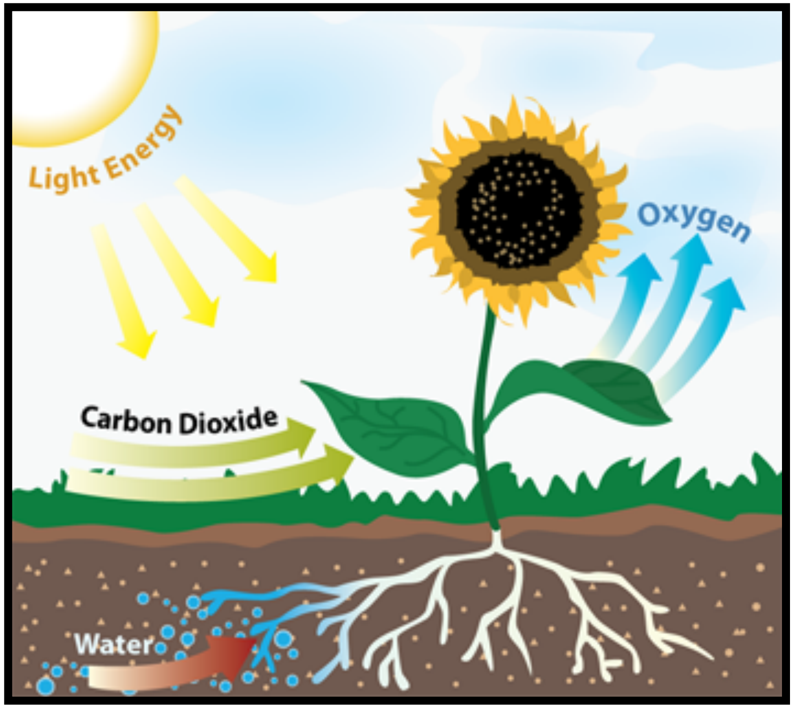
# Biogeochemical Cycles and Pollution

Environment 100

Tuesday, May 22, 2012

# Biogeochemical Cycles Outline

- What are biogeochemical cycles
- Water Cycle
- Carbon Cycle
  - Fast and Slow
  - Biofuels and Tilman's principles
- Nitrogen Cycle
  - Haber-Bausch Process



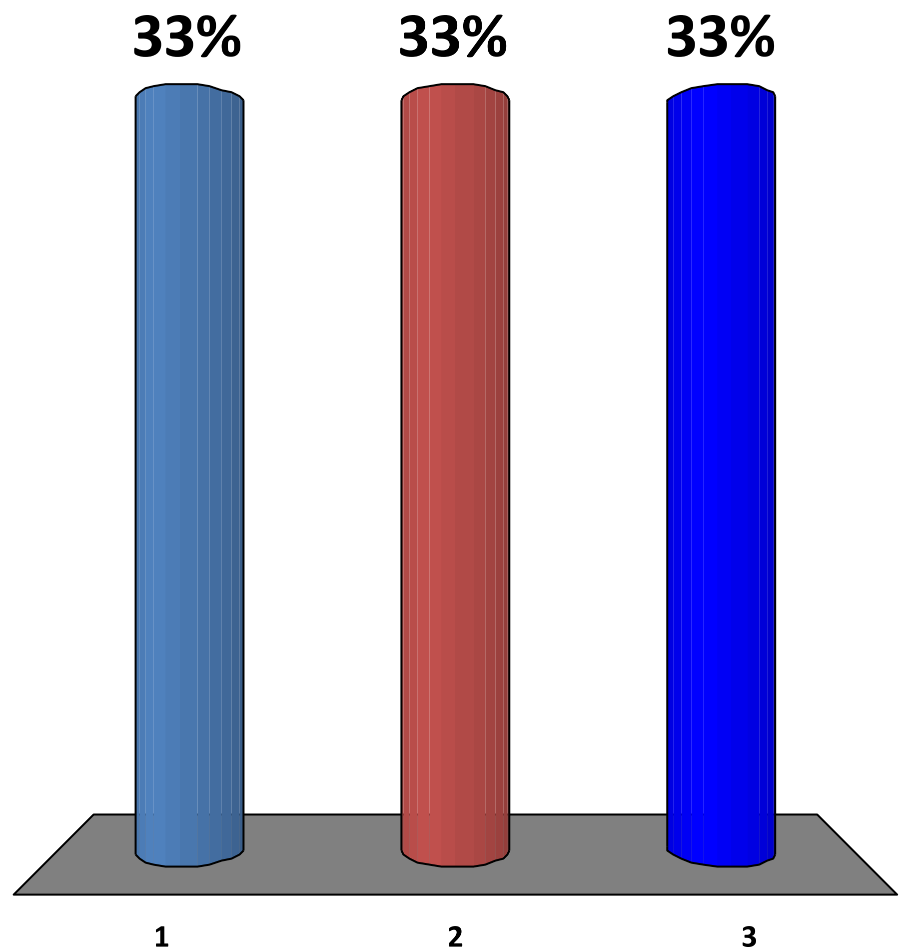

Photosynthesis drives the carbon cycle

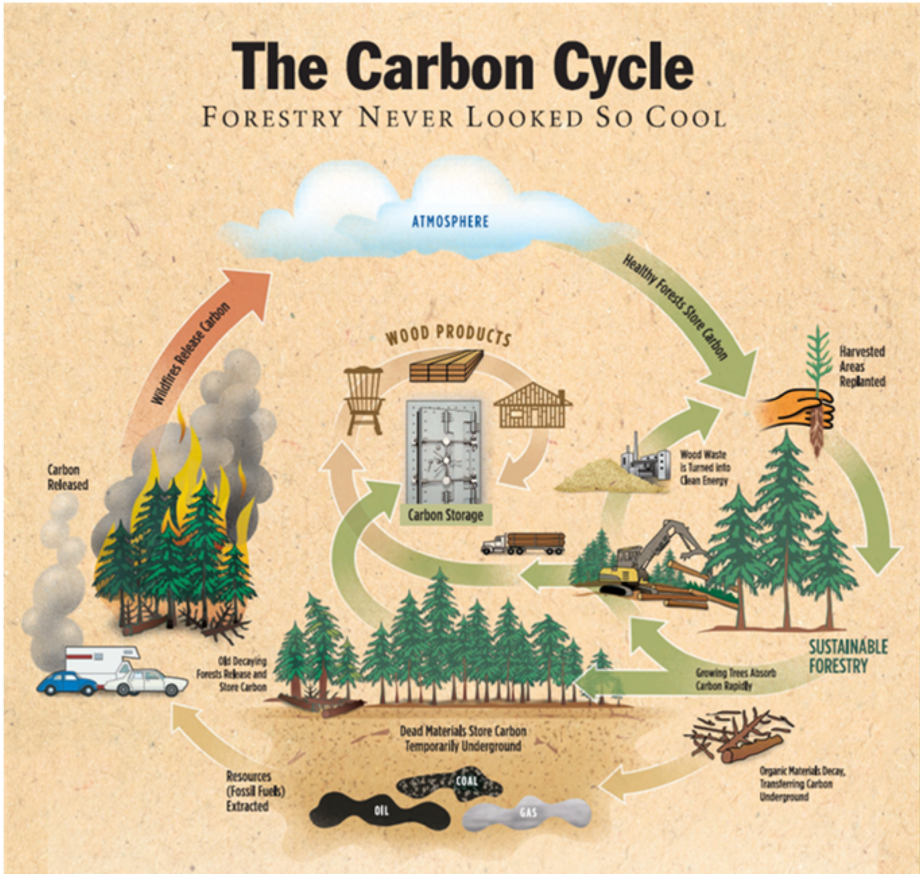
$$6CO_2 + 12H_2O \xrightarrow[\text{green plants}]{\text{light}} C_6H_{12}O_6 + 6O_2 + 6H_2O.$$

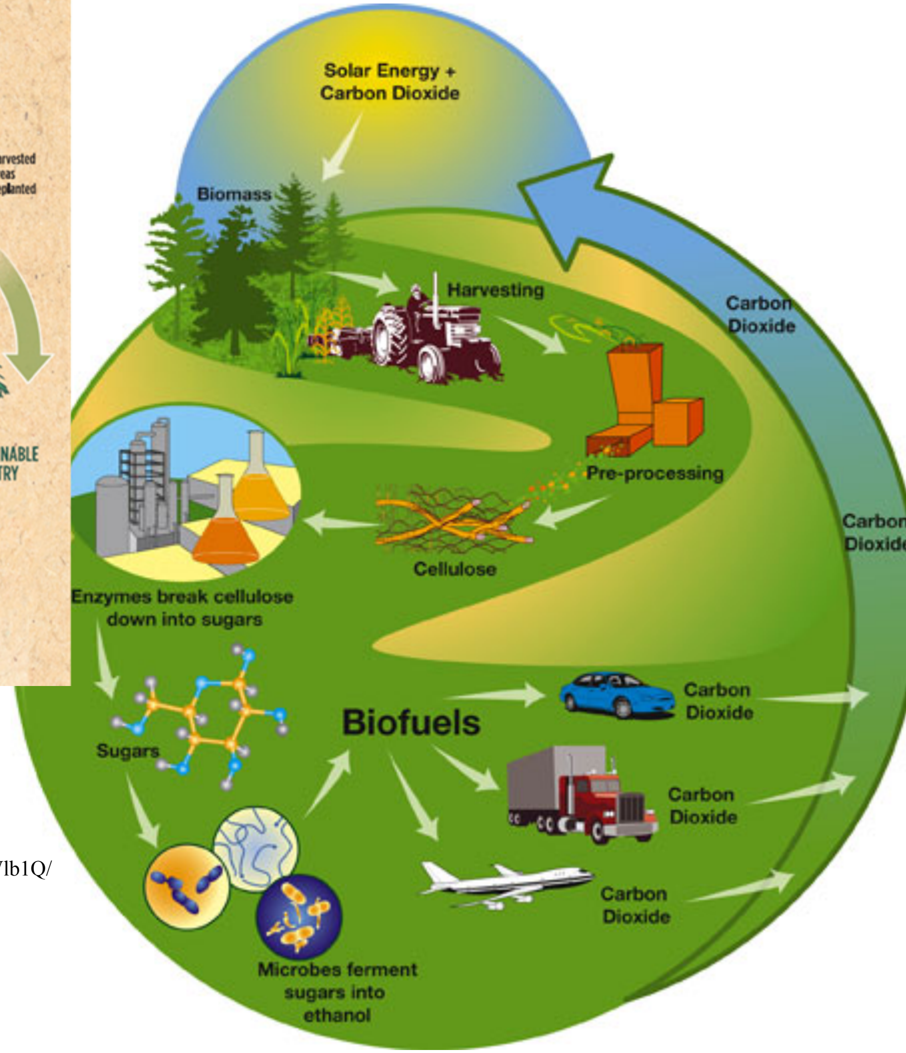
carbon dioxide | water | glucose | oxygen | water

# Most of a tree is built out of…

1. Wood, duh
2. Atmospheric $CO_2$
3. Nutrients from the soil especially nitrates and phosphates






Images: http://3.bp.blogspot.com/-6WoOGbiJmH8/TdwM568SskI/AAAAAAAAAcU/bQdGXVWlb1Q/
s1600/Carbon+Cycle+Cropped.jpg
http://1.bp.blogspot.com/-nnGuswftM74/TldnemSdMPI/AAAAAAAAAFw/140ghGfXYjs/s1600/
biofuel.jpg

# Two questions:

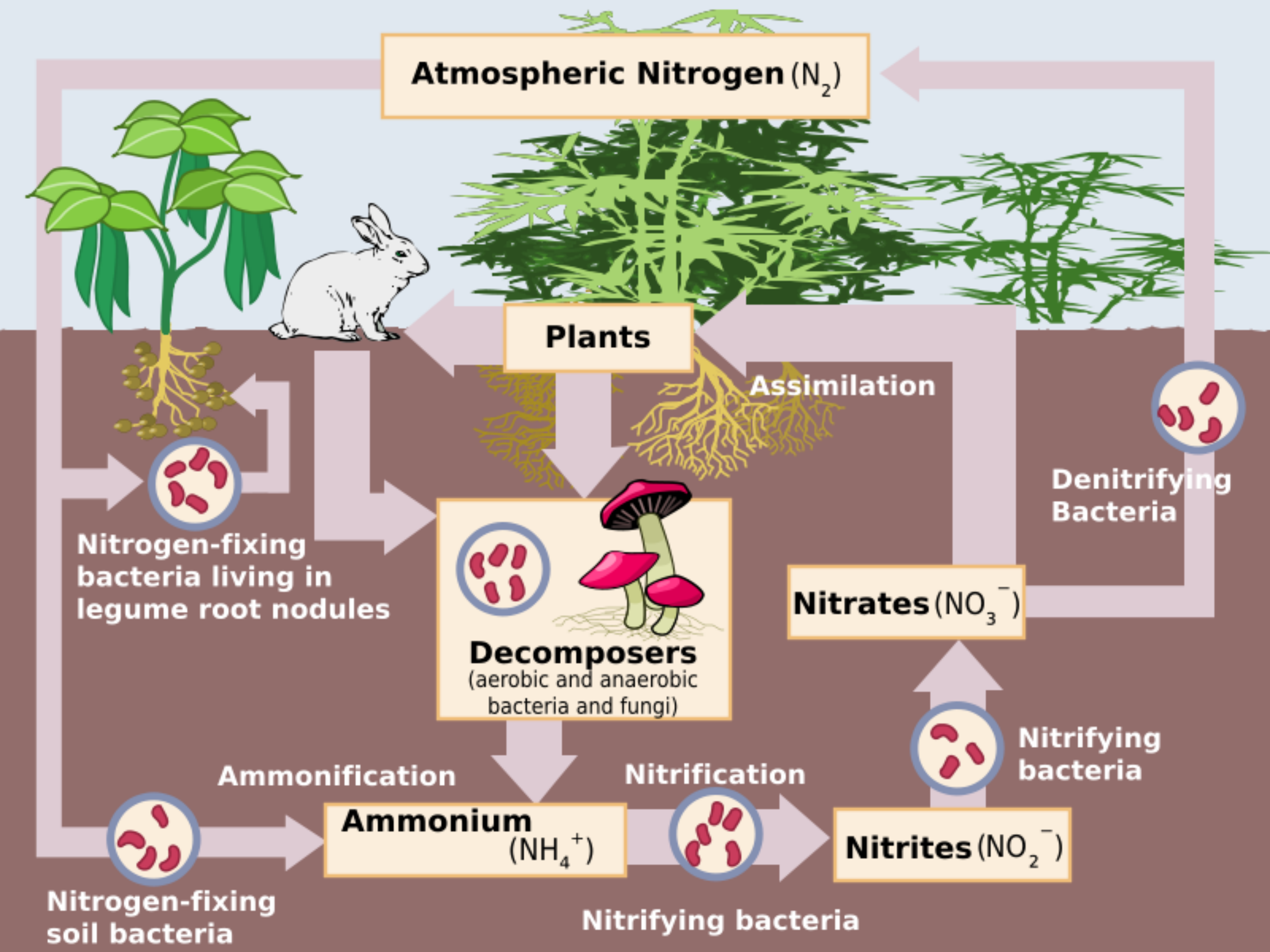
- How are biofuels related to the fast and slow carbon cycle?
- How can biofuels be carbon neutral?  Are they always carbon neutral?

# The Nitrogen Cycle

- Nitrogen is chemically/ biochemically converted into various forms between atmosphere, lithosphere, hydrosphere, and biosphere
- Atmosphere is 78% nitrogen ($N_2$)
- N in all amino acids and our DNA→ crucial to life
- BUT…$N_2$ not useful to most organisms.
- Needs to be converted to usable forms, especially ammonia, nitrates, nitrites.
- Usable N is scarce in most ecosystems

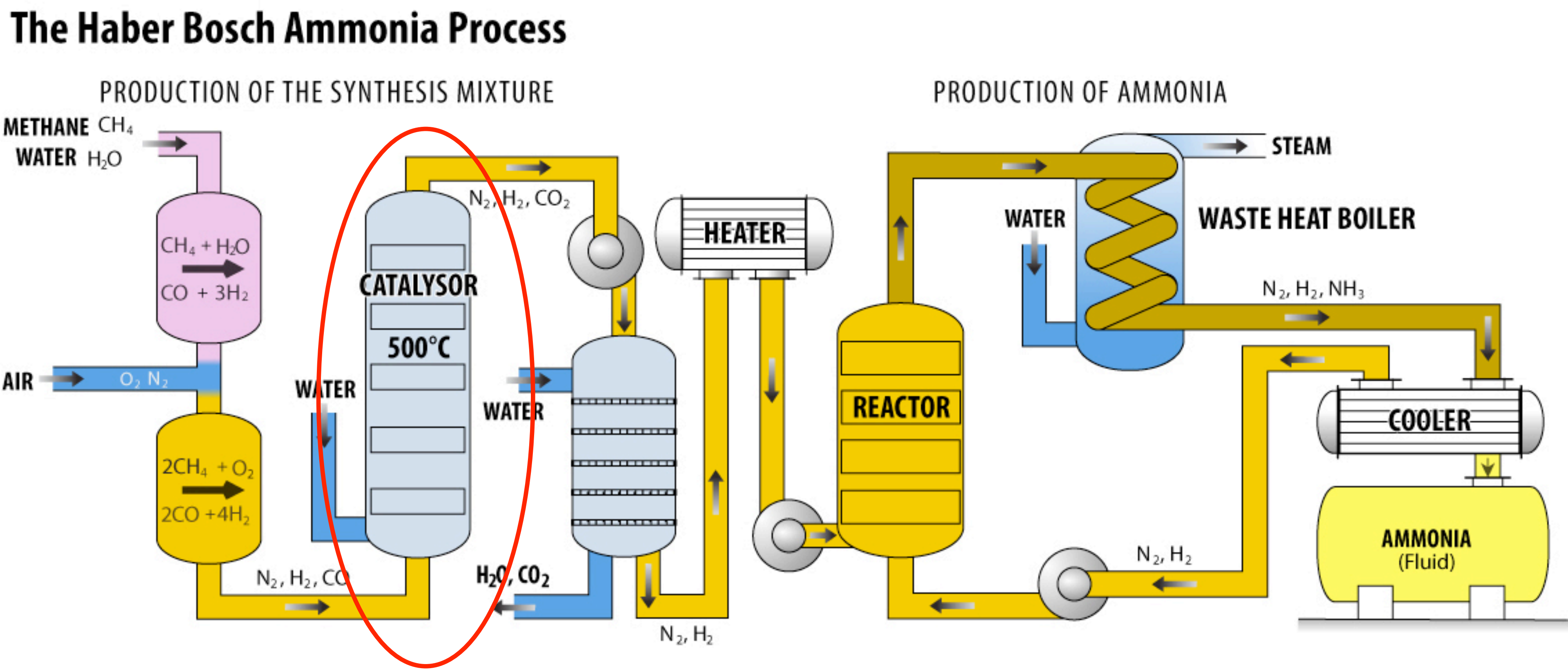
# You’ve heard about nitrogen fixation before. Nitrogen fixation is done by:

1. Most plants
2. Legumes
3. Bacteria living within legumes

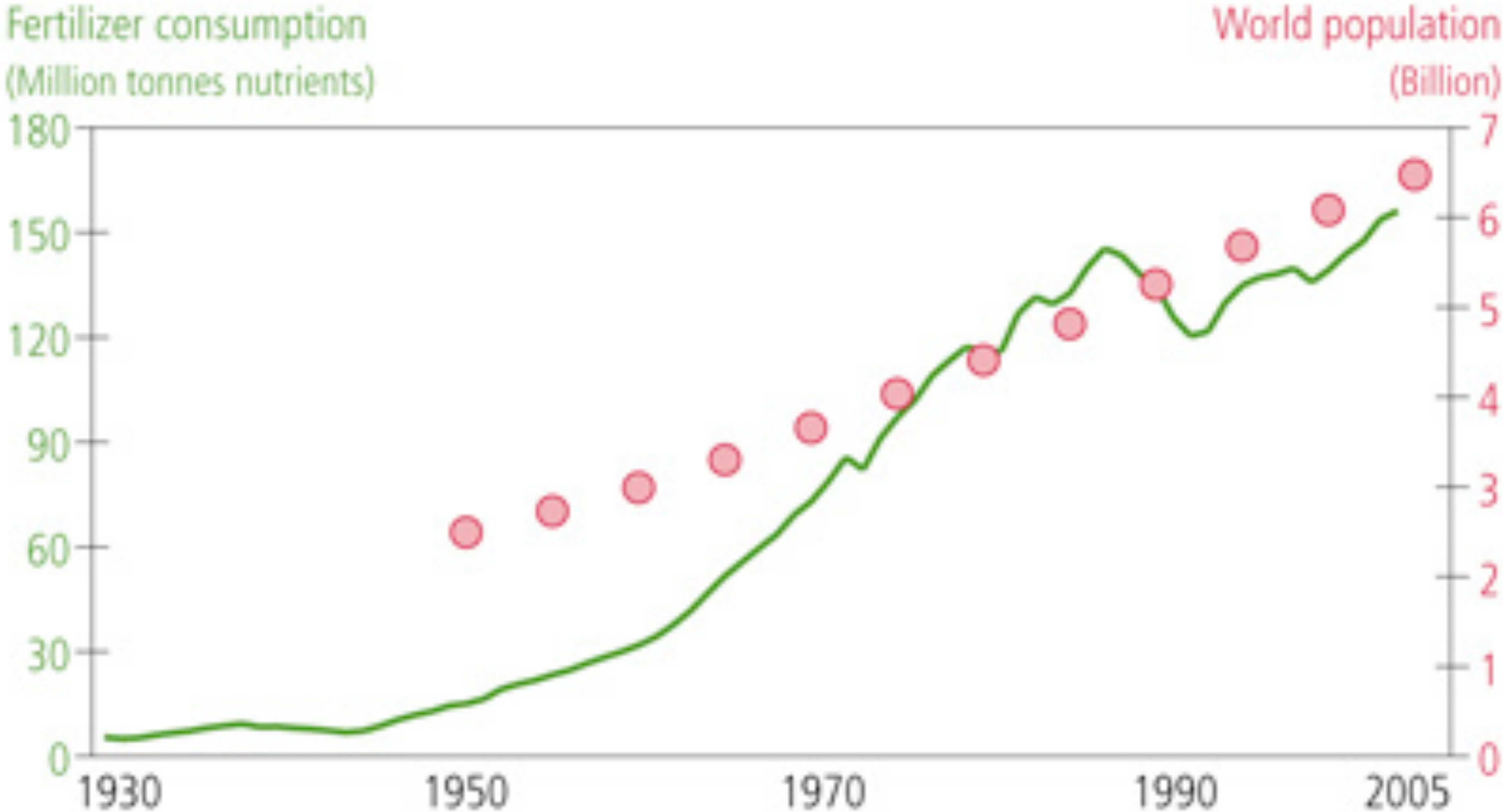


Atmospheric Nitrogen ($N_2$)
Plants
Assimilation
Denitrifying Bacteria
Nitrogen-fixing bacteria living in legume root nodules
Decomposers
(aerobic and anaerobic bacteria and fungi)
Nitrates ($NO_3^-$)
Nitrifying bacteria
Ammonification
Nitrification
Ammonium ($NH_4^+$)
Nitrites ($NO_2^-$)
Nitrogen-fixing soil bacteria
Nitrifying bacteria

# Nitrogen "Gain"



## World fertilizer consumption and population in the past century




Sources: IFA and UN Population Division

# Switching gears into pollution

# Lecture Outline

- What is pollution?
- What are the sources of pollution?
- What are the effects of pollution (toxicology)?
- One solution

# What is pollution?

- In a word, excess
- Anything in amounts high enough to harm people, other life, or valued objects
- Almost anything can be harmful if concentrated enough
  - Oxygen, water, $CO_2$
  - Noise, light, heat

http://palscience.com/wp-content/uploads/2009/11/water_drop_causing_a_ripple.jpg

# Types of Pollutants

1) Natural
   - Found in nature, not toxic at low concentrations
2) Synthetic
   - Compounds synthesized by humans in the lab that are identical to those found in nature
3) Xenobiotic
   - Compounds created by humans that never before existed on earth
   - May be toxic at very low concentrations

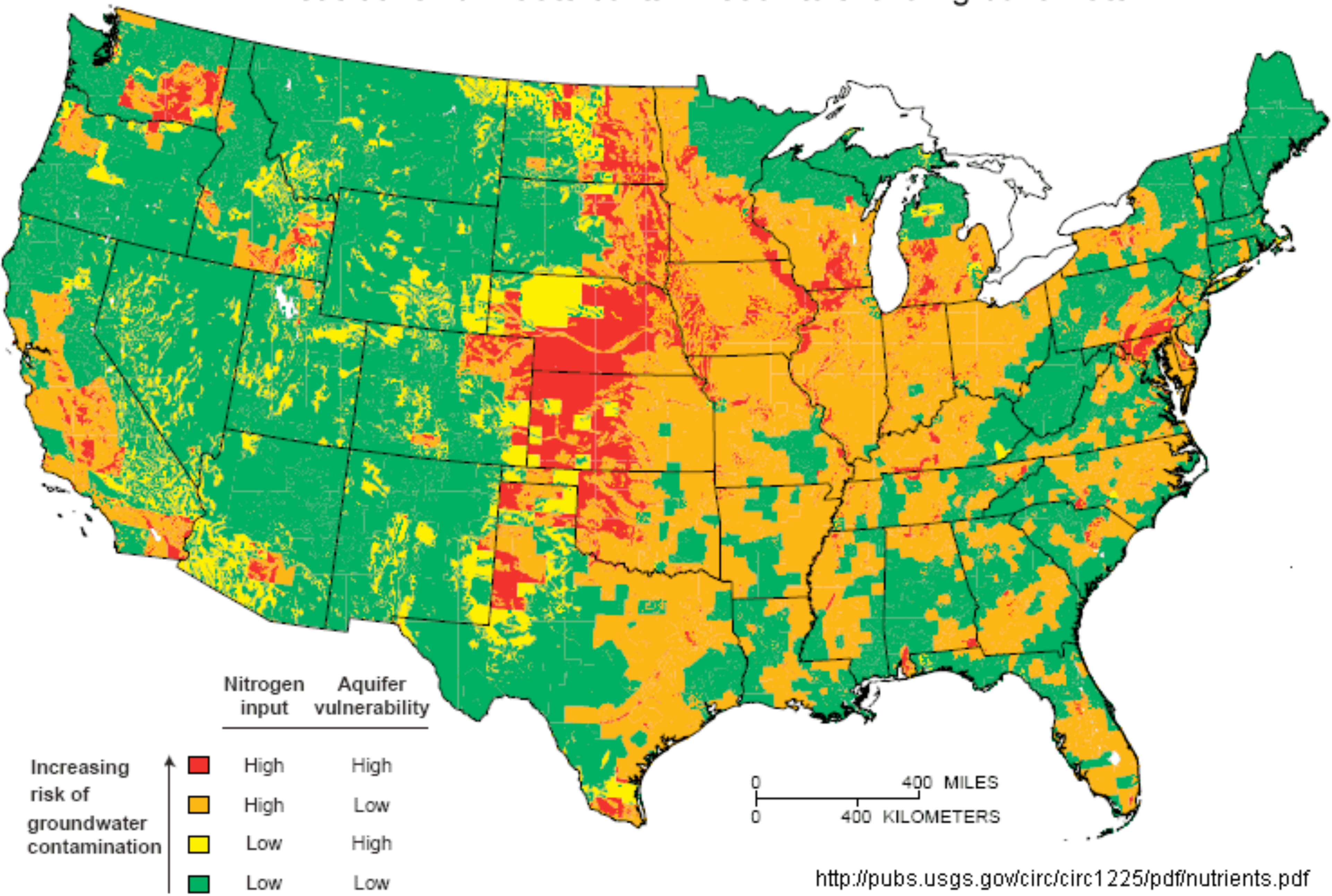
# Natural Chemicals

- Found in nature
- not toxic at low concentrations
- Can be pollutants at higher concentrations
- Examples: nutrients (nitrogen, phosphorus), heavy metals (copper, zinc)

*Image*: http://unipr.waikato.ac.nz/

http://images.nationalgeographic.com/wpf/media-live/photos/000/007/cache/sockeye-salmon_715_600x450.jpg

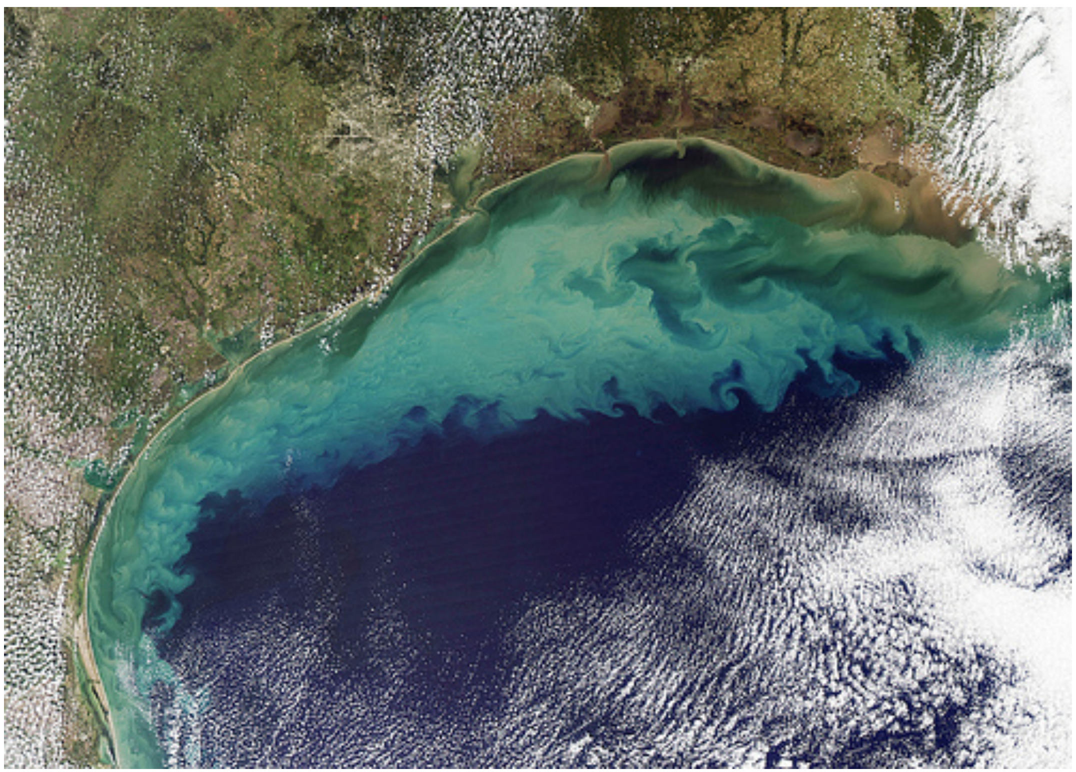
# Areas at risk of nitrate contamination to shallow ground water




http://pubs.usgs.gov/circ/circ1225/pdf/nutrients.pdf

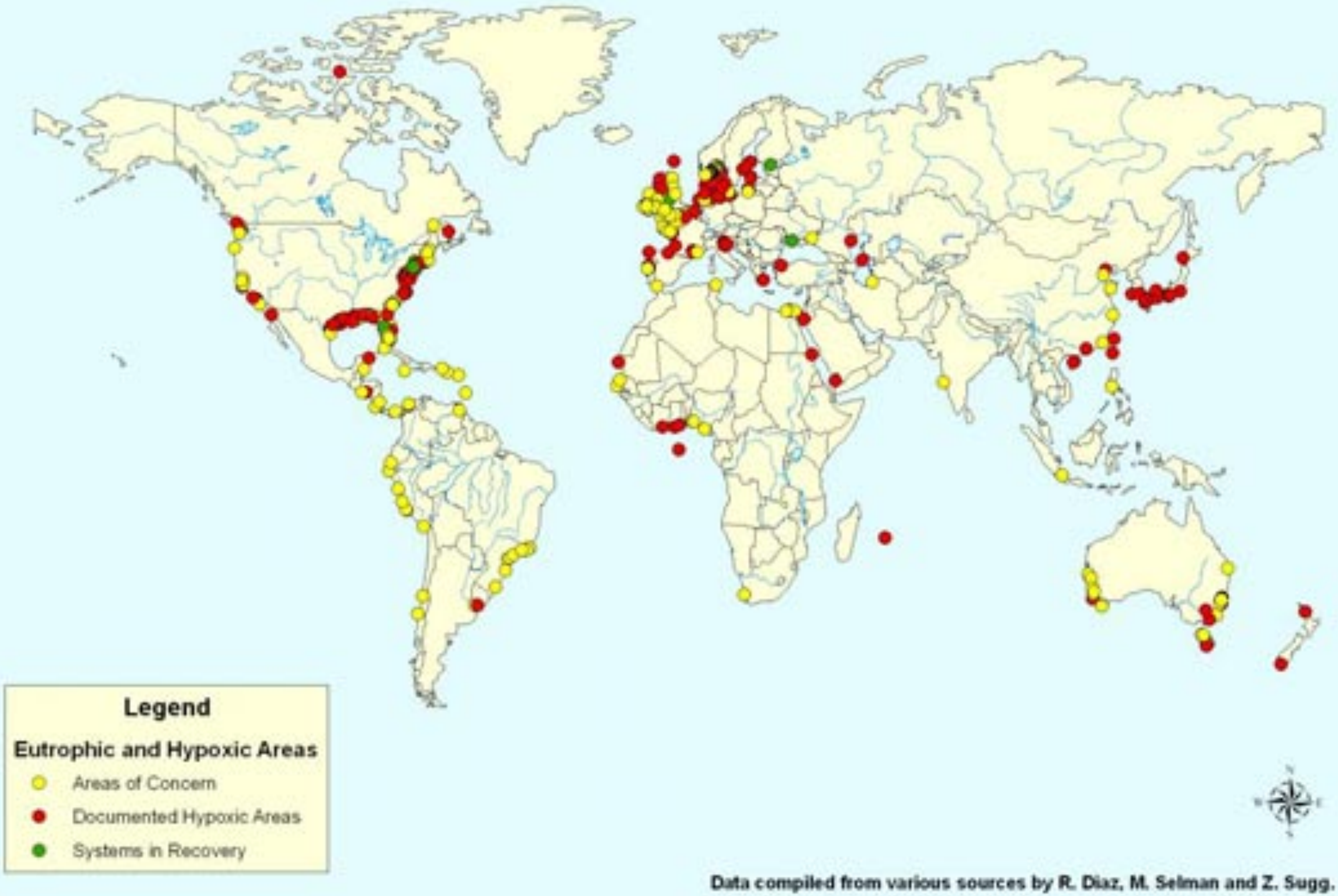
# How does extra N from fertilizers impact oceans?

- Eutrophication: increase in chemical nutrients (nitrogen & phosphorus) in an ecosystem
- Dead zones: zones where oxygen content is too low to support life.Often a result of eutrophication



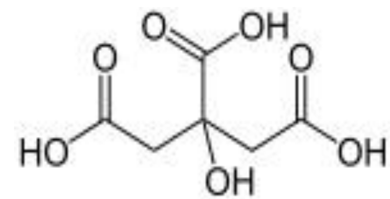
http://www.lakescientist.com/wp-content/uploads/2011/08/gulf-of-mexico.jpg

# World Hypoxic and Eutrophic Coastal Areas



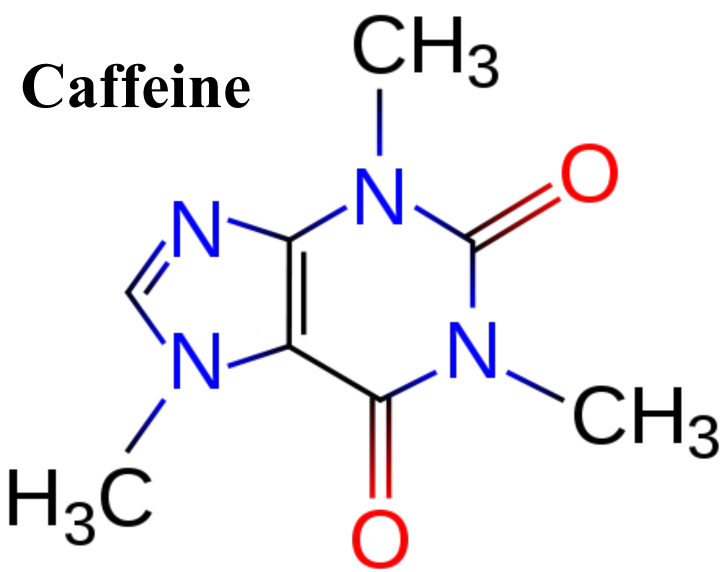
# Synthetic Chemicals

- Compounds synthesized by humans in the lab that are identical to those found in nature
- Examples: caffeine, citric acid



**Citric acid**

**Caffeine**

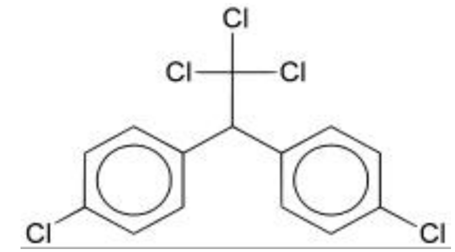


# Xenobiotic Chemicals

- Compounds created by humans that never before existed on earth
- May be toxic at very low concentrations

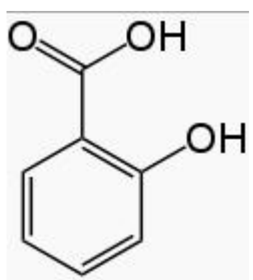
**(DDT)**

**d**ichloro**d**iphenyl**t**richloroethane



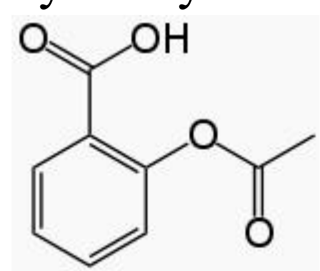

*Salix alba*

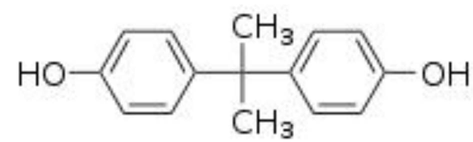
Salicylic acid




From willow tree

Aspirin
(acetylsalicylic acid)



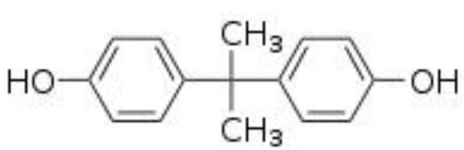




Bisphenol A
(BPA)

# Xenobiotic Chemicals

- Compounds invented by humans
  - Between 1957 and 2003, ACS recorded over 15 million new chemicals
  - ACS registers 70 new chemicals per hour
  - Less than 1% have been completely evaluated as potential health or ecological hazards

Bisphenol A (BPA)





Take home points from NPR article about BPA?

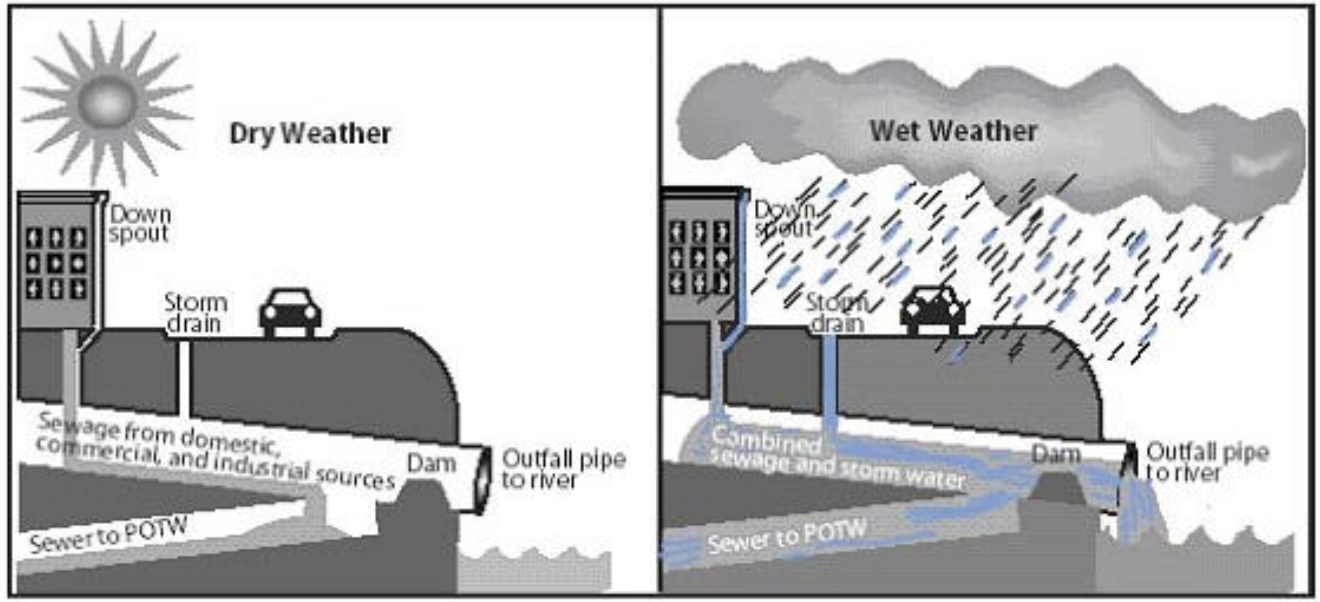
# Sources of Pollution

- Point Source Pollution
- Non Point Source Pollution

# Point Source Pollution

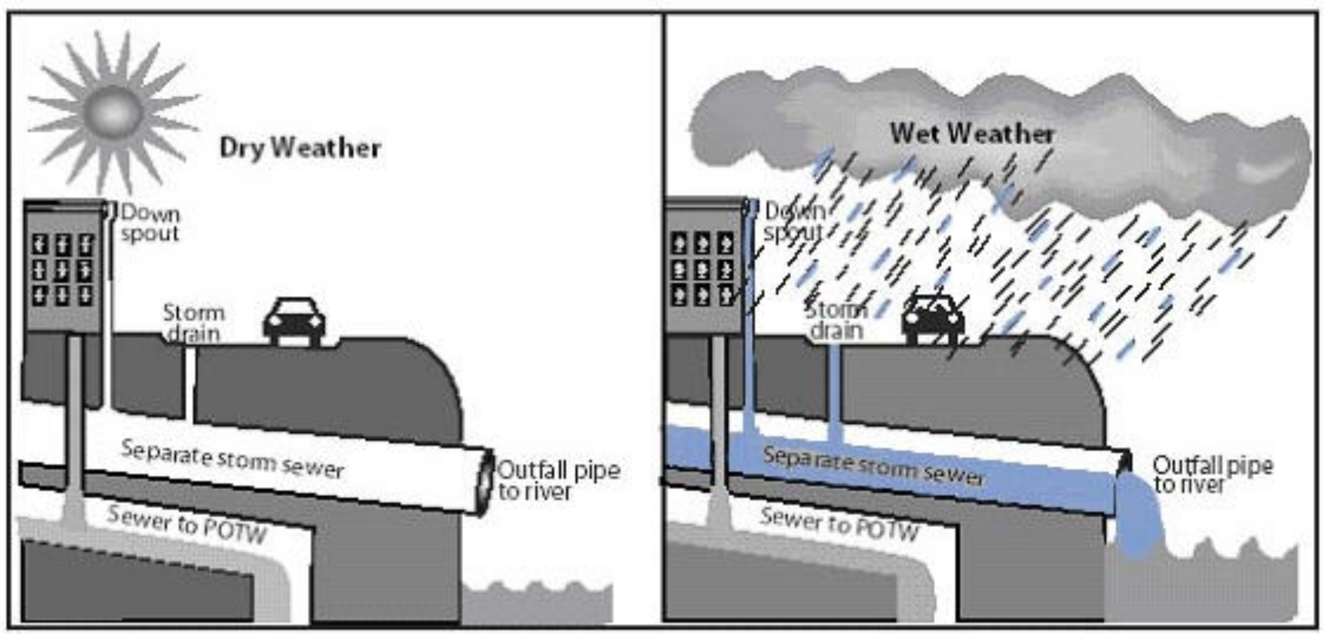
- Individual & identifiable pollution source
- Discharged from a specific facility at a specific time
- Eg. Industry or sewage treatment where discharge is readily identifiable, often a single pipe or smokestack

http://blog.enn.com/wp-content/uploads/2009/06/smoke-stack-jj-00111.jpg combined




# Point Source Pollution: <u>Combined Sewage Outflow</u>

separate



# Combined Sewage Outflow, NE Seattle



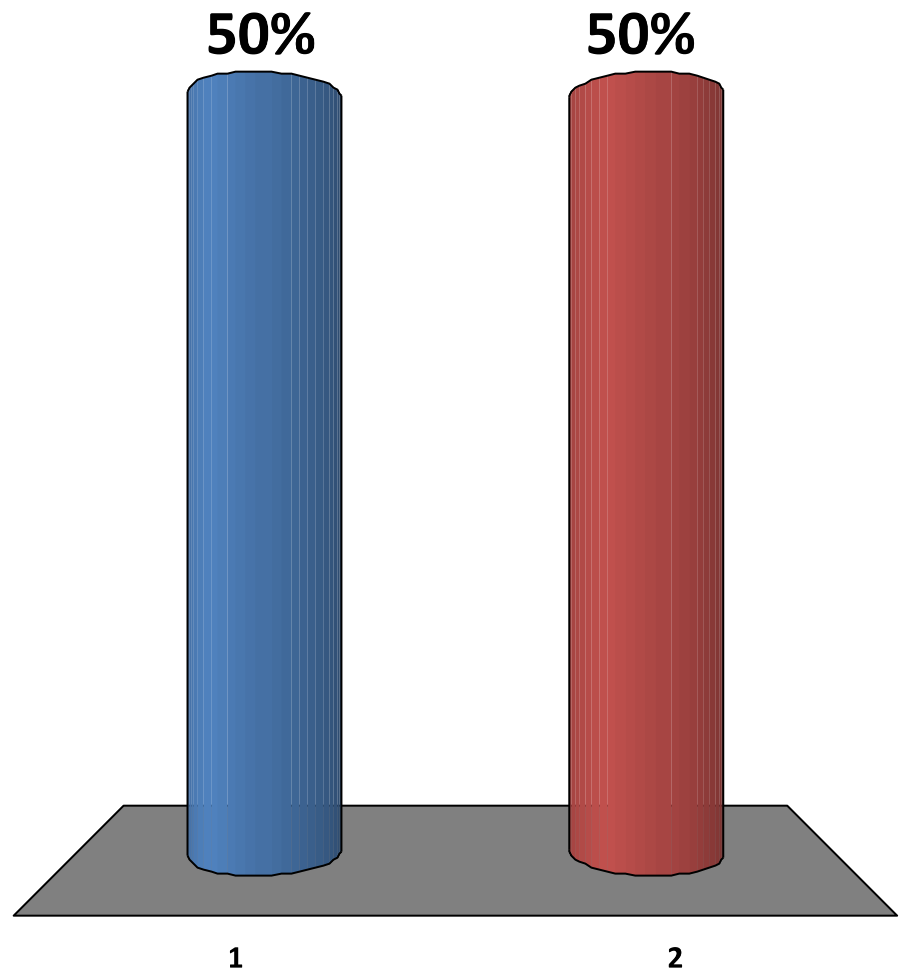
http://www.kingcounty.gov/environment/wastewater/CSOstatus/Overview.aspx

# Nonpoint Source Pollution

- Any source of pollution that does not meet the legal definition of "point source"
- From many diffuse sources
  - in water: rain water moves overland and picks up pollutants, eventually depositing these pollutants into lakes, rivers, oceans
  - In air: examples: exhaust from individual cars or smoke from individual chimneys

# Fertilizer runoff from farms leads to eutrophication in oceans. This runoff is a form of:

1. Point source pollution
2. Non-point source pollution



# Lecture Outline

- What is pollution?
- What are the sources of pollution?
- What are the effects of pollution (toxicology)?
- One solution

In Rachel Carson's *Silent Spring*, scientists in the 1950s revealed that spraying DDT to combat Dutch Elm disease did what?

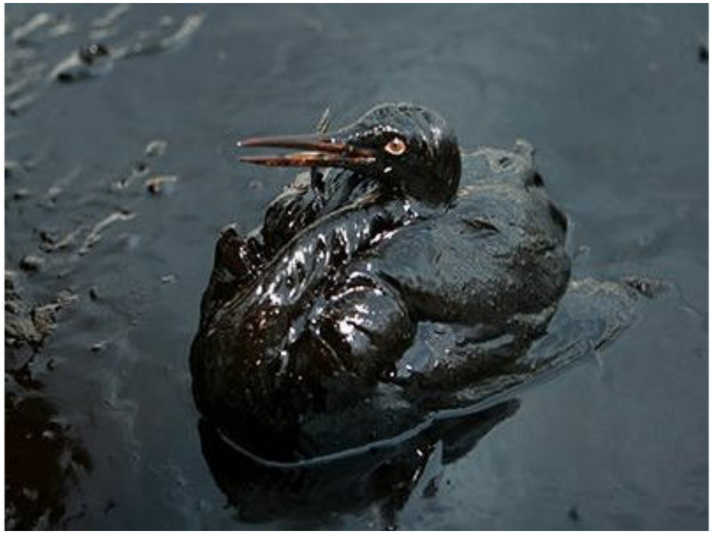
1. Actually killed the trees
2. Stressed the trees, causing them to draw more water, which led to less water in rivers, brooks, and streams
3. Led to dramatic reductions in bird populations
4. Killed the beetles responsible for Dutch elm disease with no further environmental consequences
5. Was the most effective way to protect elms from this disease

# By what method did DDT harm robins?

1. When robins perched on trees, DDT entered their blood stream through their skin and poisoned them
2. Robins ate DDT-contaminated worms, which were contaminated by eating soil made from elm leaves contaminated with DDT
3. Robins returned in the spring at the same time the trees were sprayed, and inhaled the DDT fumes
4. Robins depended on the beetles which carried dutch elm disease as food. No more beetles = no more robins.

# Levels of harm to organisms

<u>Acute toxic exposure</u> = organisms die immediately

Examples: Fish kills due to industrial discharge, oiled birds in an oil spill, robins die from DDT poisoning

# Levels of harm to organisms

Non-lethal affects may still harm organisms by changing their biology or behavior

http://www.naturesound.com/birds/hires/robin.jpg

http://www.rlrouse.com/pic-of-the-day/bald-eagle.jpg

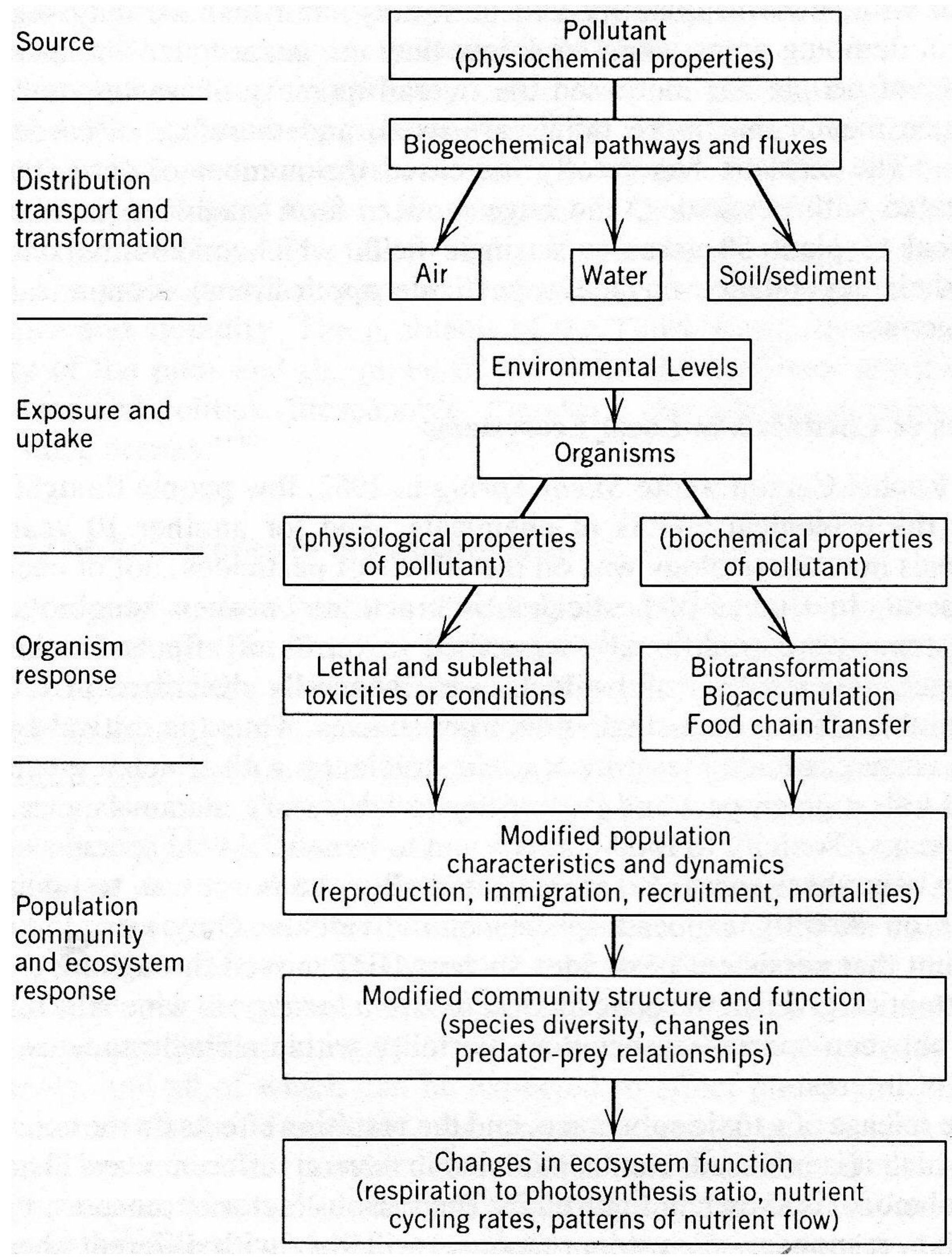
http://news.discovery.com/animals/2009/09/15/bass-278x225.jpg

Examples: DDT affects reproduction in birds, endocrine disrupters (eg birth control pills) lead to male fish developing ovaries

# Ecosystem Effects of a Chemical

Its complicated…….

Ecosystem effects must be determined separately for each chemical and for each ecosystem.



# How are chemicals degraded? Why are some persistent in the environment?

- Hydrolysis
  - Chemical process → a molecule is split into parts when a water molecule is added
  - Requires water
- Photodegradation
  - Sunlight breaks down the chemical
  - Requires sunlight
- Biodegradation
  - Chemical degradation of materials by organisms, usually microorganisms
  - Requires water and usually, oxygen

A chemical is persistent in the environment if it is not degraded by these methods!

Chemicals may be more persistent in some environments

# Biomagnification

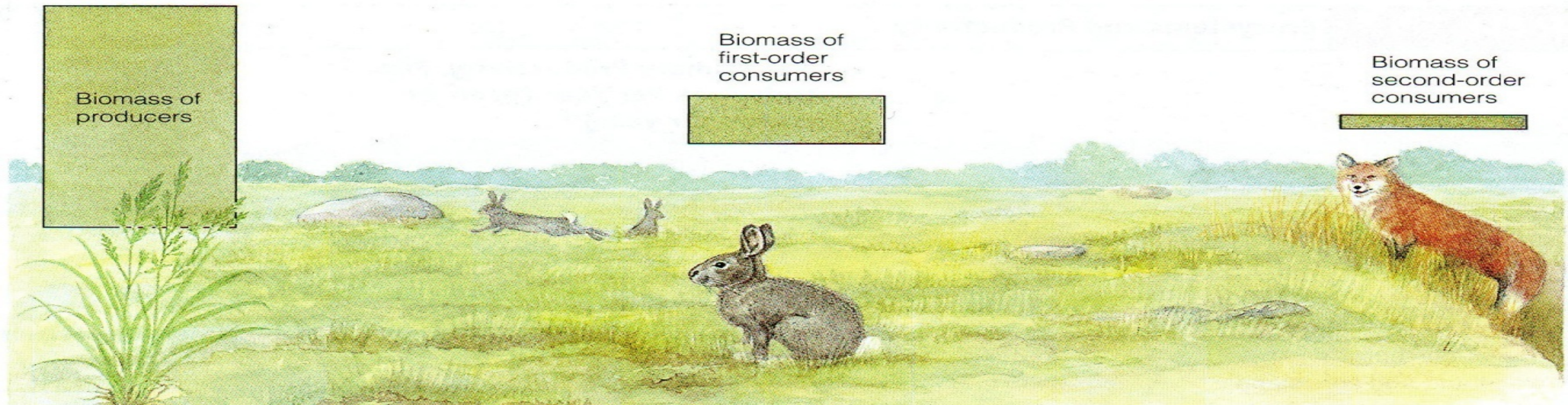
Persistent chemicals become more concentrated as they move up the food chain

# Why does biomagnification occur?

- Hard to degrade some xenobiotic chemicals because organisms lack previous exposure and do not have specific detoxification and excretion mechanisms.

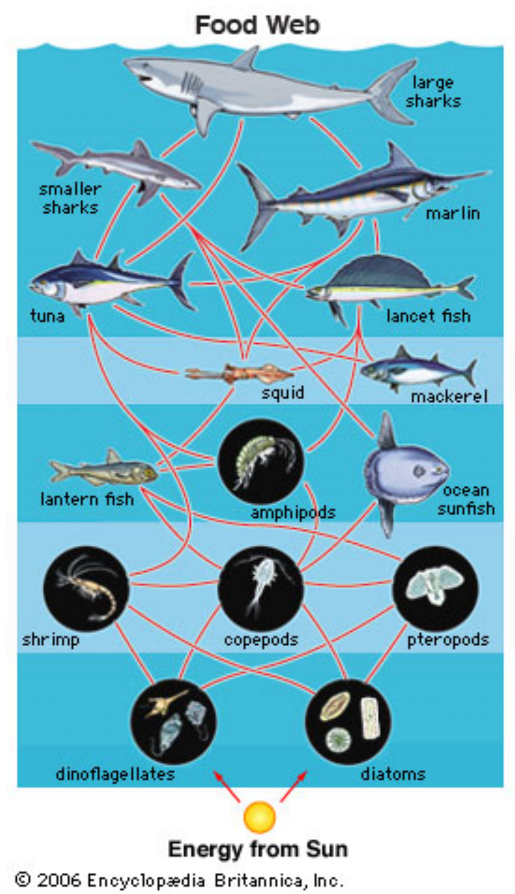
- Chemicals not degraded accumulate in the body. For example, DDT accumulates in fat.

- As one organism eats another, all the accumulated chemical stored in the prey becomes stored in the predator.



# The image below shows an ocean food chain. Due to biomagnification, mercury concentrations are likely to be highest in:

1. Fish low on the food web like shrimp
2. Fish in the middle of the food web like tuna and squid
3. Fish high on the food web like sharks



# Biomagnification in *OUR* foodchain

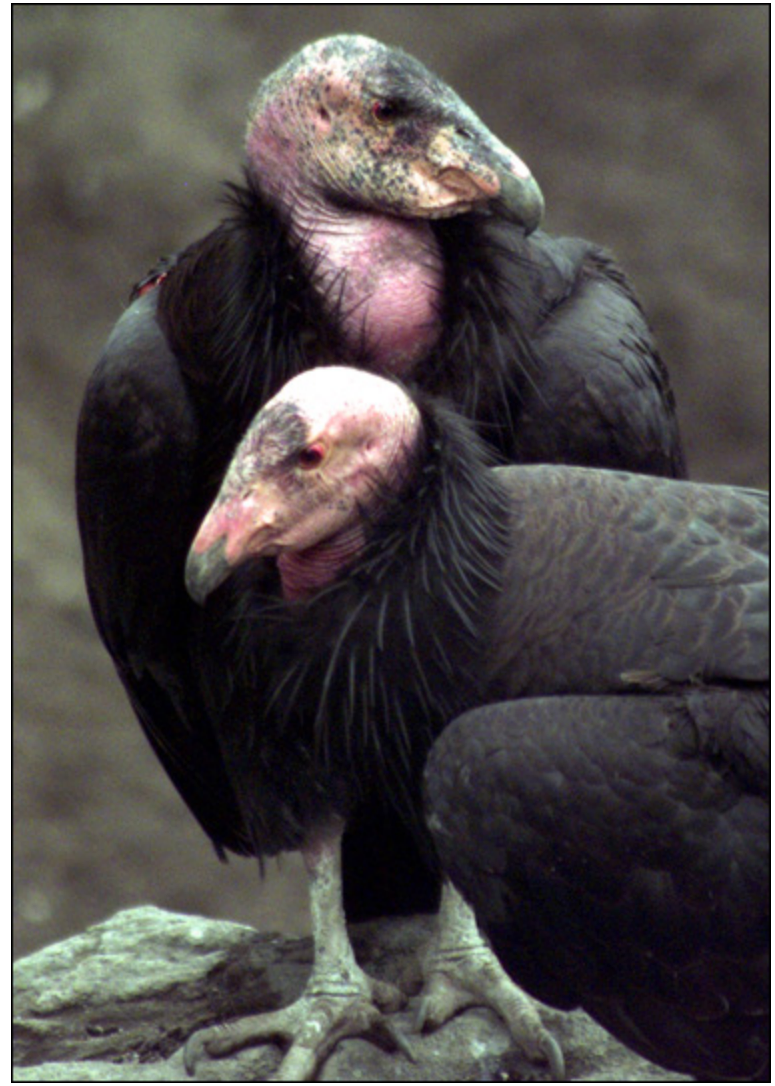
"By following these  recommendations for selecting and eating fish or shellfish, women and young children will receive the benefits of eating fish and be confident that they have reduced their exposure to the harmful effects of mercury.

1) Do not eat Shark, Swordfish, King Mackerel, or Tilefish because they contain high levels of mercury.
2) Eat up to 12 ounces (2 average meals) a week of a variety of fish and shellfish that are lower in mercury."

**-2004 EPA / FDA advice for: pregnant women, nursing mothers and kids**

# Back to DDT

- Banned in the US since 1972
- Extremely persistent in the environment
- California condor story
  - Lead shot
  - Biomagnification
  - Captive rearing
  - Now DDT trouble



http://animal.discovery.com/guides/endangered/birds/gallery/california_condor.jpg

# DDT and malaria

- Malaria is a public health challenge
  - In 2008, 243 million cases with 863, 000 deaths (WHO)
  - 89% of these deaths are in Africa
- DDT is used to fight the disease
  - Powerful insecticide against mosquitoes that carry the disease
  - istance, often due agricultural use


We know the side effects. Should DDT be used? What do you think?

http://www.doctorswithoutborders.org/images/news/malaria/malaria_header_550x367.jpg

# Should DDT be used to fight malaria?

1. Absolutely
2. No, never
3. Under some circumstances

# Lecture Outline

- What is pollution?
- What are the sources of pollution?
- What are the effects of pollution (toxicology)?
- One solution

"You cannot run a linear system on a finite planet indefinitely." –*Story of Stuff*


## Soil Nutrient Example

**THEN**

nutrients in soil → nutrients in food → nutrients in human waste → nutrients in soil

**NOW**

nutrients in soil → nutrients in food → nutrients in human waste

“You cannot run a linear system on a finite planet indefinitely.” - *Story of Stuff*


- In nature, there is no waste. No linear system, but a cycle of nutrient flows.
- Waste of one organism is food for another
- Biological and chemical processes break everything down into nutrients used again and again
- Can we design a industrial process that mimics nature?

# According to McDonough and Braungart

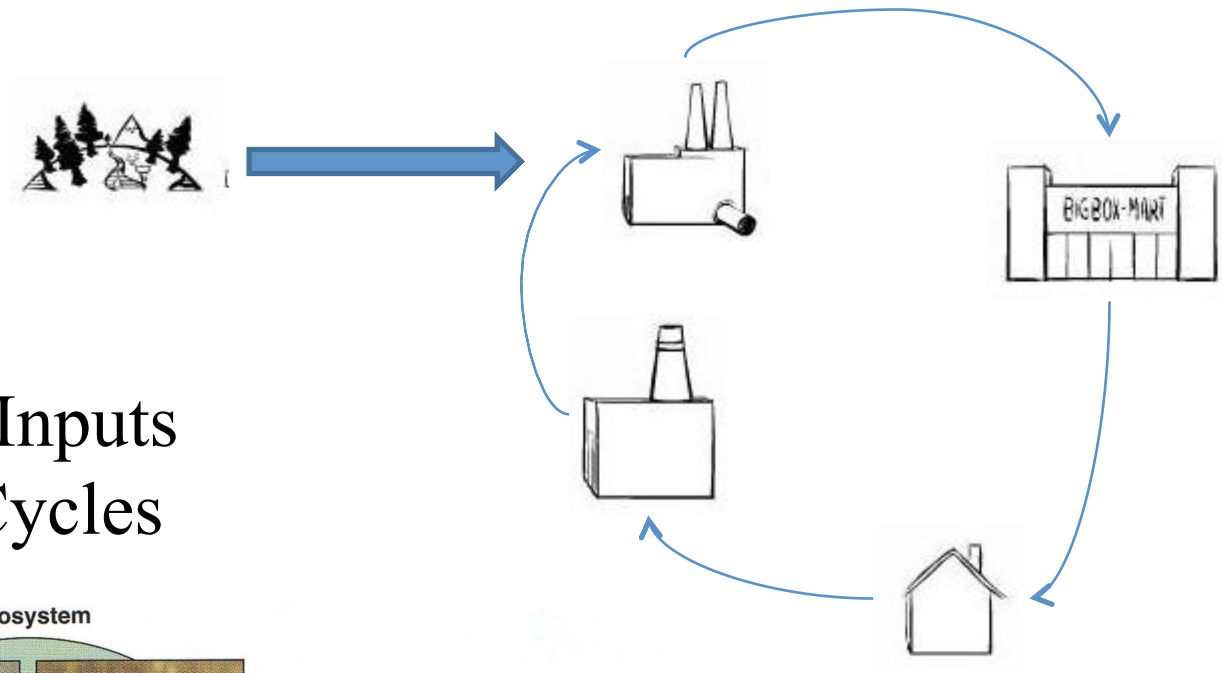
1. We can design an industrial process that mimics nature
2. We cannot design such a system

In the *Cradle to Cradle* chapter titled "Waste Equals Food," the authors claim that there are currently two types of metabolisms on the planet which are:

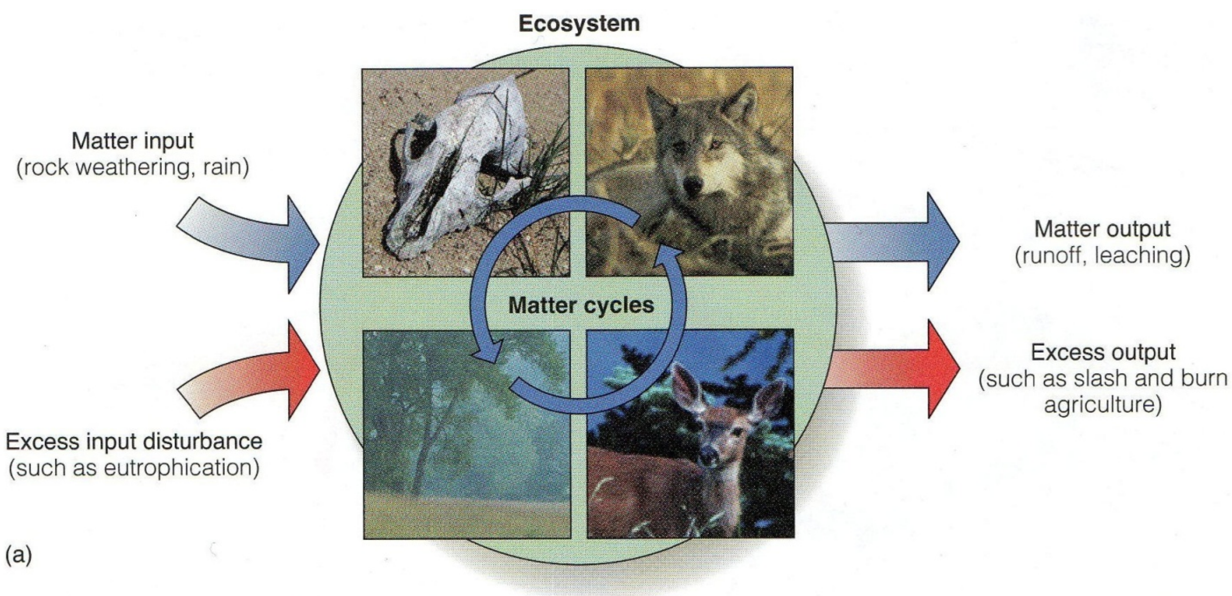
1. Ecological and internal biological metabolism
2. Political and ecological metabolism
3. Technical and biological metabolism
4. Psychological and biological metabolism

# Two Ways to Design Products

## Closed-Loop Technical Cycles




## Biodegradable Inputs to Biological Cycles



# Biological Nutrients (McDonough and Brangart)

- Designed to return to the biological cycle
- Compostable—designed to be consumed by microorganisms

UW Housing and Food Services Greenware cups

# Technical Nutrients (McDonough and Brangart)

- A product that can be broken down and reused indefinitely in industrial cycles, to be made and remade
- We currently do not think this way, manufacture this way, recycle this way.

# "Monstrous Hybrids" (McDonough and Brangart)

- Mix of materials both technical and biological
- Neither the technical nor the biological materials can be salvaged after their current lives
- Conventional leather shoe

# Other thoughts on McDonough and Brangart?

# Life Cycle Analysis/ Assessment

- Aims to understand the environmental impact of a product throughout its lifespan—including all raw material production, manufacturing, transport, use, and disposal
- Goal is to compare different products or services so one can chose the best one


http://www.interfaceglobal.com/getdoc/82768bfc-6c67-4b1e-a594-35b2f8b187c5/LCA_diagram1.aspx