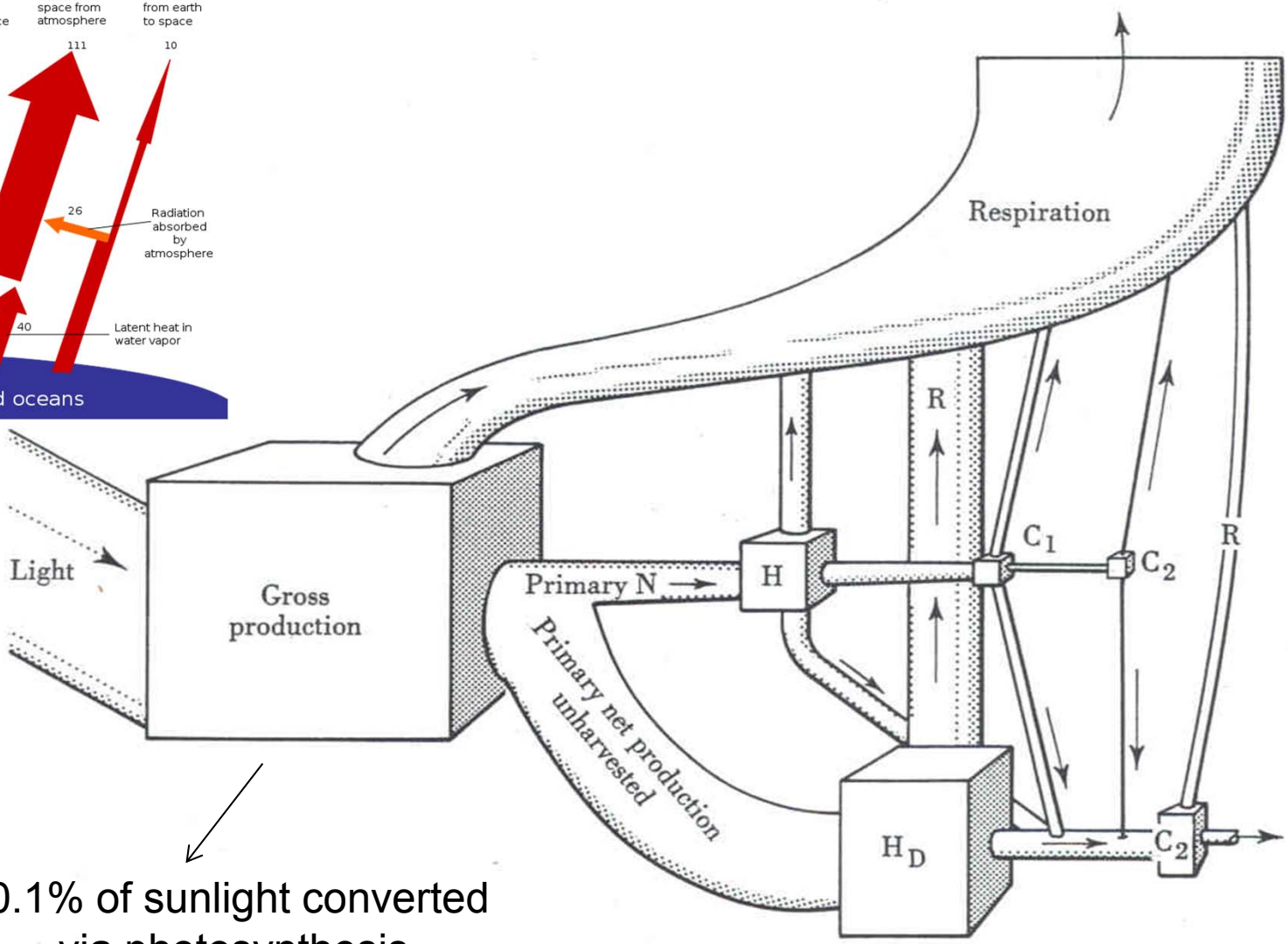
  **i.e. problem interconnected with the process of its solution**

  - To ask all the relevant questions you must already know all the conceivable alternative solutions
  - You can not tell when the problem is ‘solved’
  - The adequacy of the solutions depends on stakeholders
  - ‘One-shot’ operation, no room for trial & error; every attempt counts and no way to ID all solutions to consider

*Dilemmas in a General Theory of Planning, pp. 155–169, Policy Sciences, Vol. 4, Elsevier Scientific Publishing Company, Inc., Amsterdam, 1973

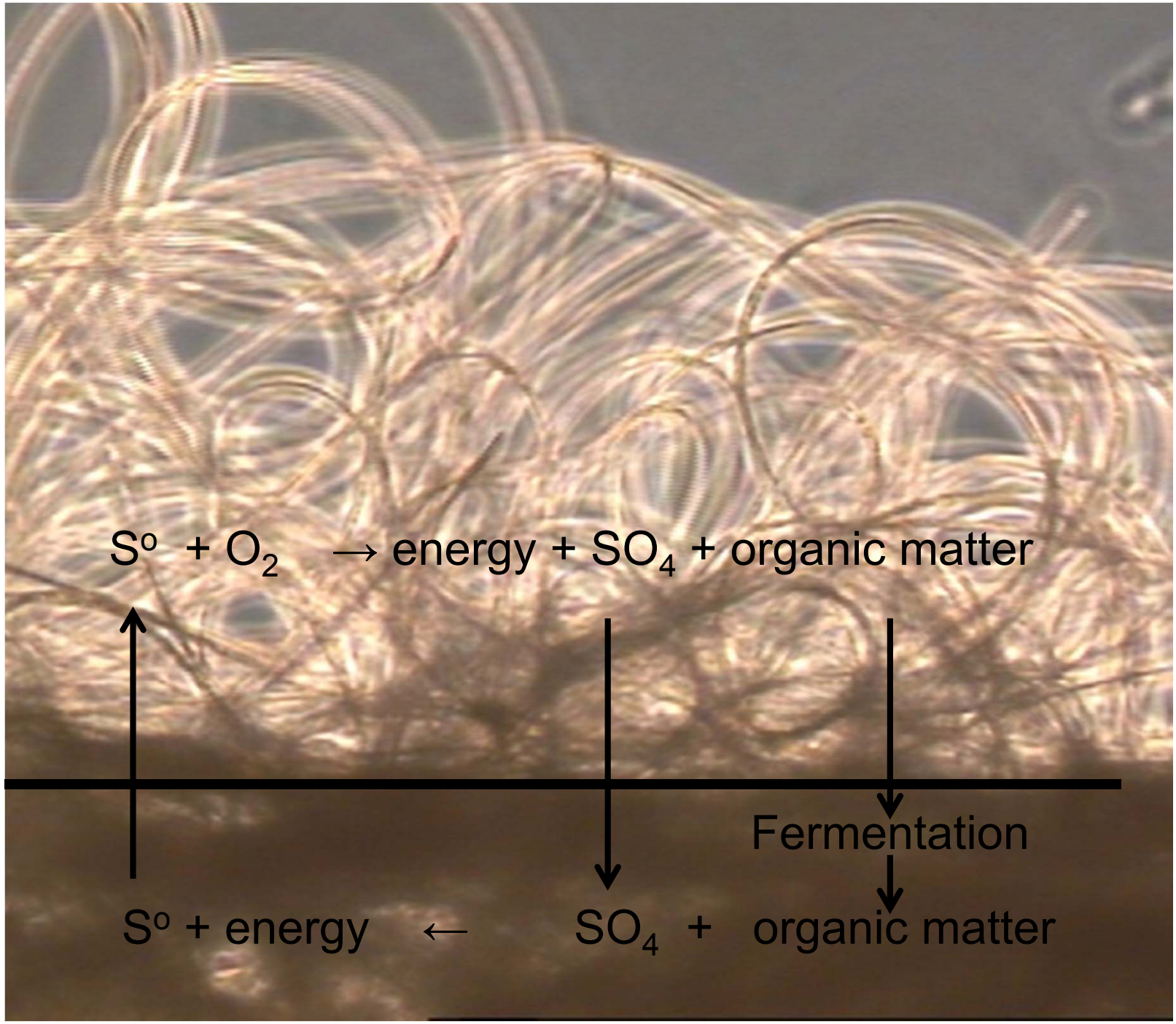



- 10,000 times more Energy than civilization currently produces




0.1% of sunlight converted via photosynthesis

***Figure 3-7*** *A generalized diagram showing energy flow through the ecosystem. There are two major pathways, through the herbivore chain and through the decomposer chain. N = net production; H = herbivore; $H_D$ = herbivore decomposers; C = carnivores; R = respiration.*


$S^o + O_2 \rightarrow$ energy + $SO_4$ + organic matter
Fermentation
$S^o$ + energy $\leftarrow$ $SO_4$ + organic matter

# Traditional Wastewater Treatment

Anaerobic Treatment of Biosolids
(eating dinner from the garbage can)

Aerobic Treatment to Oxidize Organics (and $NH_3$)
(Spend Energy to Get Rid of Energy)

Combined Nitrification/Denitrifcation
(Feeling good about doing less bad)

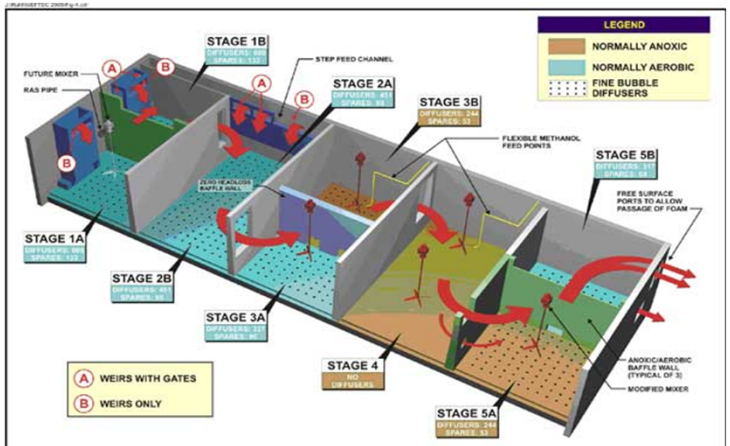
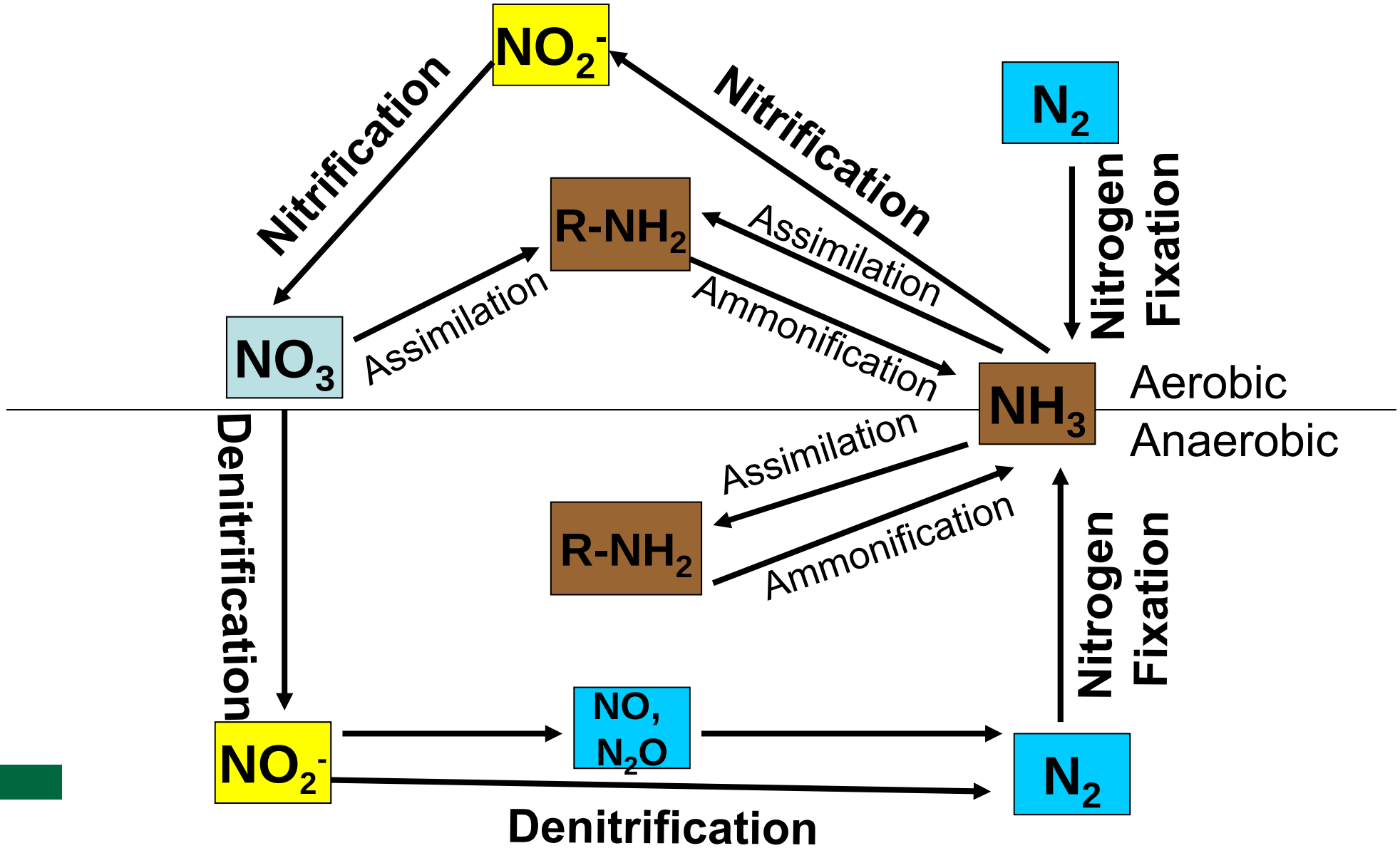


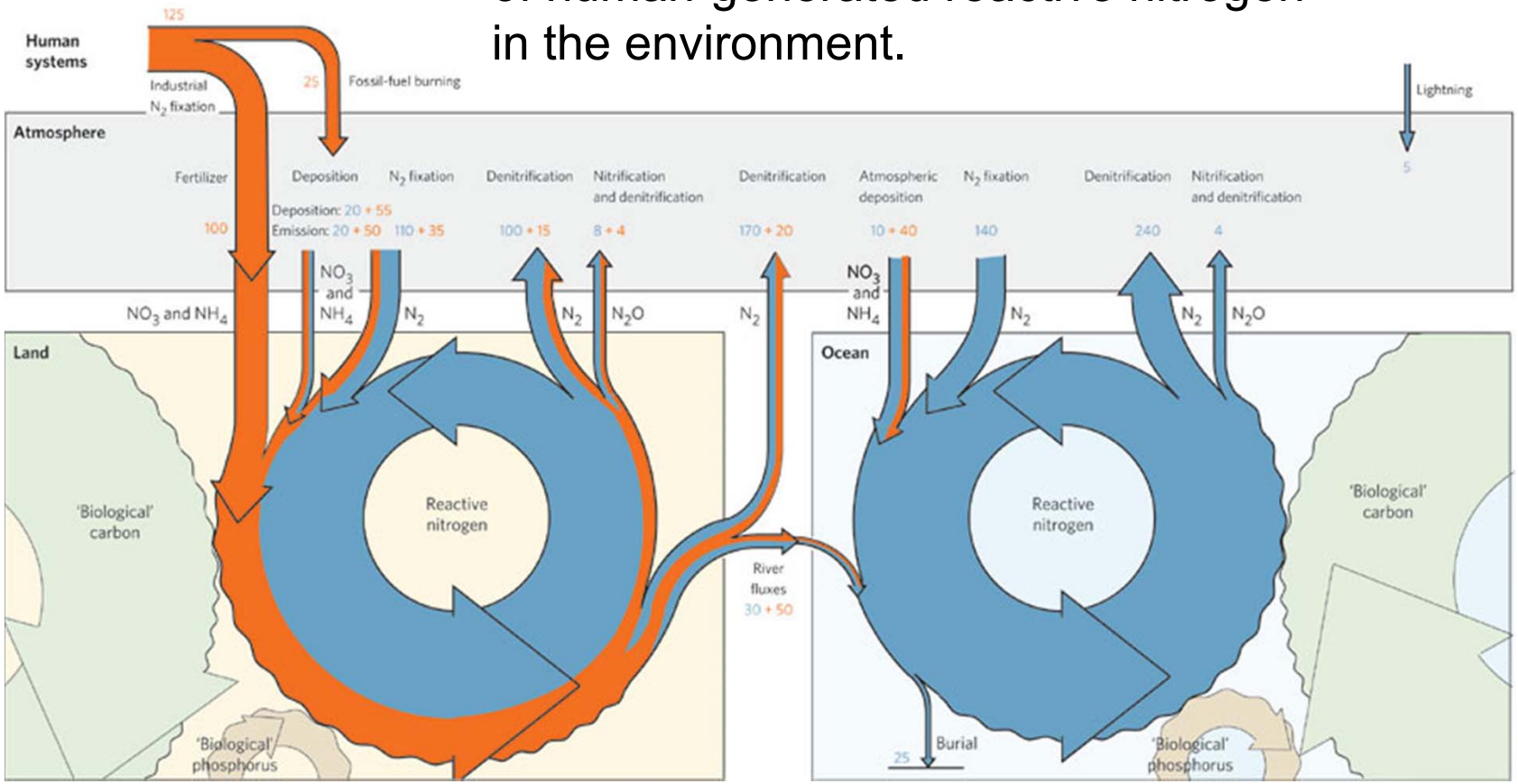
Figure 4 : Upgraded Nitrification / Denitrification Reactor

# Microbial Transformation Of Nitrogen



# So what's bad about the Haber Bosch process?

nitrogen cascade" – cumulative impact of human-generated reactive nitrogen in the environment.




What about the energy costs?

And greenhouse gas production (3.7 lbs of $CO_2$ produced per lb of ammonia fertilizer?)

# Urine as a Nutrient Source

## What about human urine?

- Average per capita production of N in urine is anywhere from 3.6-16.80 g per day
- Assume an average of 10 g per day, or 3650 g per year
- Given 6.7 x $10^9$ people on the planet, 24 x $10^{12}$ g or 24 Tg N
- Same magnitude of current level of BNF on Earth (33 Tg per year)
- Within the range of Haber Bosch (100 Tg per year)

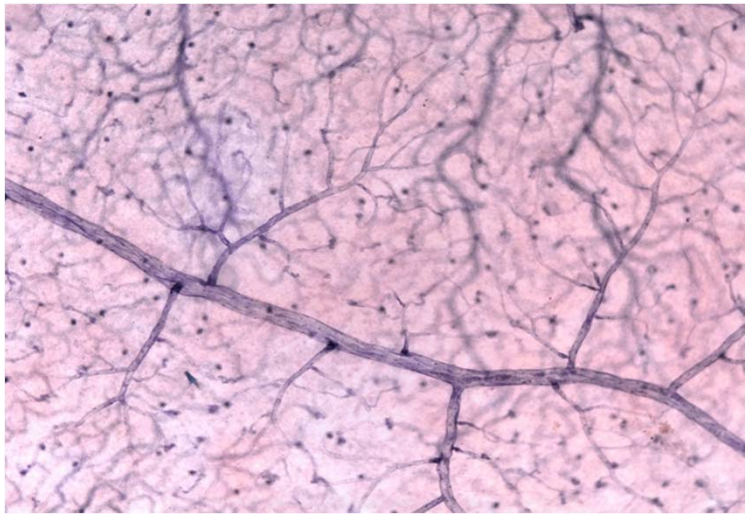
# Struvite: $MgNH_4PO_4.6H20$

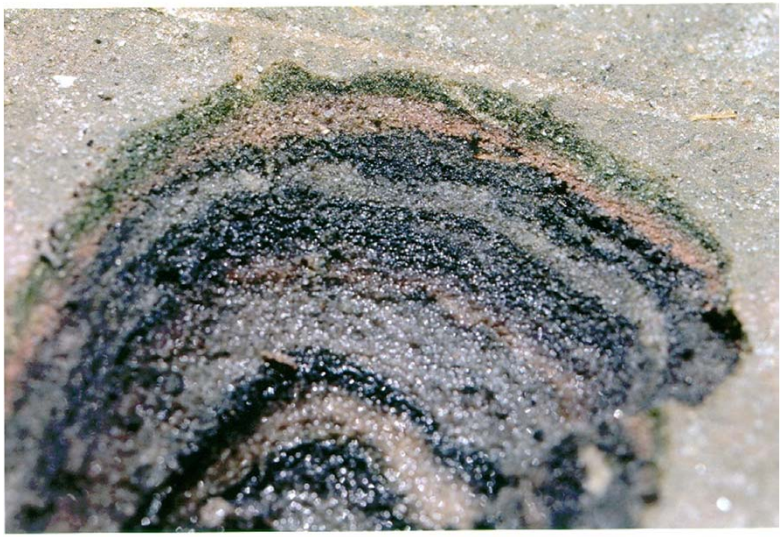
Crystal formed under alkaline conditions in urine

Microbial action increases potential for precipitation
Due to urea hydrolysis to ammonia (consumes H+)

Can be a problem
- kidney stones
- scaling of wastewater systems

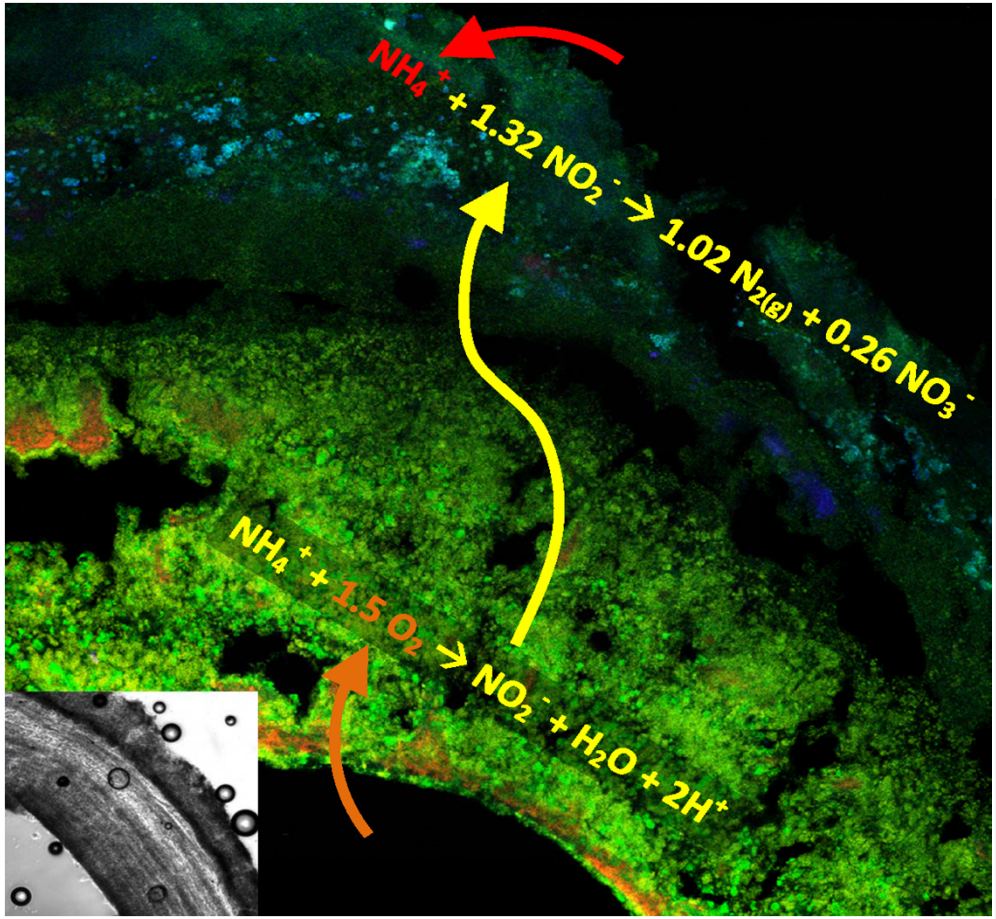
But is a “spontaneous” way to produce a purified (i.e, crystal) slow release fertilizer





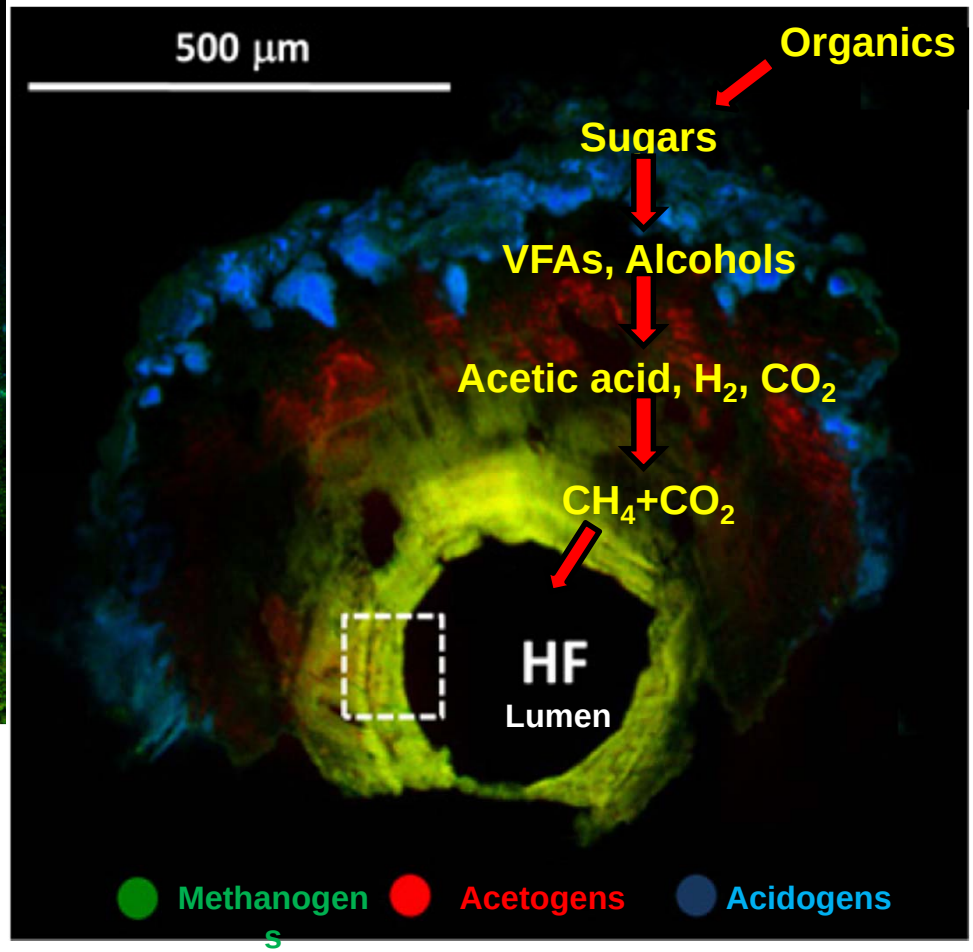
# Hollow Fiber Bioreactors as a Form of Ecological Mimicry

# Self-Organized, Stratified Ecologies




Aerated Biofilms For Nitrogen Removal

## Methane Extracting Biofilms (proposed)



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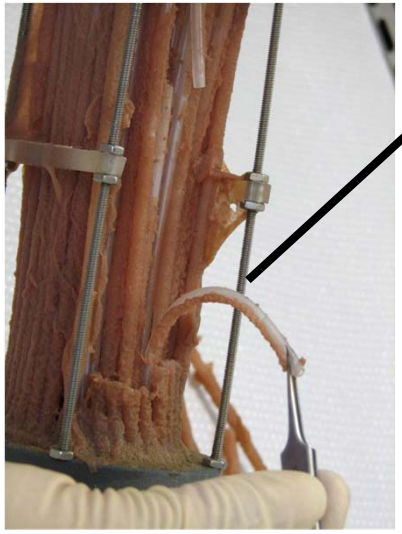
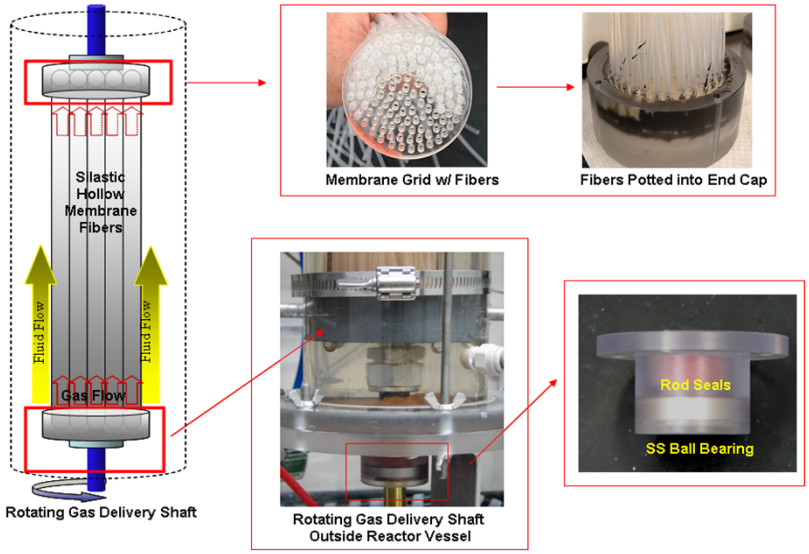
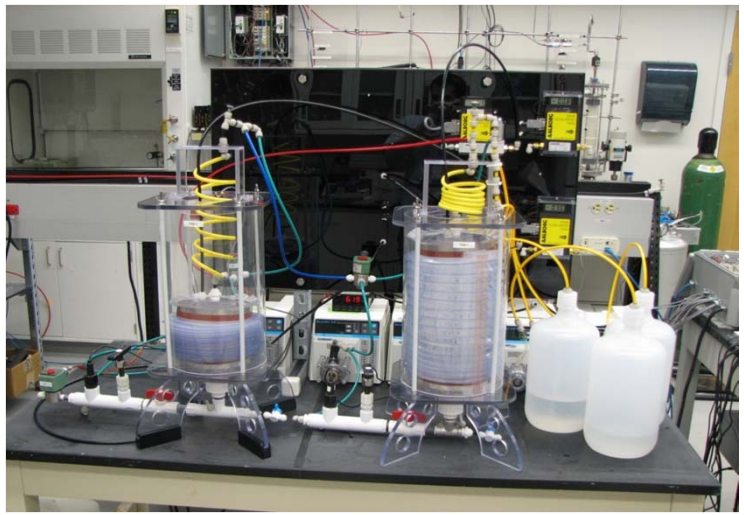


Mass transfer limitations to the inner fiber module, high liquid recycle is limited, and requires energy

## Rotation as a cost-effective means of increasing mass transfer



Biofilm “bridging” limits mass transfer over time



Alternative , “bellows” design to open up spaces between fibers & mix

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Nanomaterial or
Microtubule interface

Solar powered
“organic hoses” for
water purification
and transport

Stormwater or Graywater
Uptake at roots

Linking biophillia and low environmental impact design to a new paradigm of sustainable development, referred to as ‘restorative environmental design’

*Stephen Kellert*

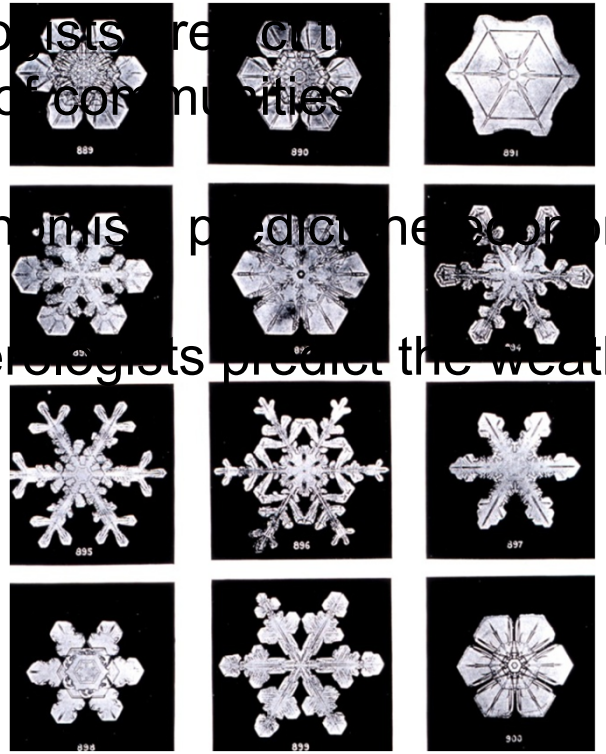
# Do we understand how complex systems work?

## "..consisting of interconnected or interwoven parts"

Can ecologists predict the behavior of communities?

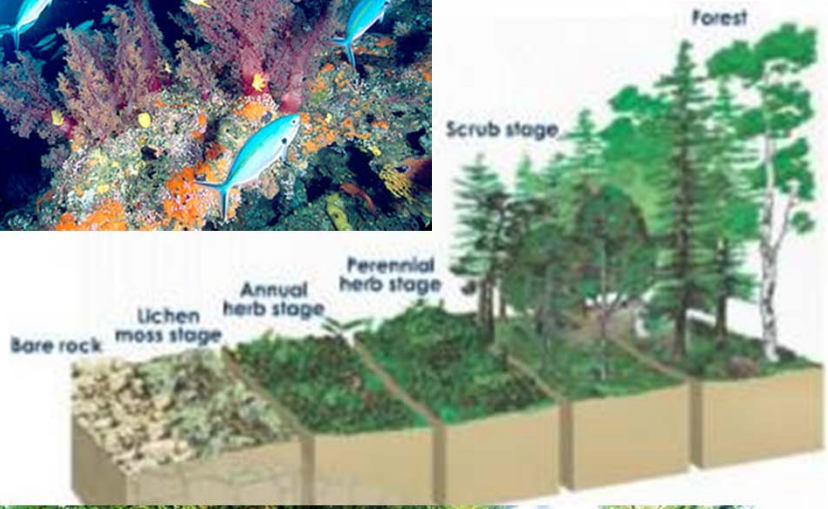
Can economists predict the economic cycles?

Can meteorologists predict the weather?



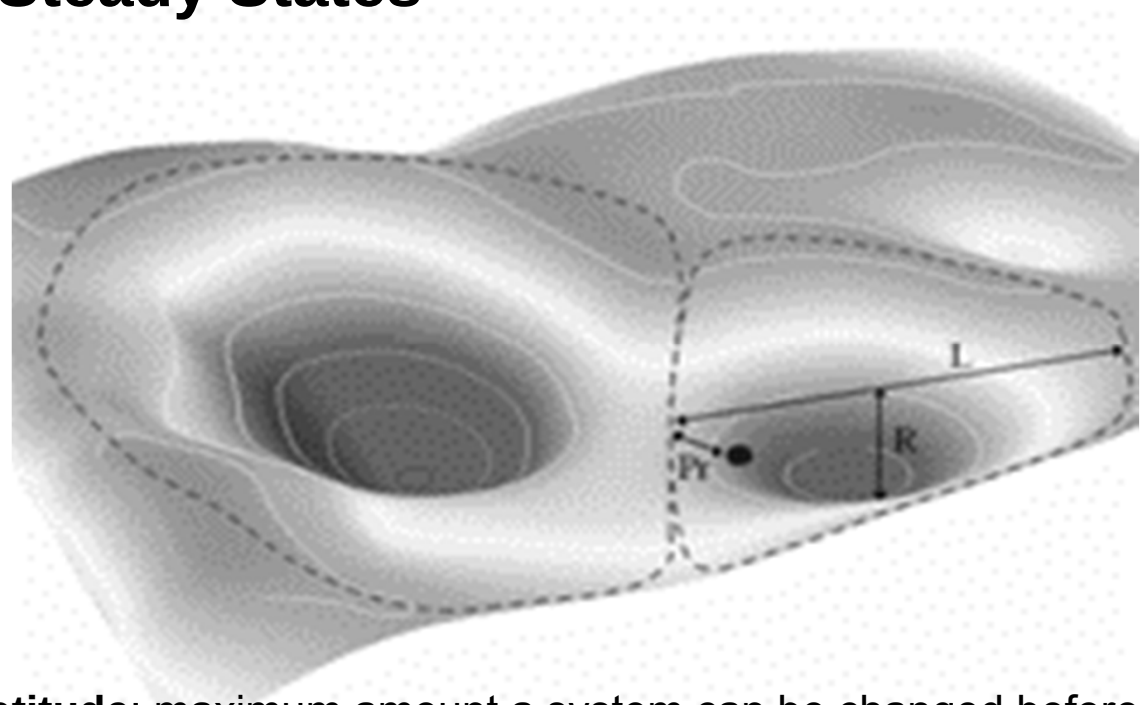
Snowflakes ~$10^{18}$ water molecules aggregating under varying temperature and humidity

# Life Creates Conditions Conducive for Life



# Ecological Communities in Complex System “State Space”

## Responding to the Environment, Existing In Multiple Steady States




**State space**: defined by state variables (e.g., structure, function of the community)

**Basin of attraction**: region in State Space in which a systems tends to remain

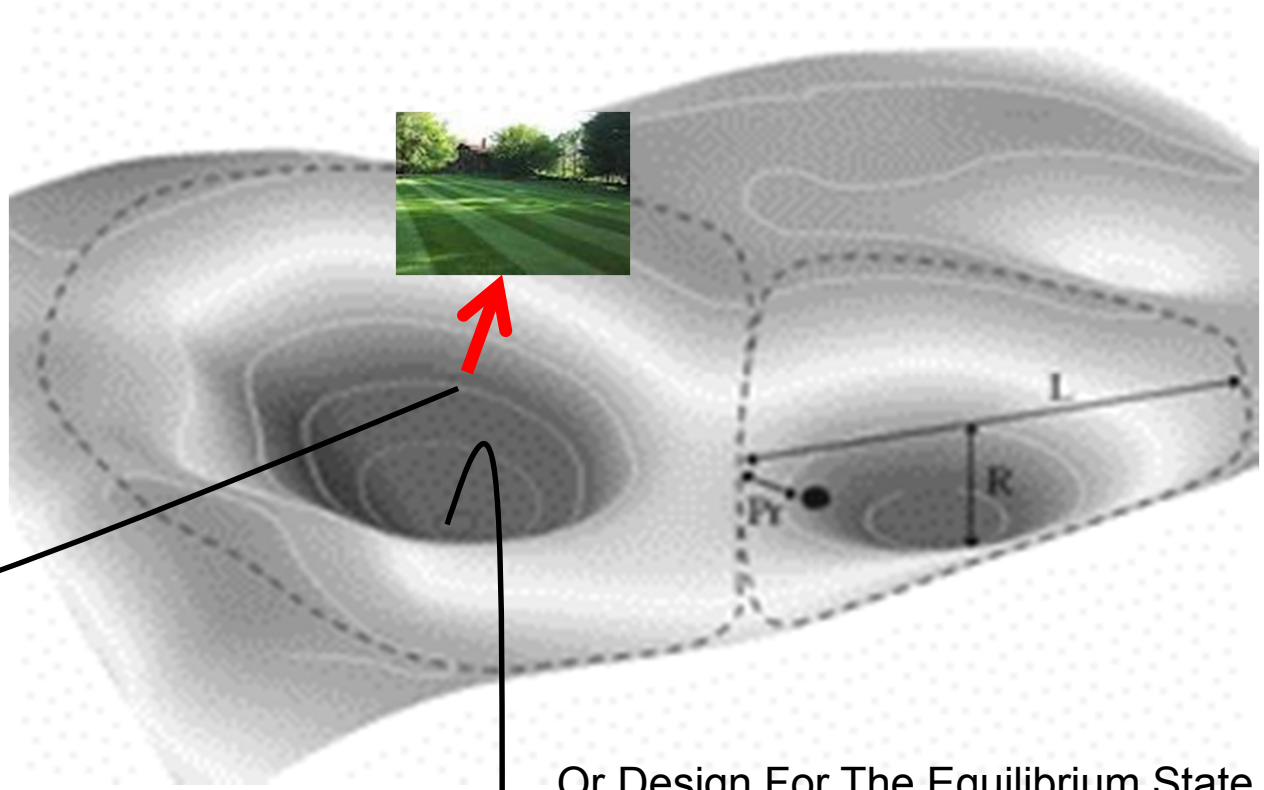
equilibrium state as an attractor

**Latitude**: maximum amount a system can be changed before losing its ability to recover

**Resistance**: the ease or difficulty of changing the system

**Precariousness**: how close the current state is to a limit or threshold

How much exogenous energy do you want to spend to maintain disequilibrium?




Or Design For The Equilibrium State

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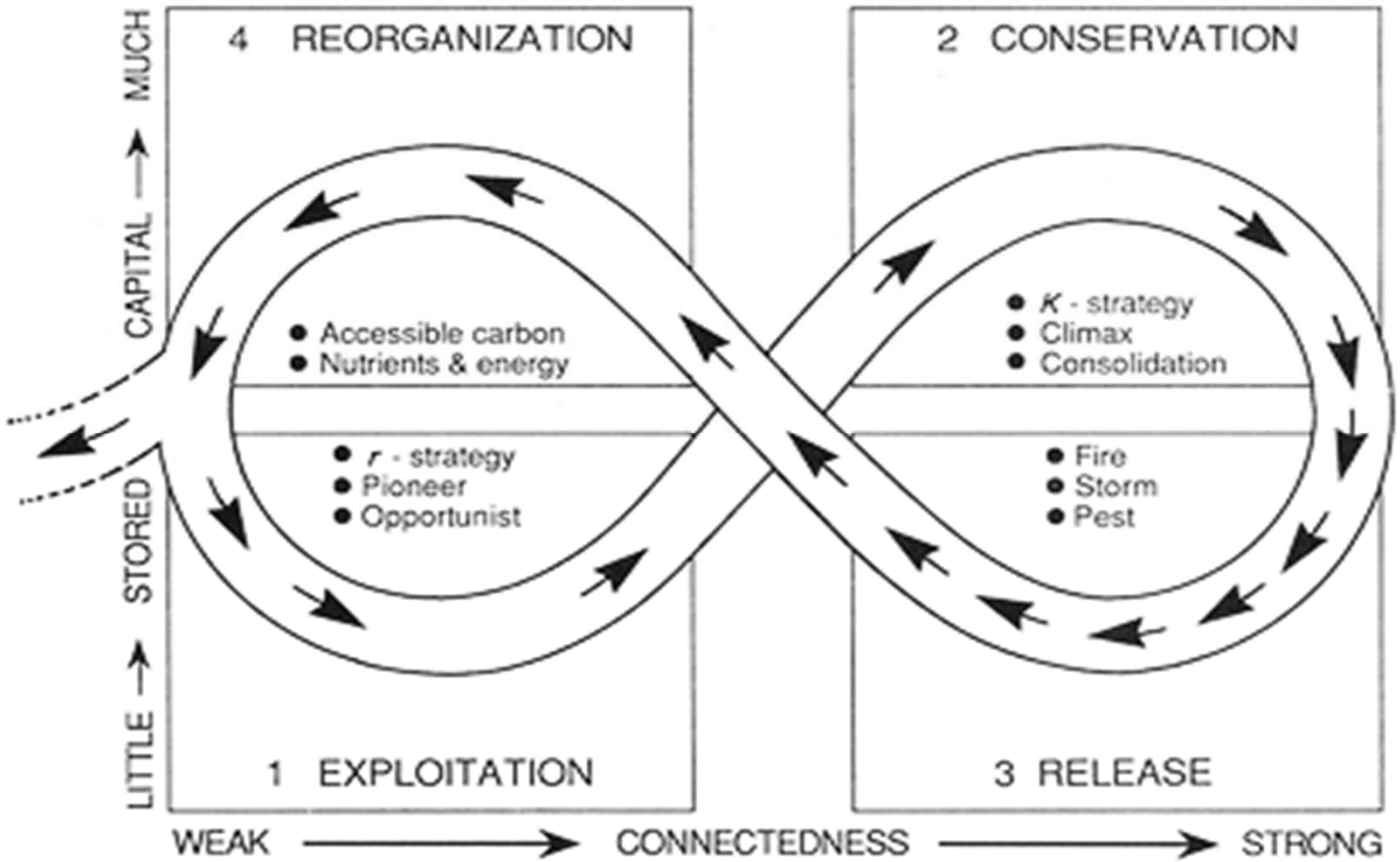
# Complex Adaptive Systems (according to Holling)

- Systems are self-organized and a small set of critical processes create and maintain the self-organization
  - Multiple outcomes are possible depending on history
  - A diversity of components
  - Localized interaction of those components
  - Autonomous processes “use” the outcomes of the interactions to select for “a consistent template”
    - Other, subsidiary factors or elements may be important or interesting, but they exist at the whim of the small set of critical self-organizing variables
- Holling and colleagues developed a framework based on the following criteria
  - Be as simple as possible but no simpler
  - Dynamic and prescriptive, not static and descriptive
  - Embrace uncertainty and unpredictability; surprise and structural change are inevitable in systems of people and nature

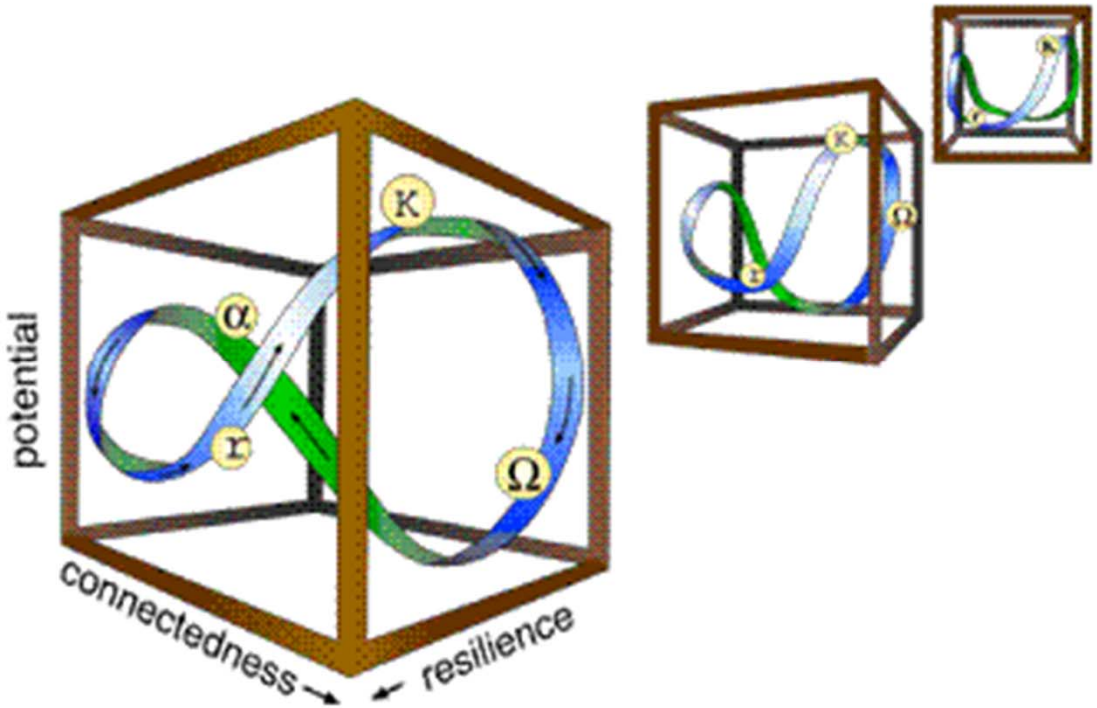
# The Adaptive Cycle

Ecosystem = nutrients, biomass, physical structure
Economic system = skills, networks of relationships




**Internal controllability**

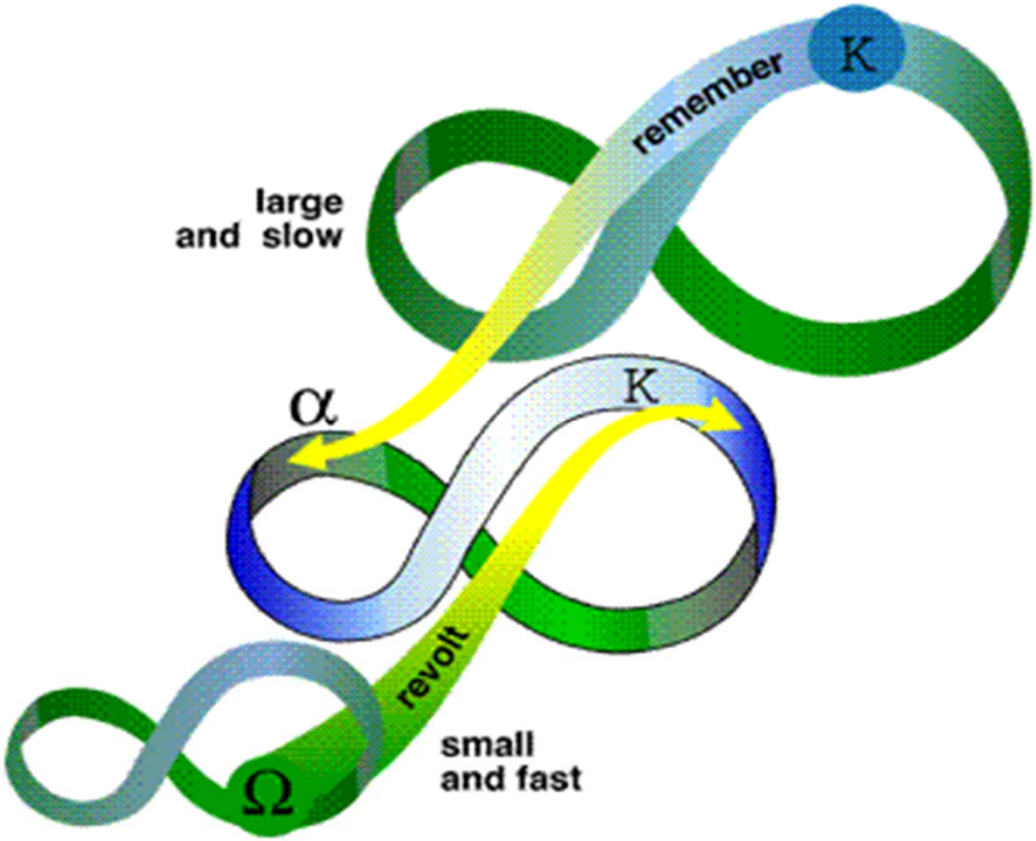
An ecosystem accumulates biomass and nutrients , and those resources are controlled by the existing interconnected system. But the system becomes overconnected, overly rigid (an accident waiting to happen). Resources are suddenly released, and reorganized . “Creative destruction”. Two opposites: growth and stability vs. change and variety)




The third dimension of resilience. Poorly connected, or weakly controlled, system are more resilient. Novel reassortments are rapidly tested “creative experimentation “

4 key features of the adaptive cycle

1) As potential increases so does efficiency and rigidity
2) As potential increases, vulnerability increases (i.e., decreased resilience)
3) Innovation occurs in pulses, when connectedness is low (controls are weak). “Previously isolated or constrained innovations can nucleate new opportunities”
4) Innovations are tested. Successful ones survive and adapt in a succeeding phase of growth from r to K,




Revolt examples

Ecological: fire spreads from local site to crown, patch, stand of trees

Social: local activists transform regional institutions

Remember

Ecological: leakage of nutrients released by fire is slowed by the slower processes or soil accumulation

or renewal hastened by the “seed bank”

The whole panarchy is both creative and conserving, with the interactions between cycles combining learning with continuity

# Is this “Pie in the Sky”?

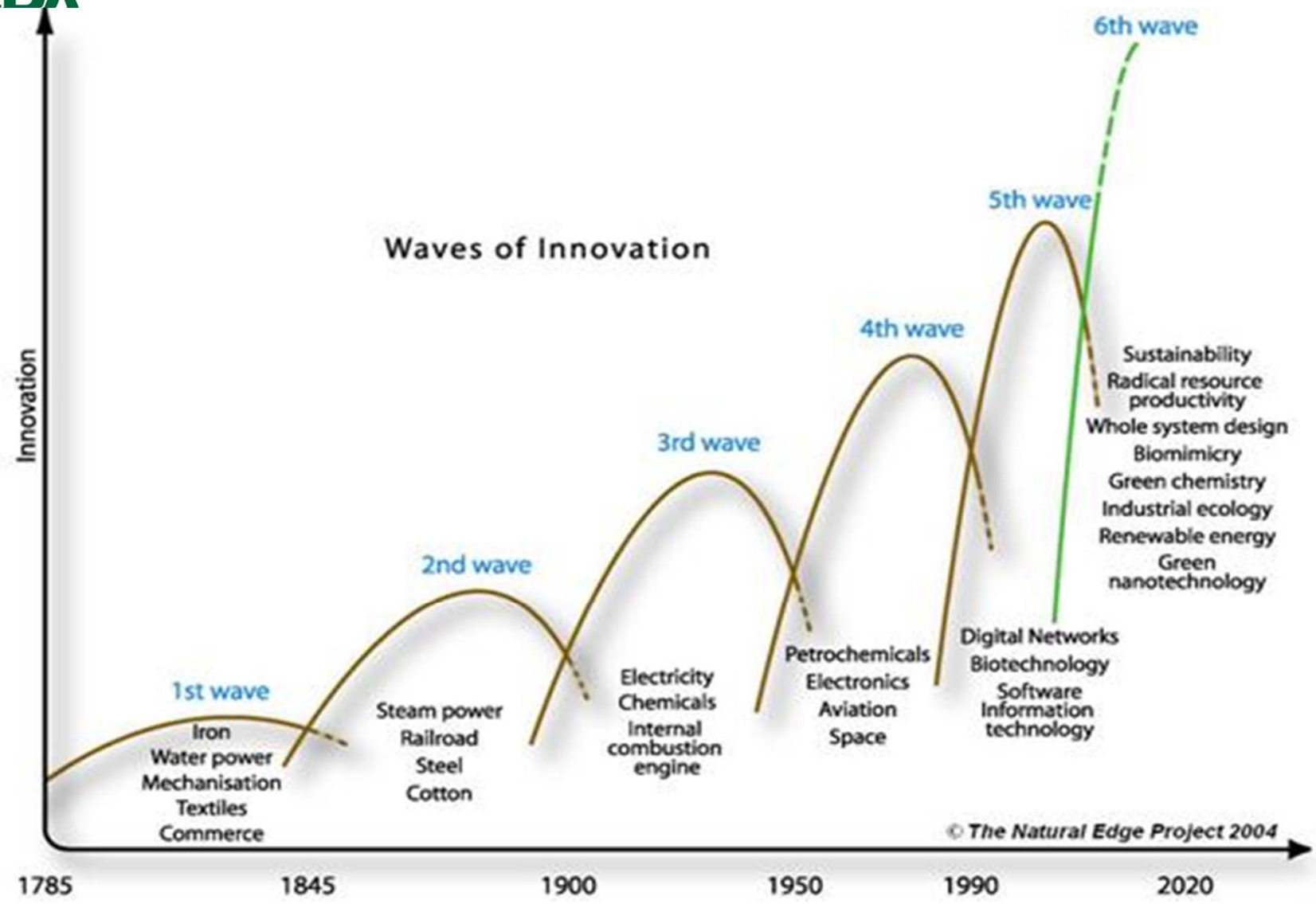
*The real problem is that there are too many people.*

There is more biomass of ants or microbes on the planet, yet their activities have positive effects on the biosphere

The real problem is how we live, not how many of us there are.

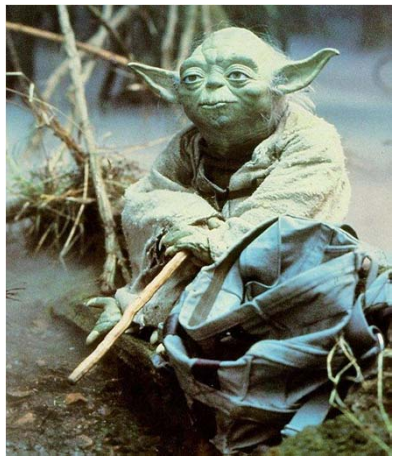
*It’s not economically feasible.*

This is not the old ecology versus industry argument. This is ecology as industry.


Waves of Innovation
Innovation
1st wave
Iron
Water power
Mechanisation
Textiles
Commerce
2nd wave
Steam power
Railroad
Steel
Cotton
3rd wave
Electricity
Chemicals
Internal combustion engine
4th wave
Petrochemicals
Electronics
Aviation
Space
5th wave
Digital Networks
Biotechnology
Software
Information technology
6th wave
Sustainability
Radical resource productivity
Whole system design
Biomimicry
Green chemistry
Industrial ecology
Renewable energy
Green nanotechnology
© The Natural Edge Project 2004
1785
1845
1900
1950
1990
2020

# What will these products (or markets) looks like?

- Less beaten, less heated, less treated
- Actually look green (biophillic)
- Look more like a system then a thing
- They may be highly distributed



"Size matters not. Look at me. Judge me by my size, do you? Hmm? Hmm. And well you should not"

Yoda

The longer a system is "locked in" to its growth phase, says Buzz Holling, "the greater its vulnerability and the bigger and more dramatic its collapse will be…..The only way to approach such a period, in which uncertainty is very large and one cannot predict what the future holds, is not to predict, but to experiment and act inventively and exuberantly via diverse adventures in living."

## Be creative designers (technology development)

The great enemy of truth is very often not the lie – deliberate, contrived and dishonest – but the myth – persistent, persuasive, and unrealistic. Too often […] we enjoy the comfort of opinion without the discomfort of thought**.** John F. Kennedy

Such solutions always involve a definition of the problem that is either false or so narrow as to be virtually false.. The whole problem must be solved, not just some handily identifiable and simplifiable aspect of it. A bad solution is bad, then, because it acts destructively upon the larger patterns in which it is contained… A bad solution solves for a single purpose or goal, such as increased production. And it is typical of such solutions that they achieve stupendous increases in production at exorbitant ecological and social costs

## Be system thinkers (integrated assessment)

from the essay, *Solving For Pattern*, Wendell Berry

Socialism failed because it couldn't tell the economic truth; capitalism may fail because it couldn't tell the ecological truth

Lester Brown