Ecosystems:

Where they came from, how they work, and why they stick around

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Entropy:

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Entropy:

state of disorder, low energy

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High Energy → **Low Energy**

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Order → Disorder

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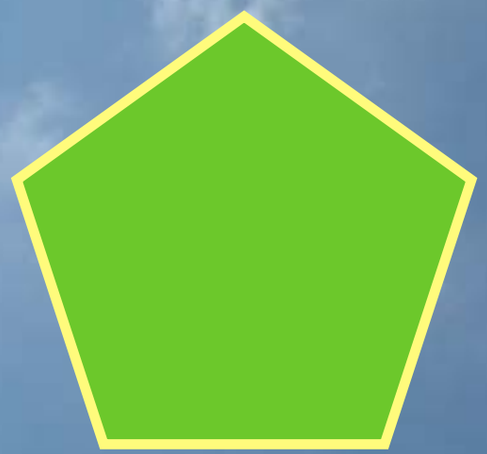

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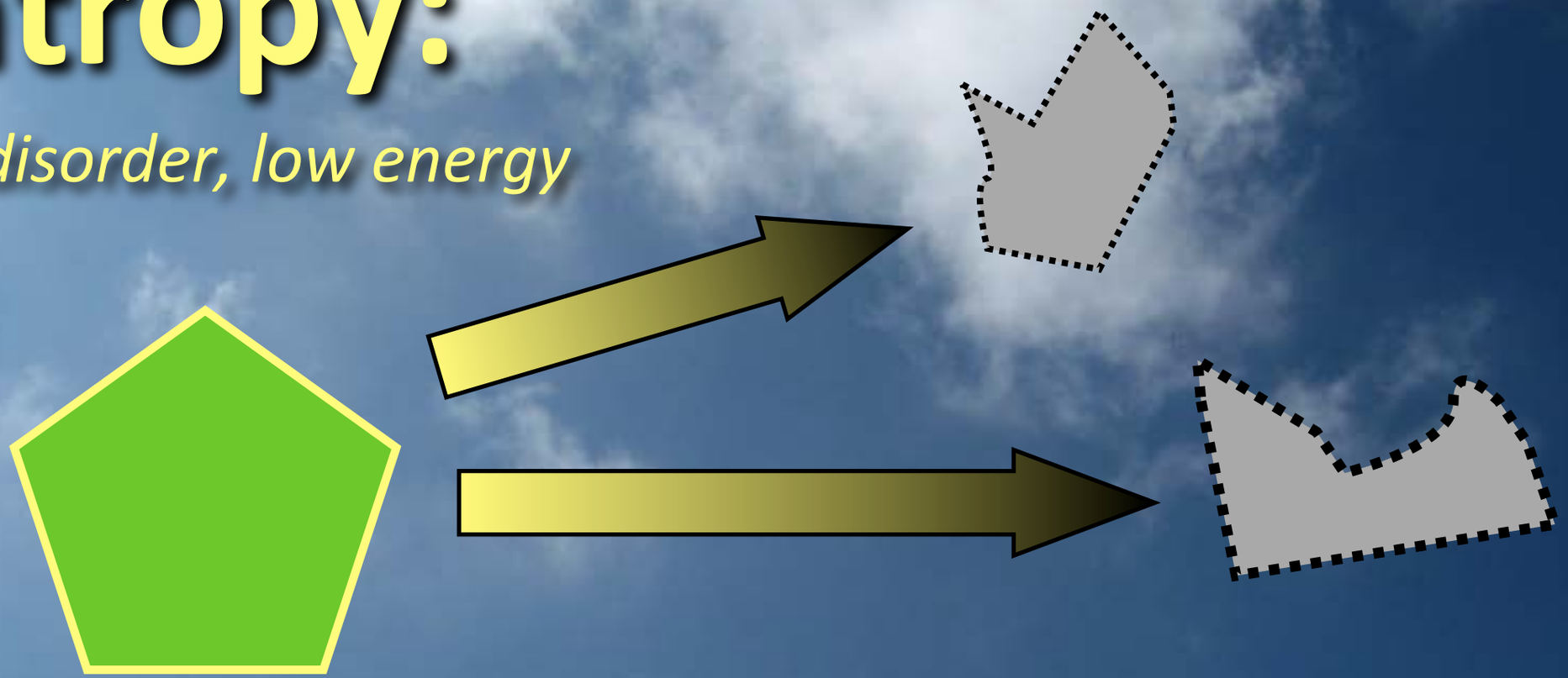

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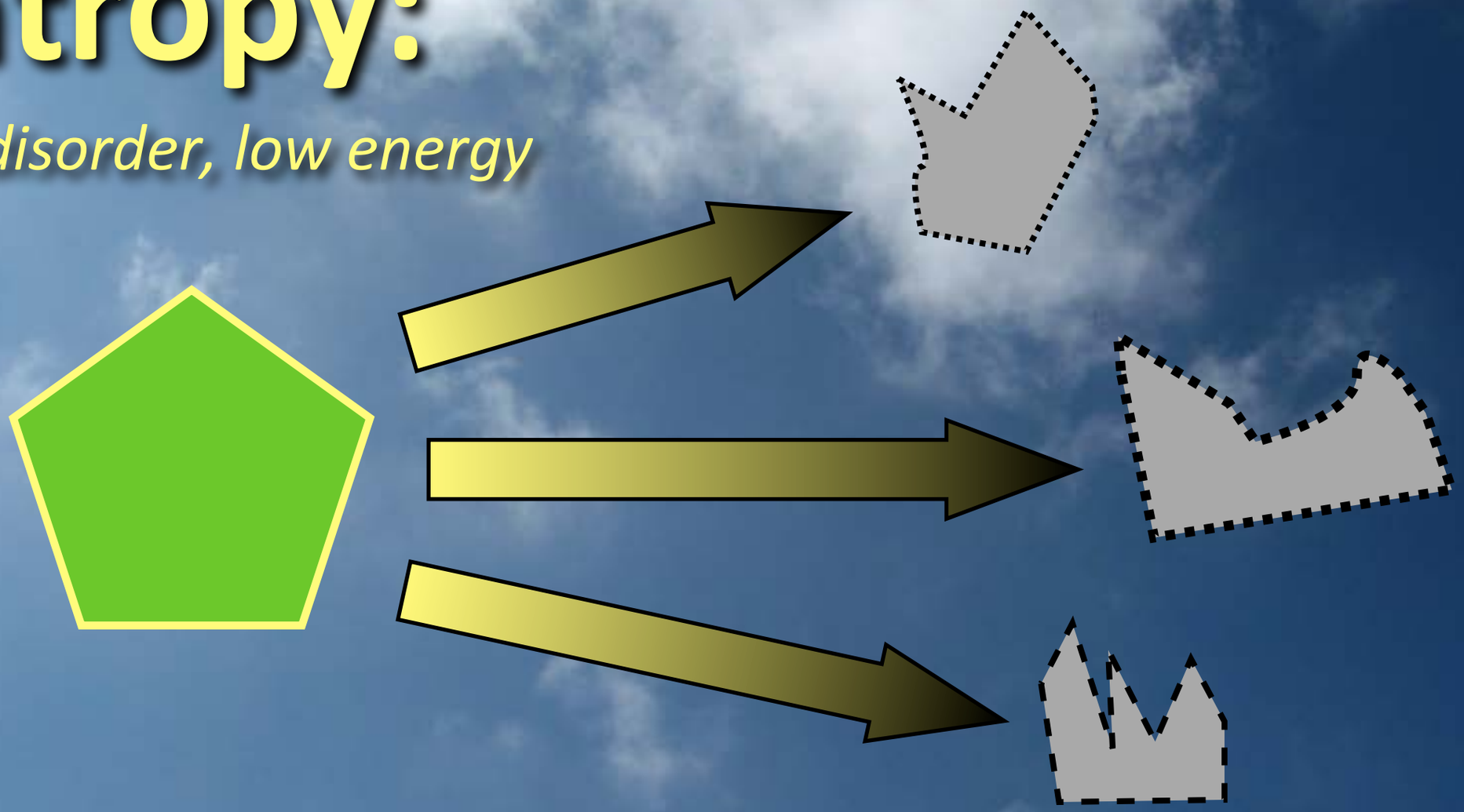

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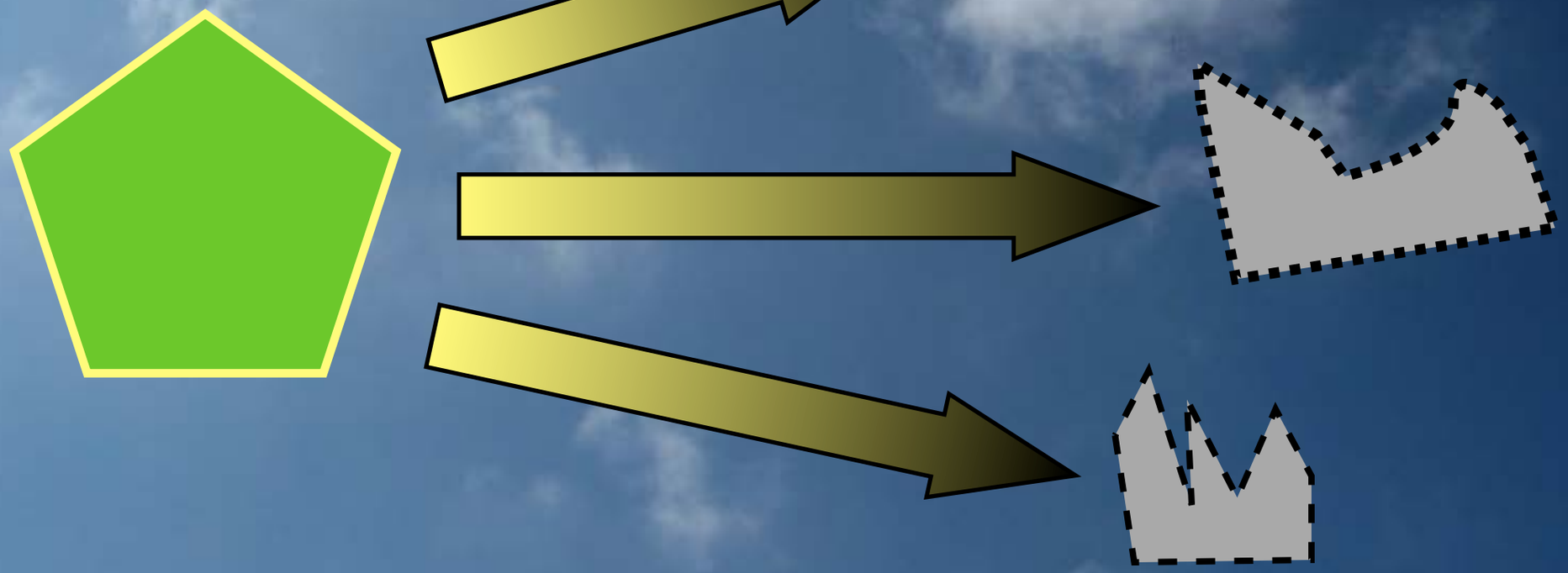

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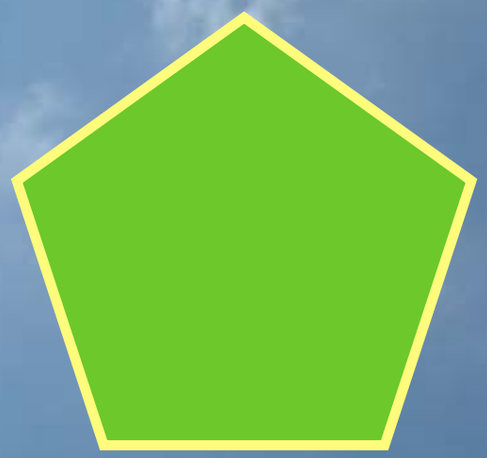

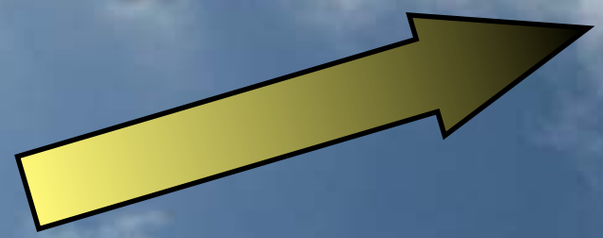

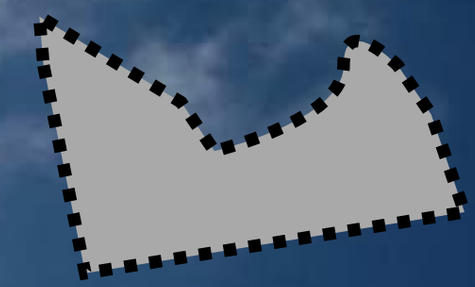

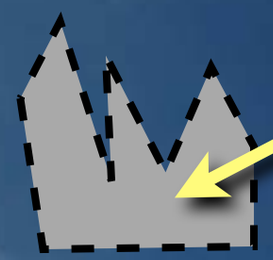

Disorganization of matter

Loss of energy

High Energy → **Low Energy**

Order → **Disorder**

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How do living systems overcome entropy?

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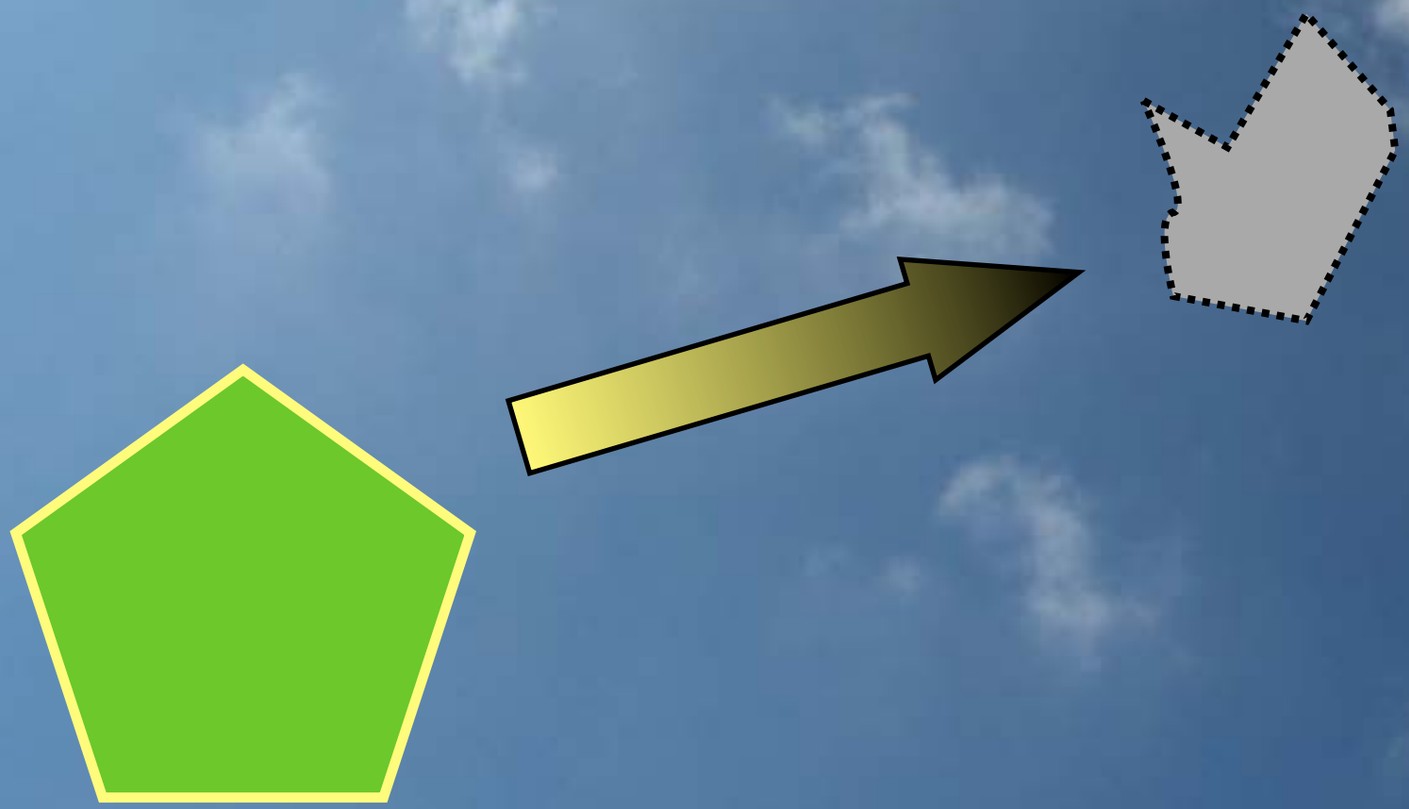

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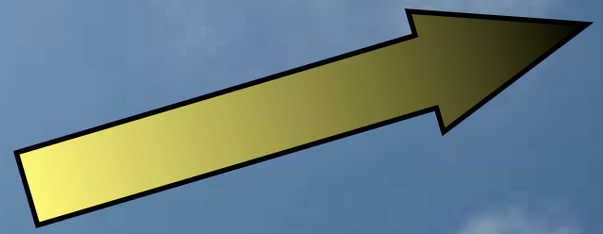

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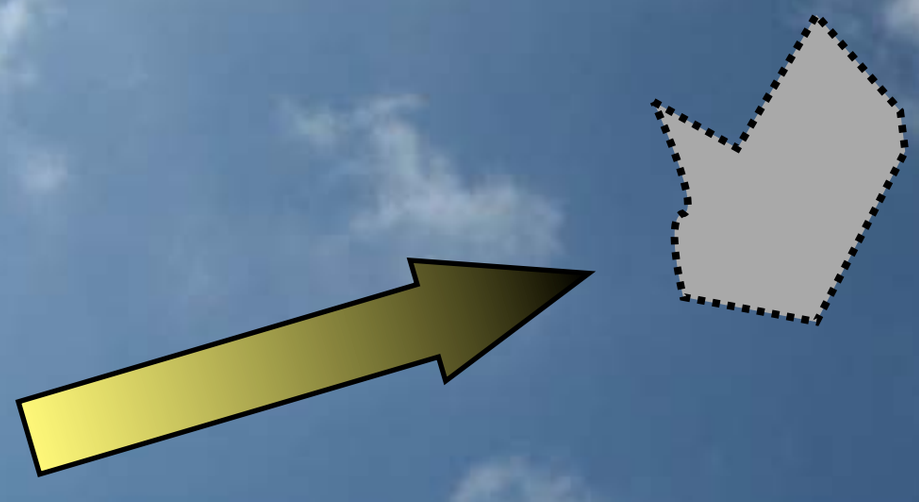
How do living systems overcome entropy?

Entropy is an average outcome



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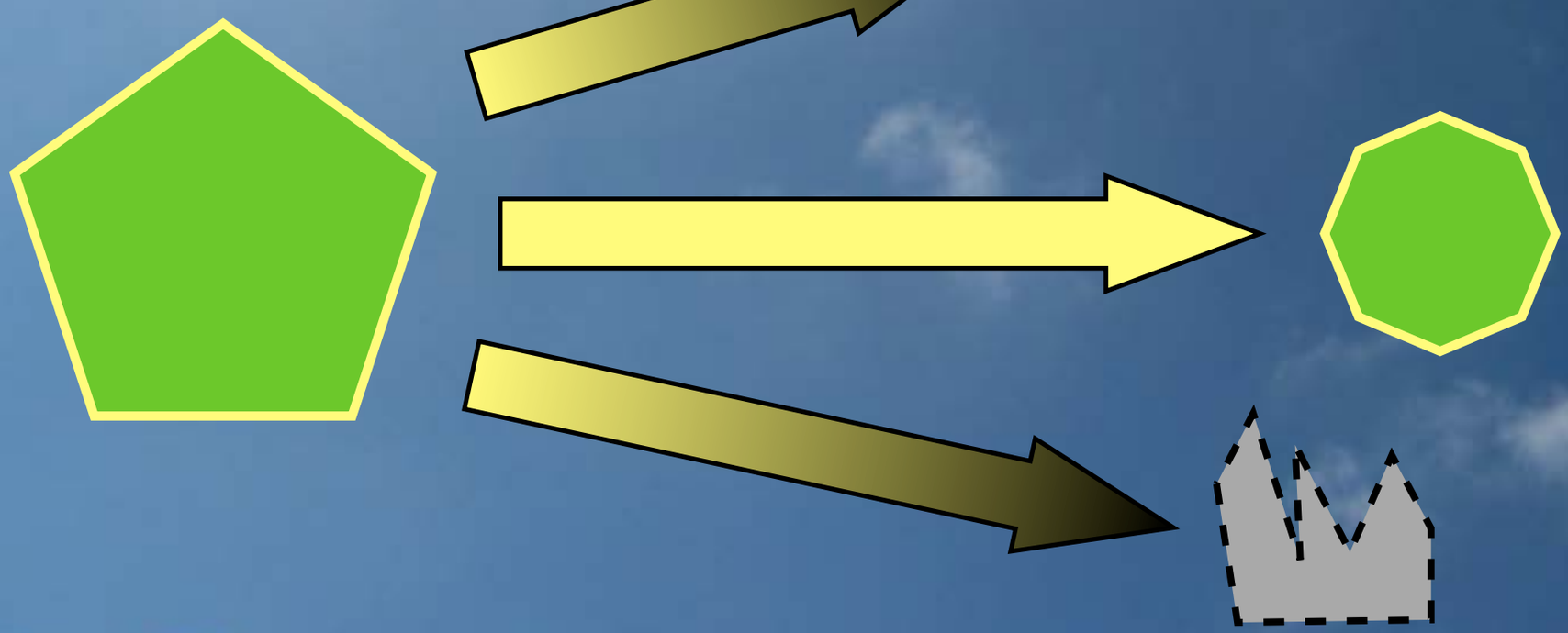

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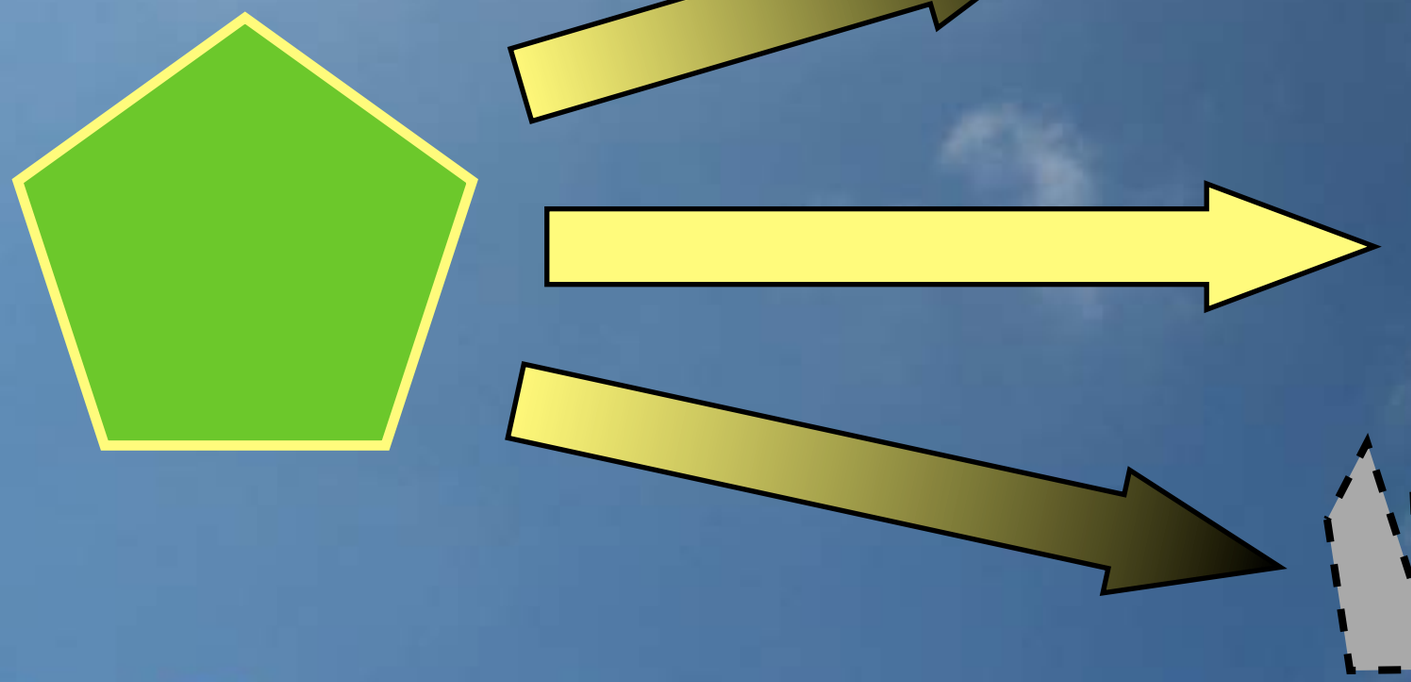

Occasionally, random events can lead to increases in organization and/or energetic state

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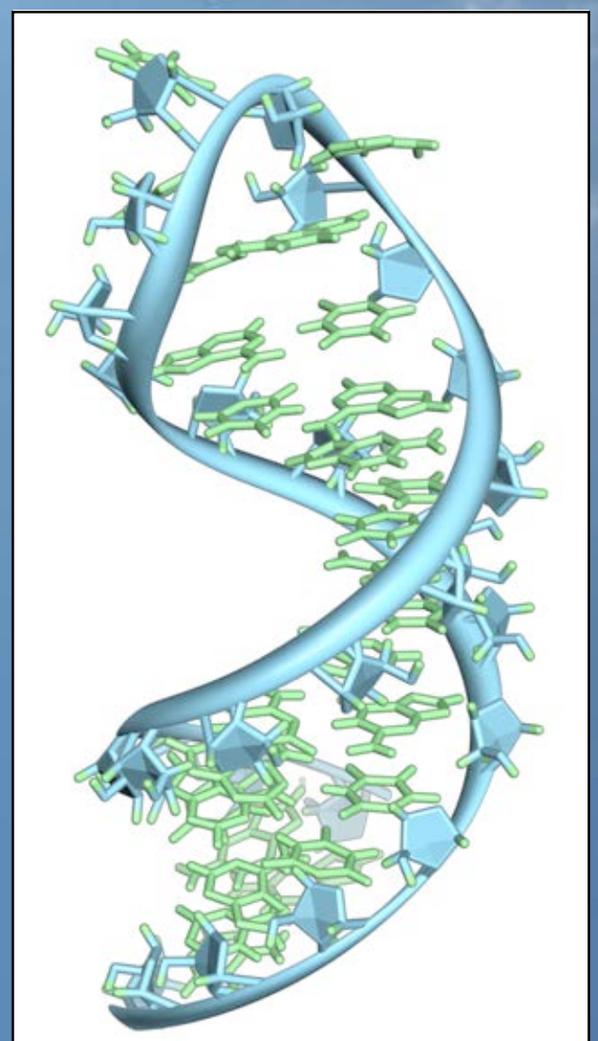
RNA origin of life:

RNA



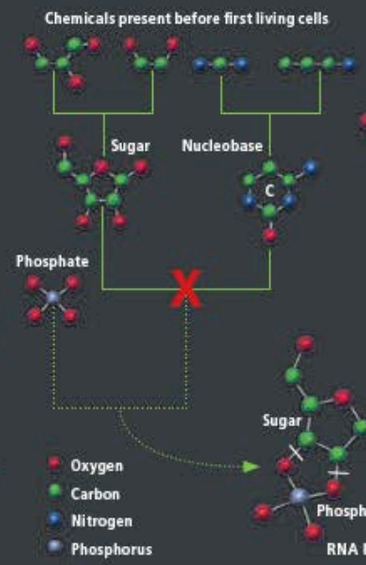
[BUILDING BLOCKS]

FIRST GENETIC MOLECULES

The first entities on earth capable of reproducing and evolving probably carried their genetic information in some molecule similar to RNA, a close relative of DNA. Both DNA and RNA are chains of units called nucleotides (*highlighted, left*), so a major question is how nucleotides first arose from simpler chemicals. The three components of a nucleotide—a nucleobase, a phosphate and a sugar—can each form spontaneously, but they do not readily join together in the right way (*center*). Recent experiments, however, have shown that at least two types of RNA nucleotides, those containing the nucleobases called C and U, could arise through a different route (*far right*). (In modern organisms, RNA nucleobases come in the four types A, C, G and U, the letters of the genetic alphabet.)

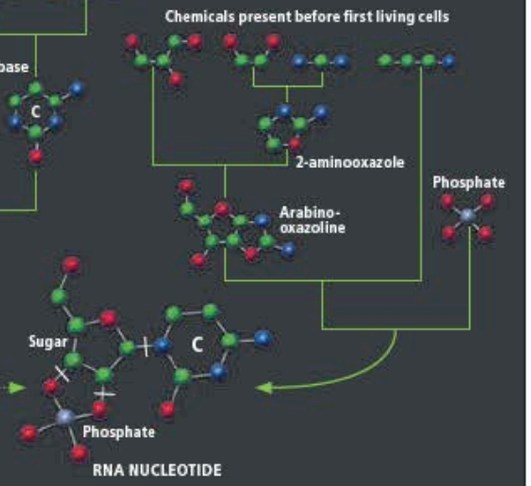
FAILED NUCLEOTIDES

Chemists have long been unable to find a route by which nucleobases, phosphate and ribose (the sugar component of RNA) would naturally combine to generate quantities of RNA nucleotides.



A NEW ROUTE

In the presence of phosphate, the raw materials for nucleobases and ribose first form 2-aminooxazole, a molecule that contains part of a sugar and part of a C or U nucleobase. Further reactions yield a full ribose-base block and then a full nucleotide. The reactions also produce "wrong" combinations of the original molecules, but after exposure to ultraviolet rays, only the "right" versions—the nucleotides—survive.



Sources: 1, 2

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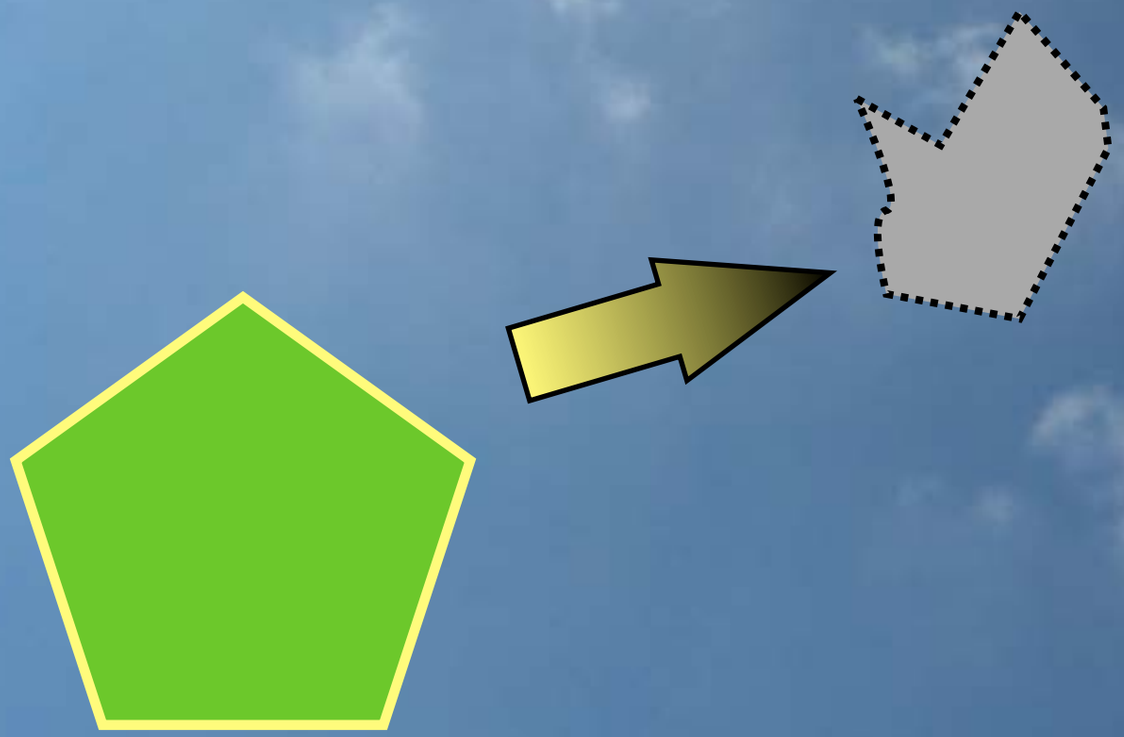

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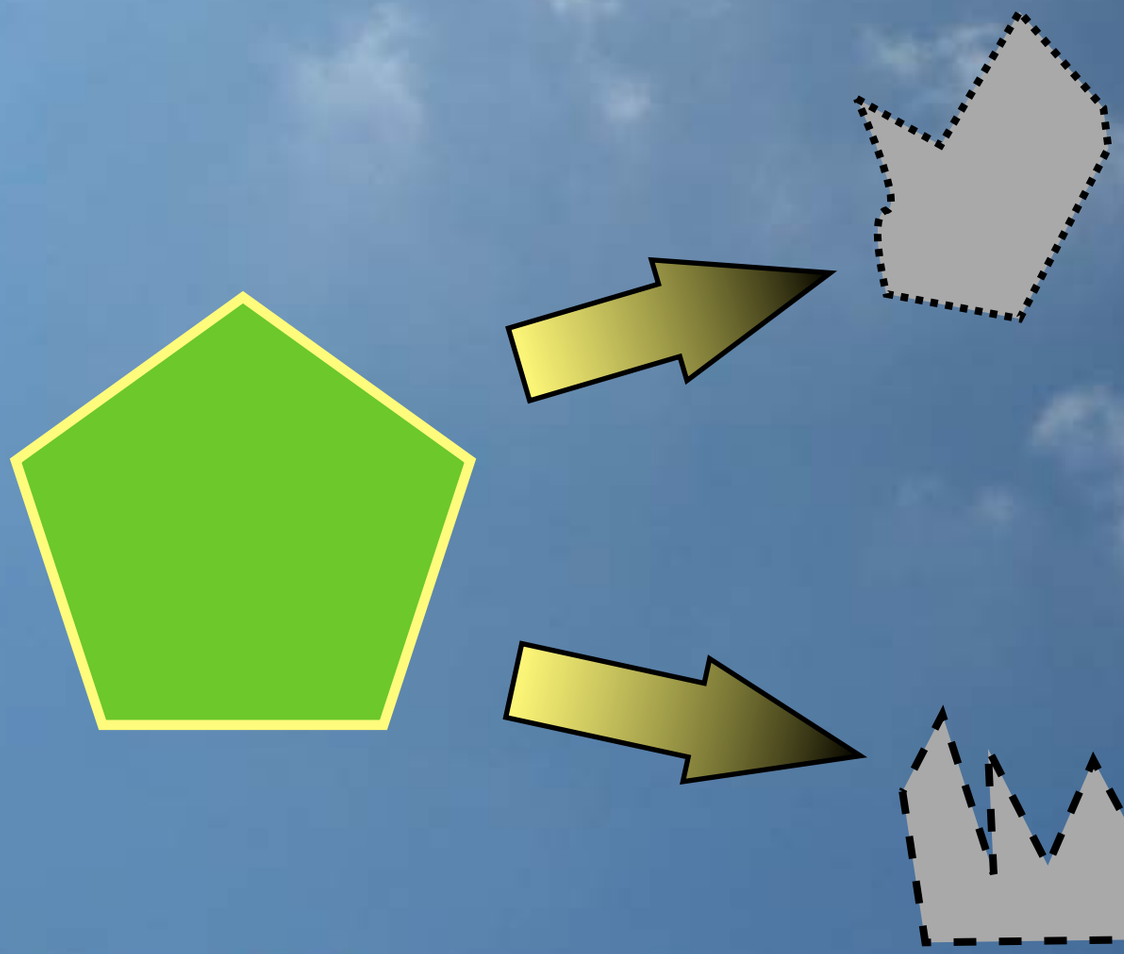

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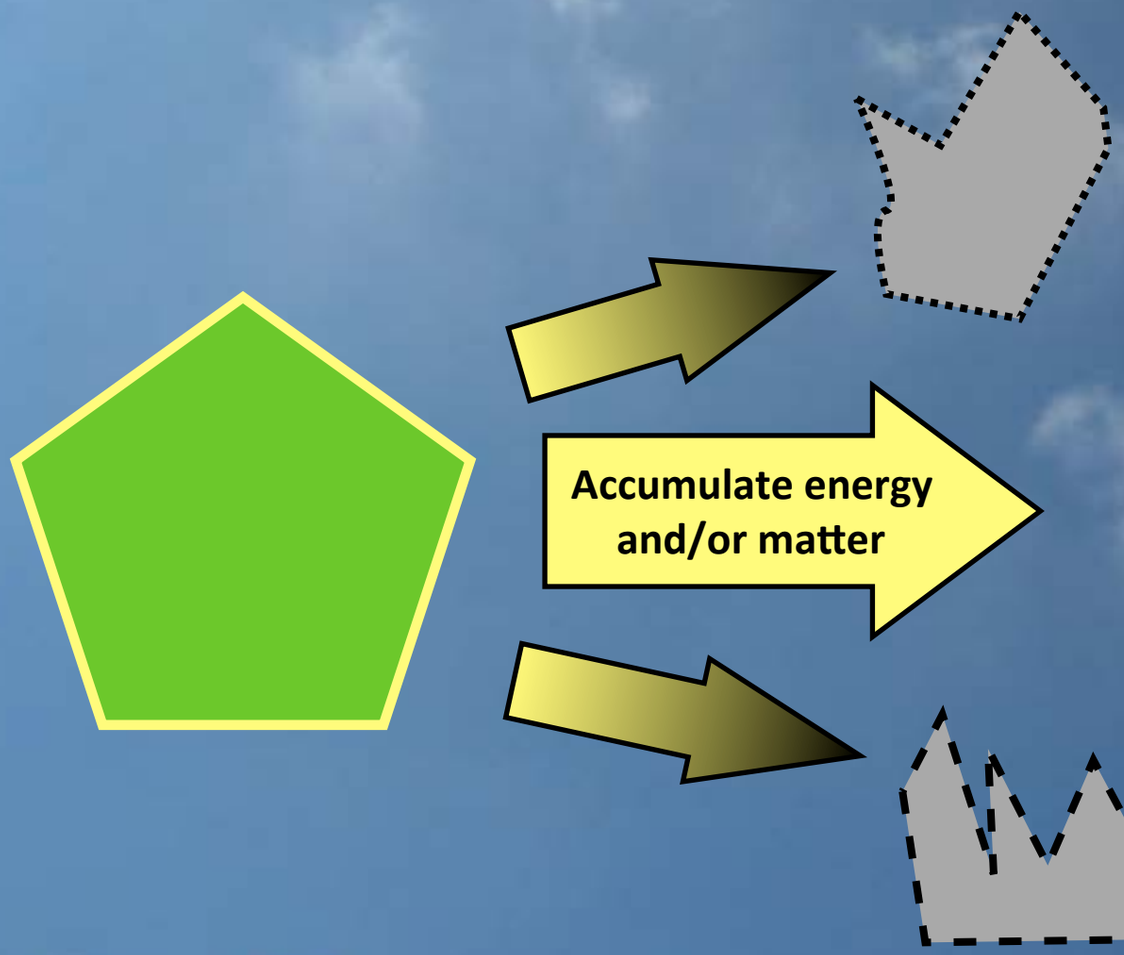

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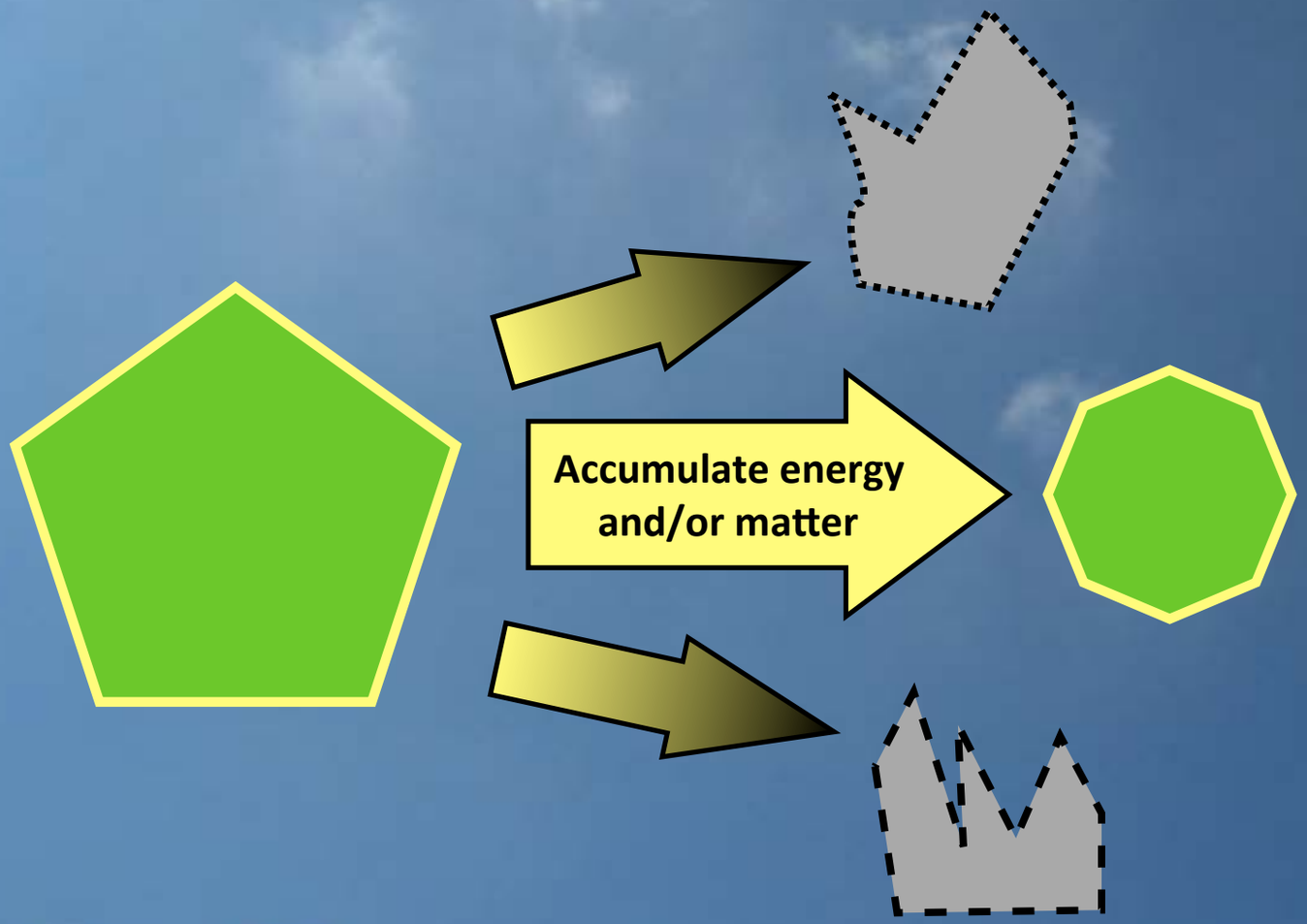

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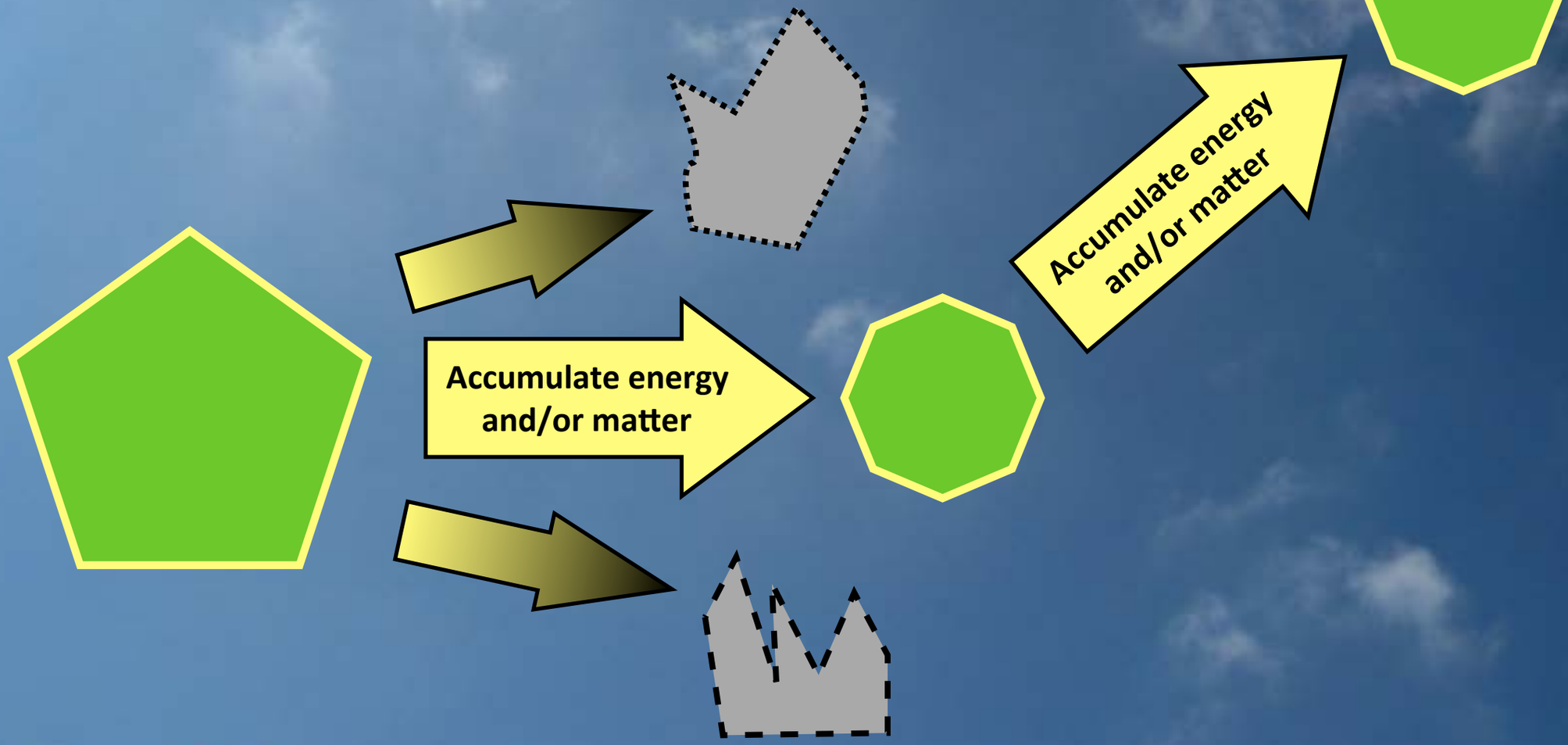

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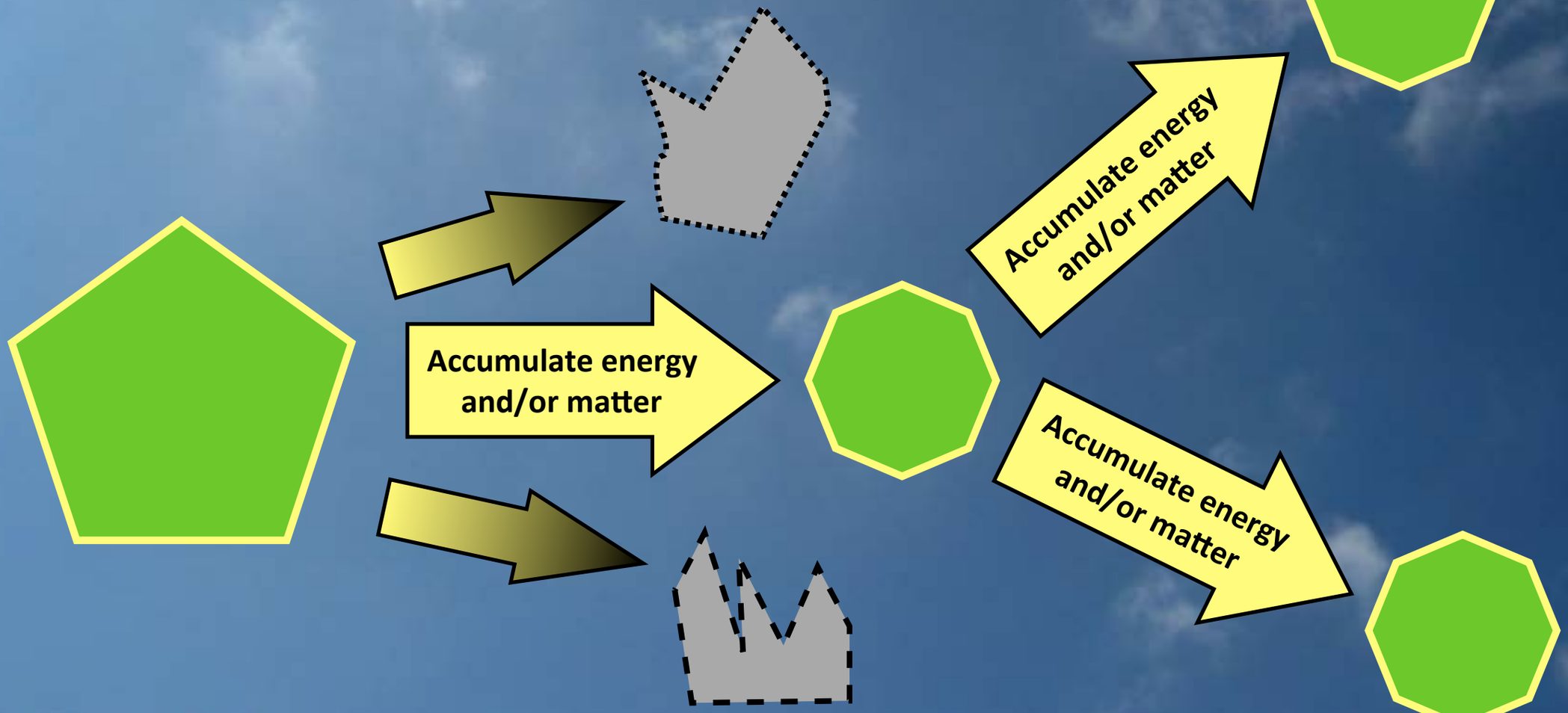

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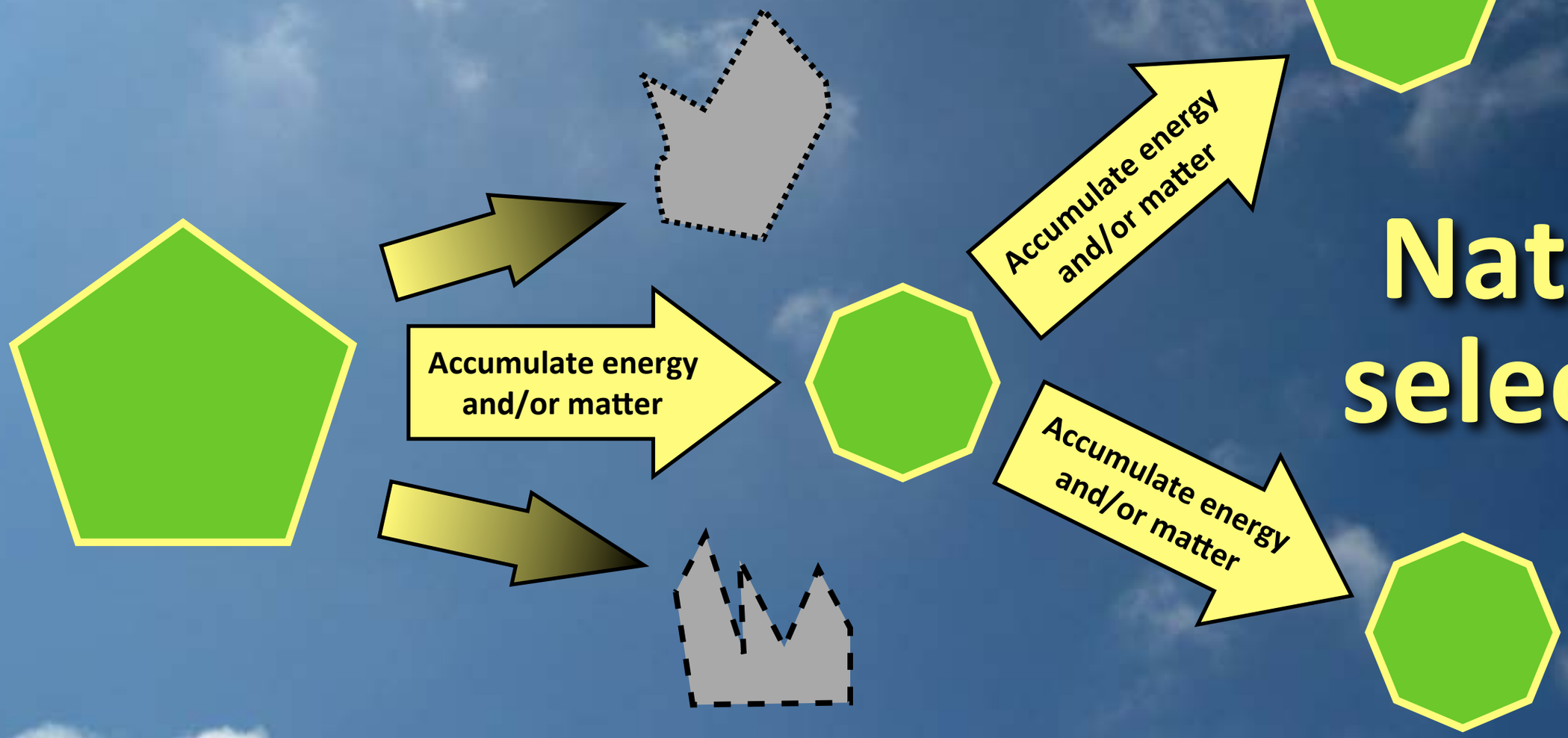

Natural selection

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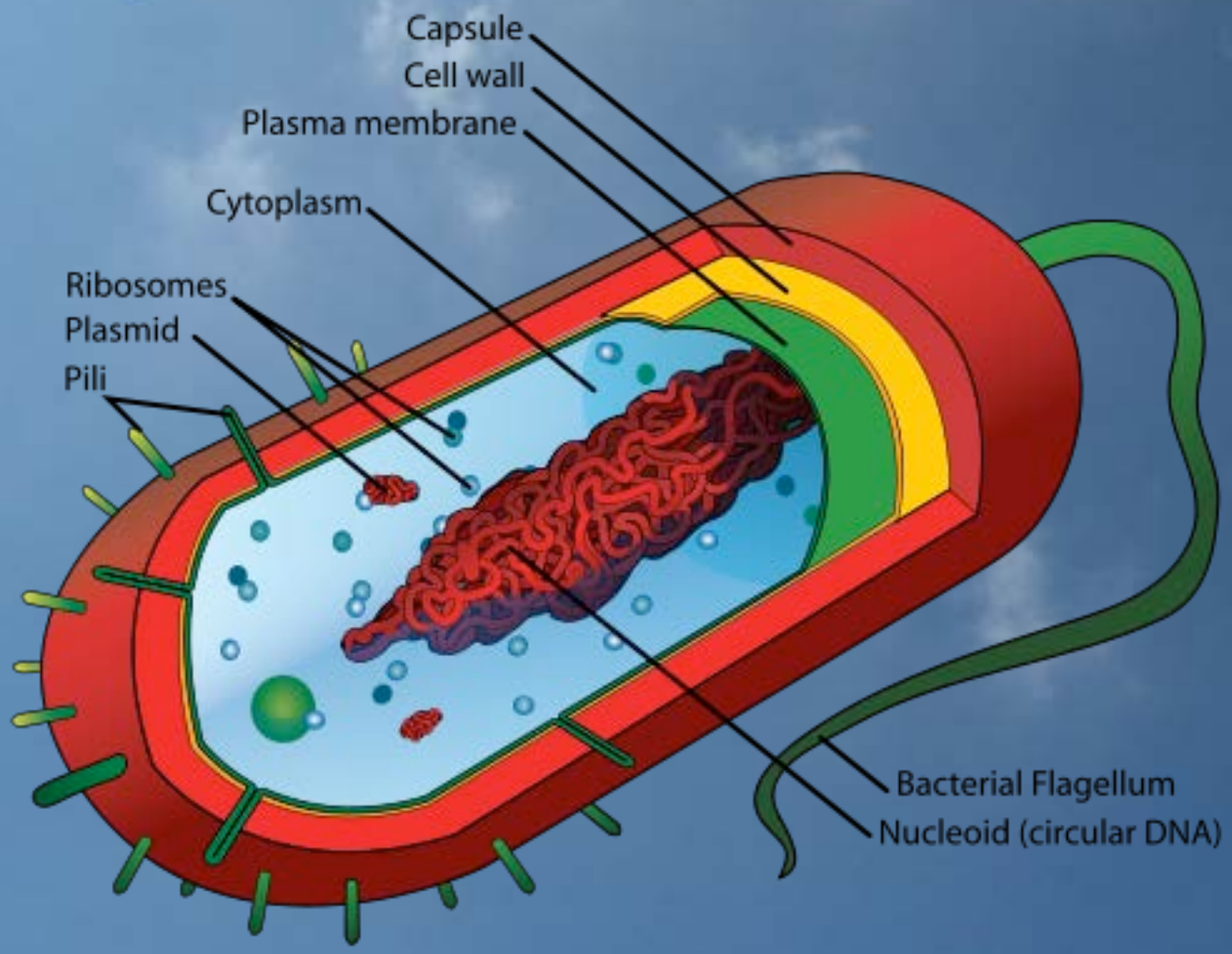
Early organisms:



Sources: 3

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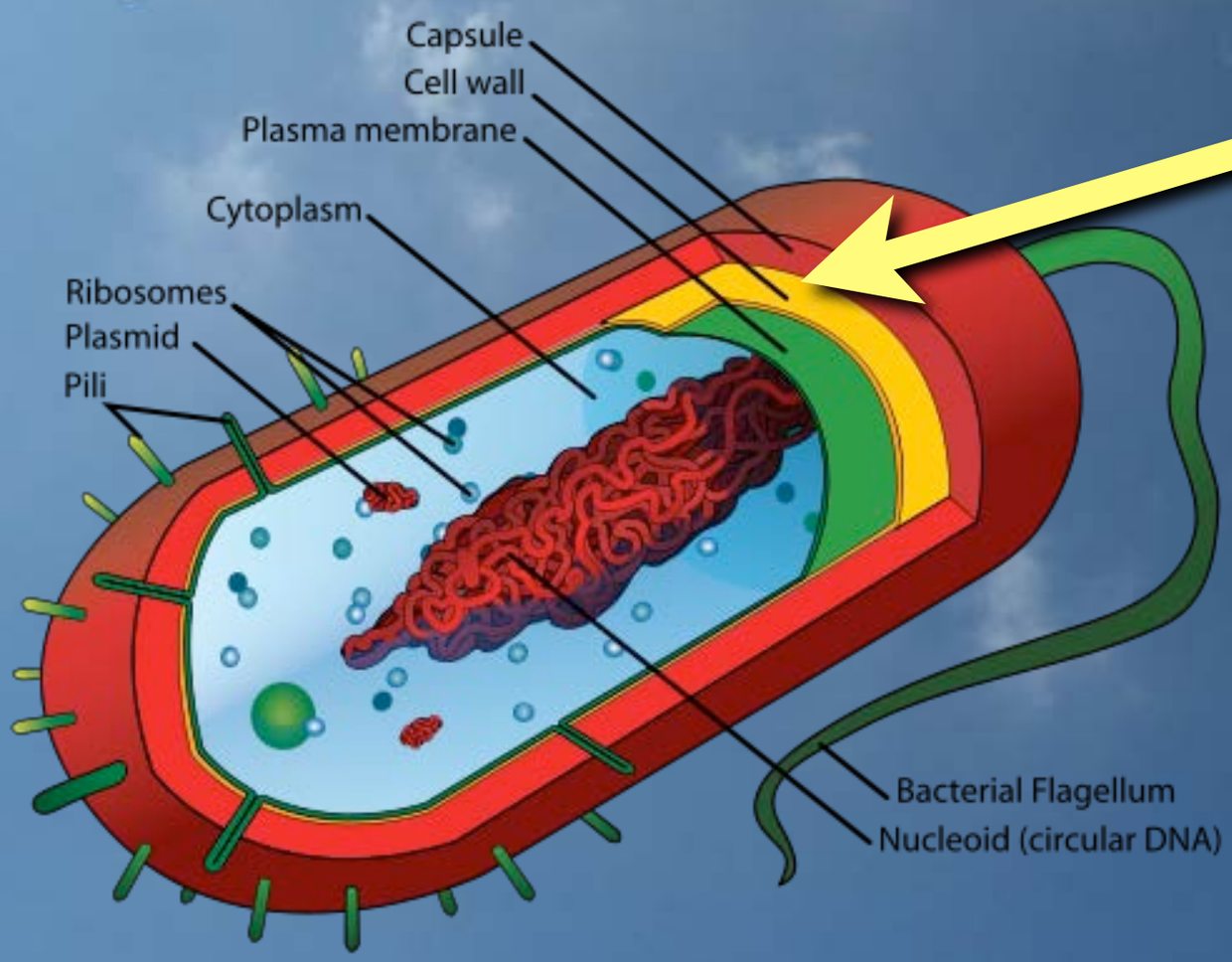

Absorption

Sources: 3

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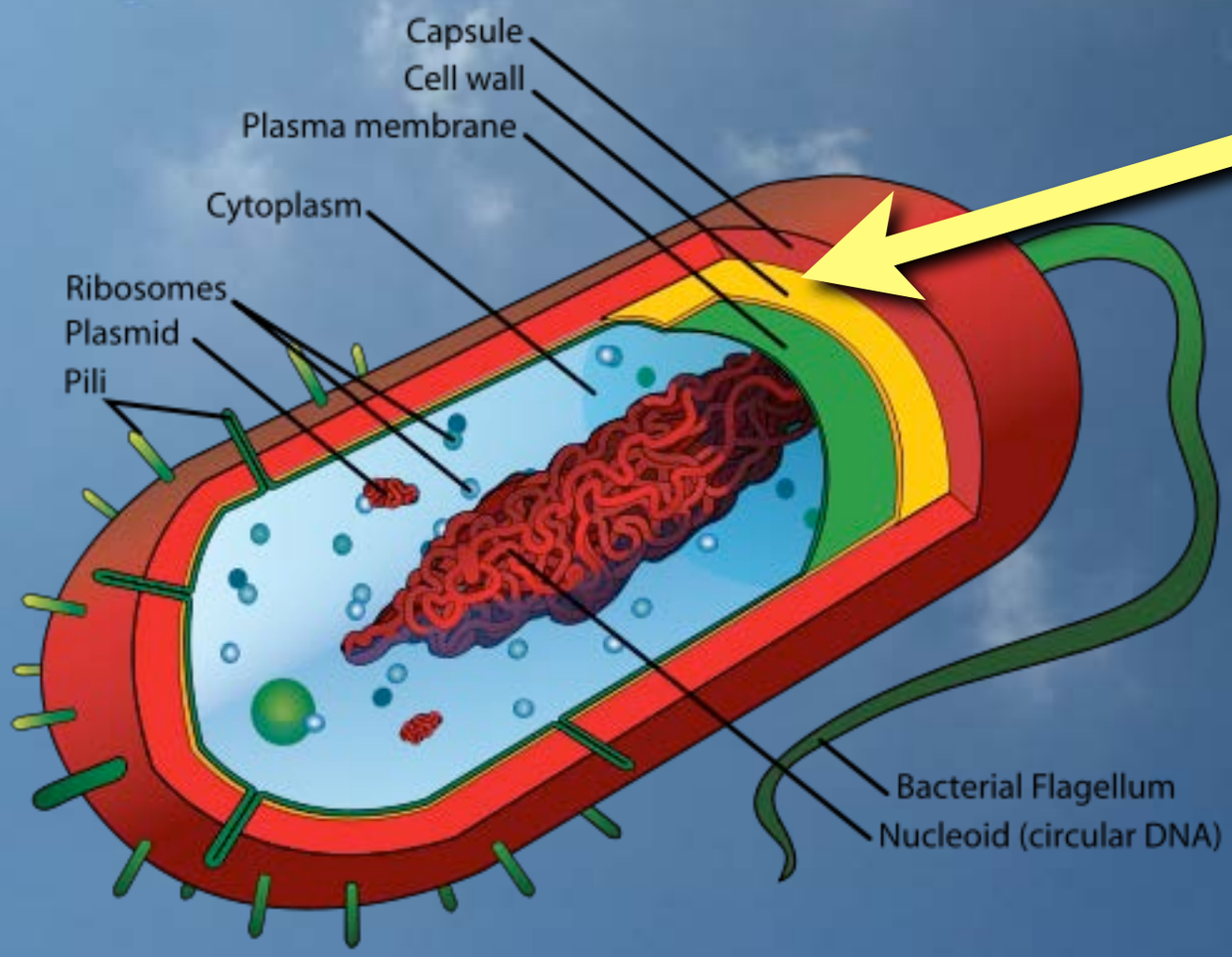

Absorption

trophic = ***feeding***

Sources: 3

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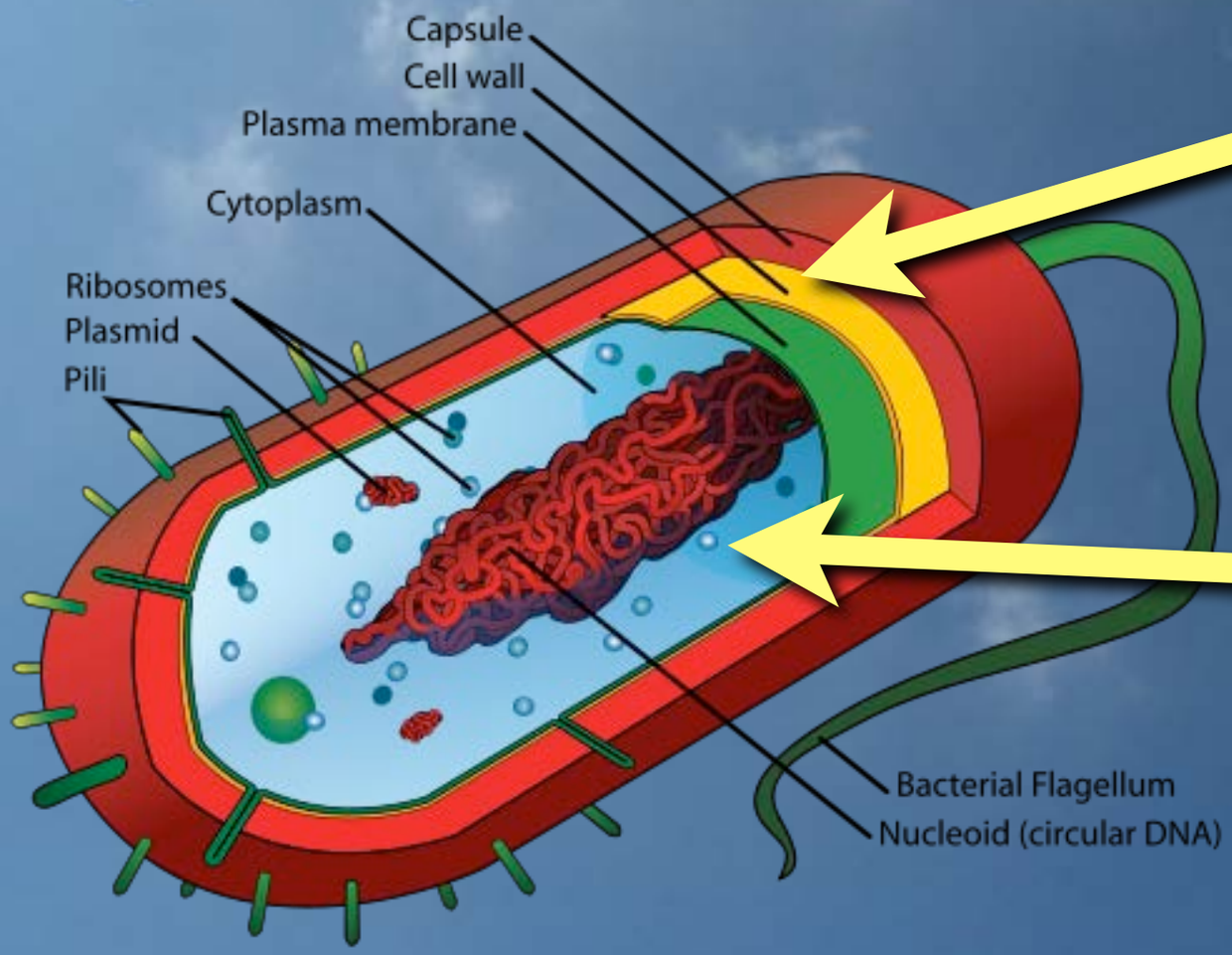

Absorption

trophic = *feeding*

Metabolism

Sources: 3

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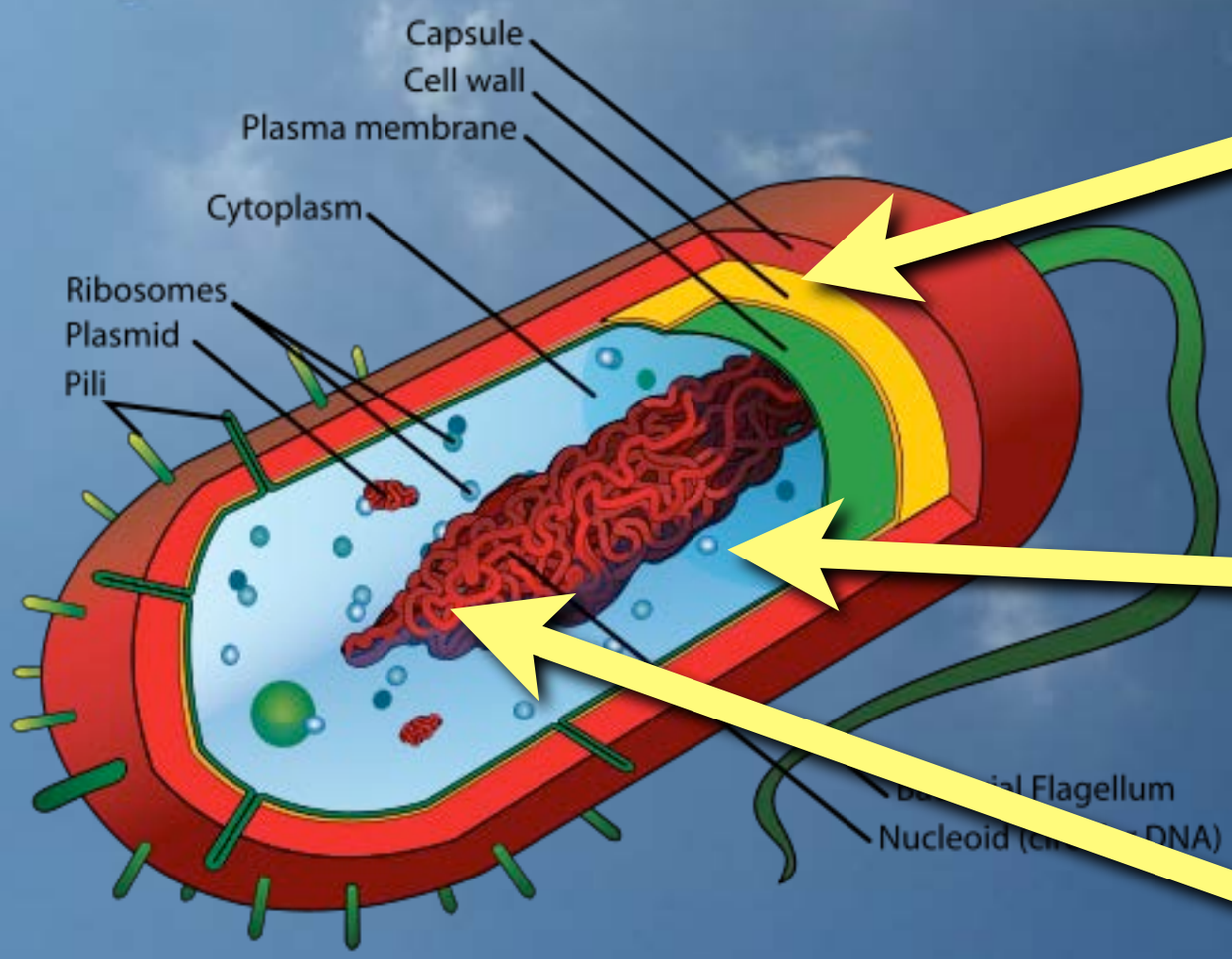

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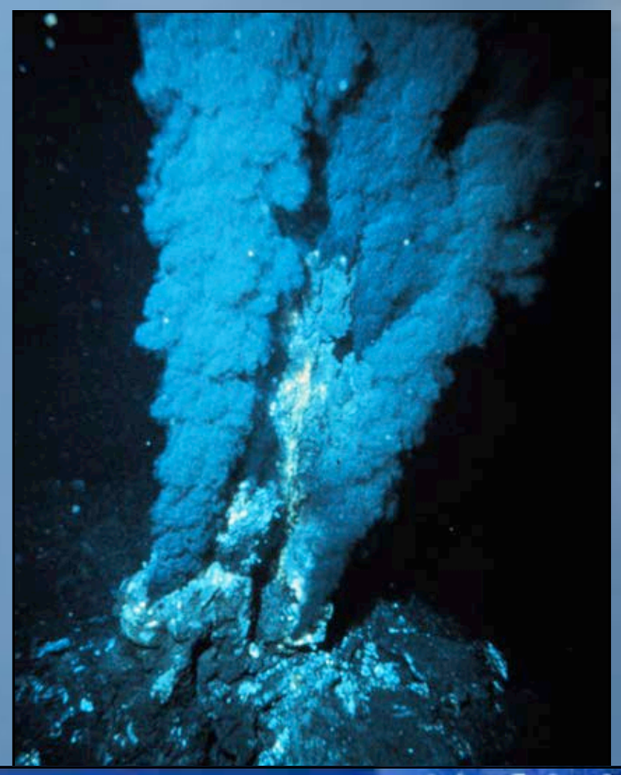
Metabolism

Reproduction

Sources: 3

Deep sea thermal vents:



Sources: 4, 5, 6

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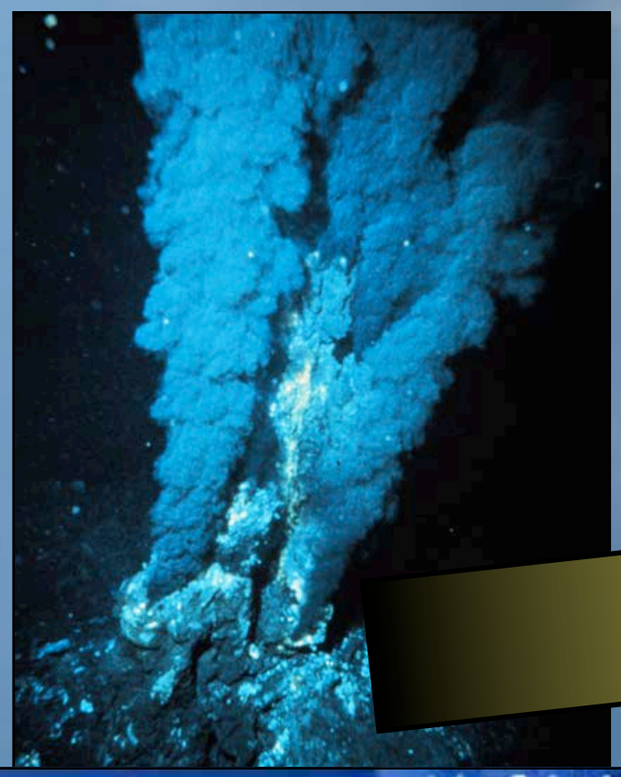

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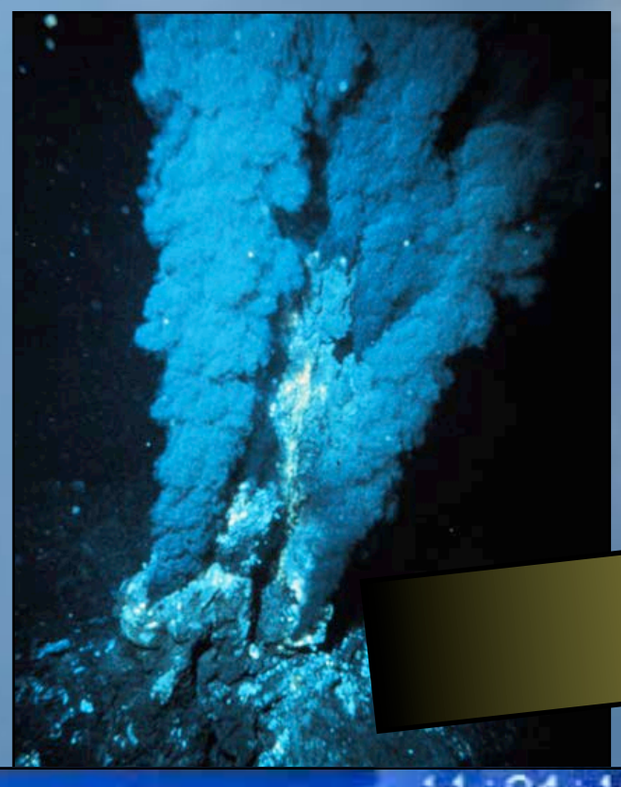

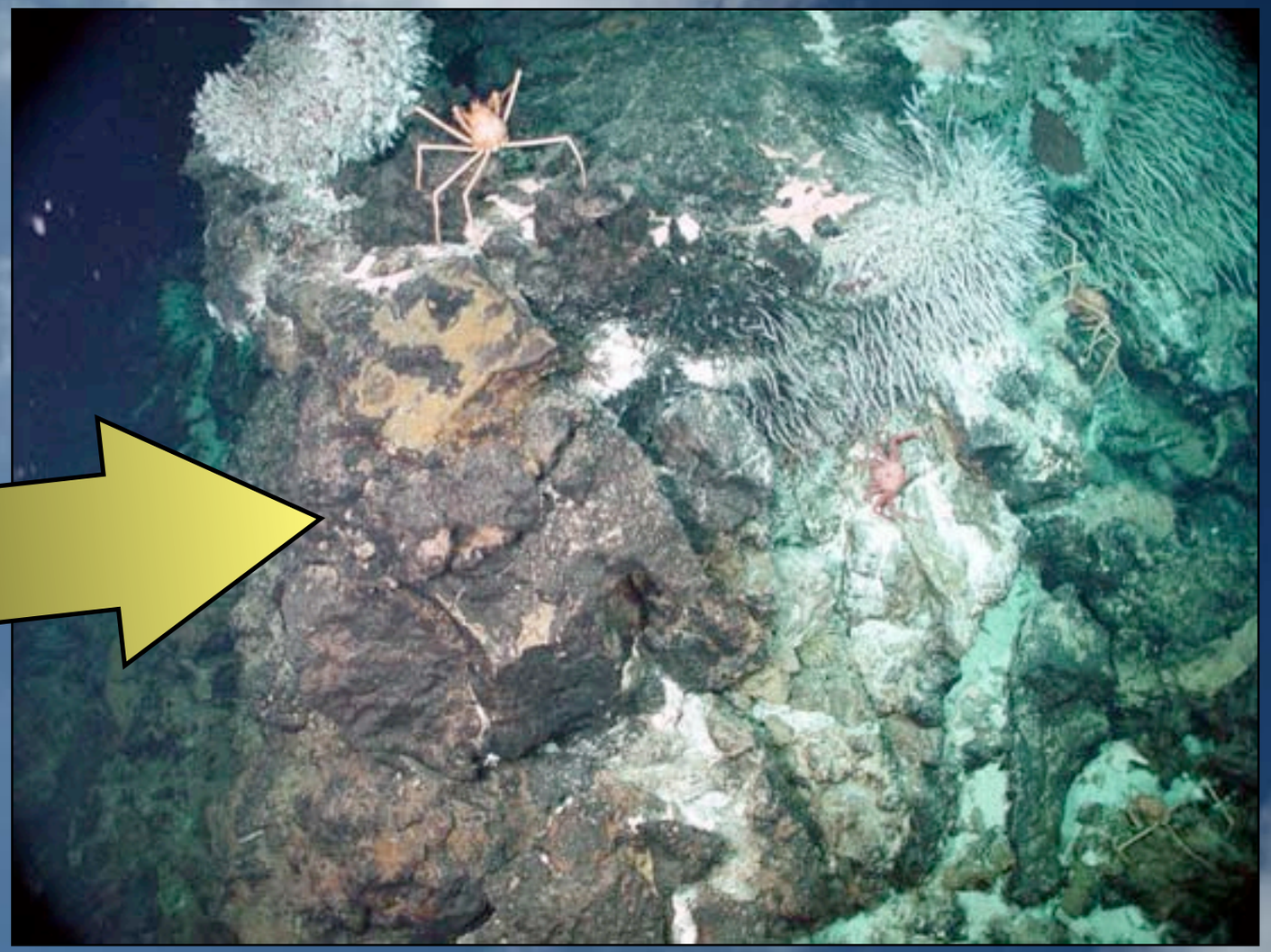

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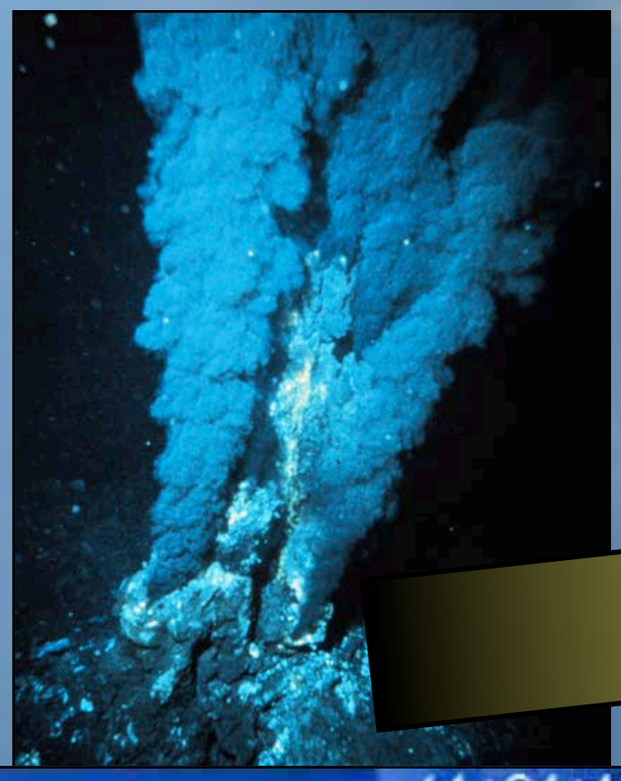

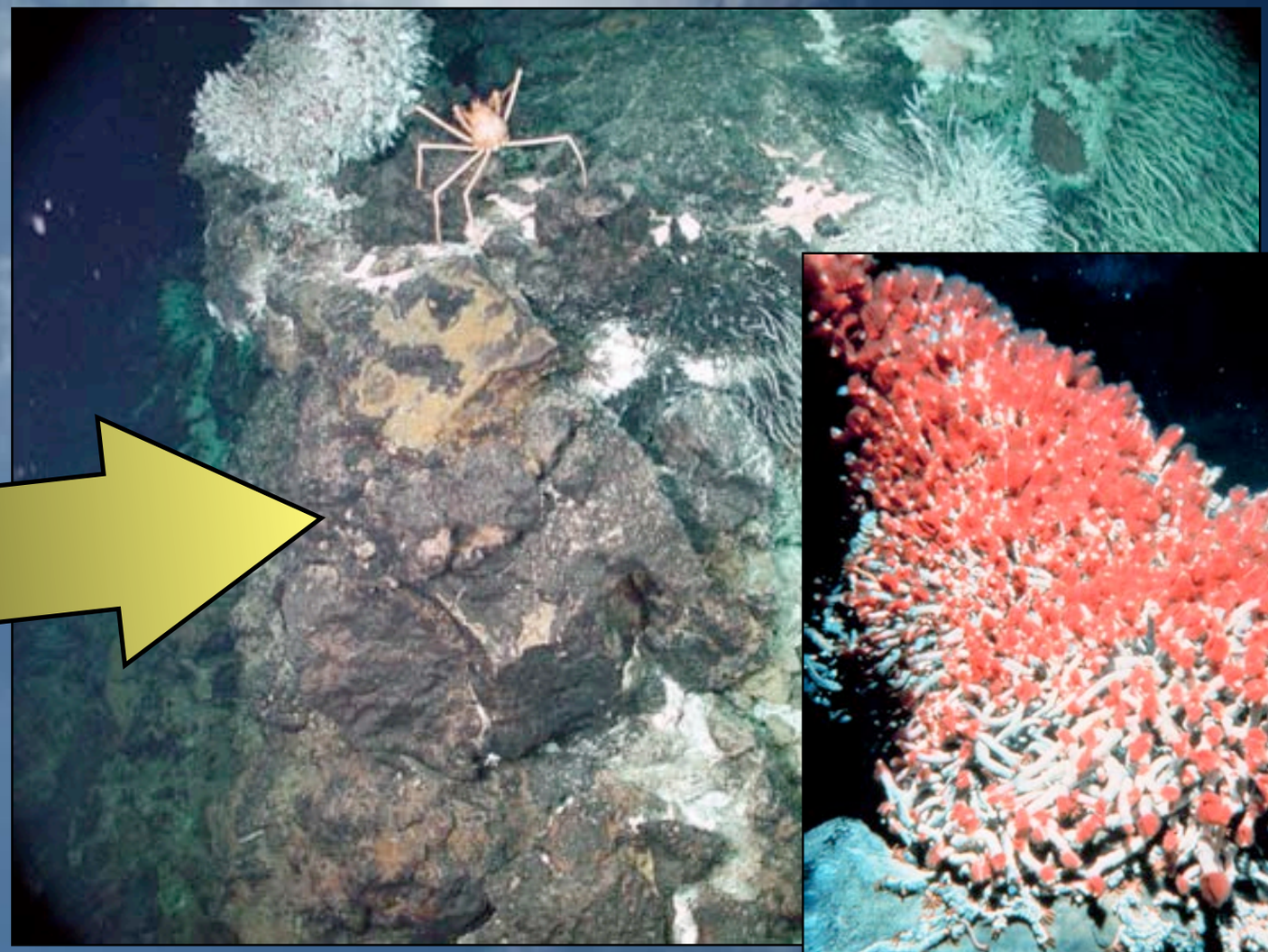

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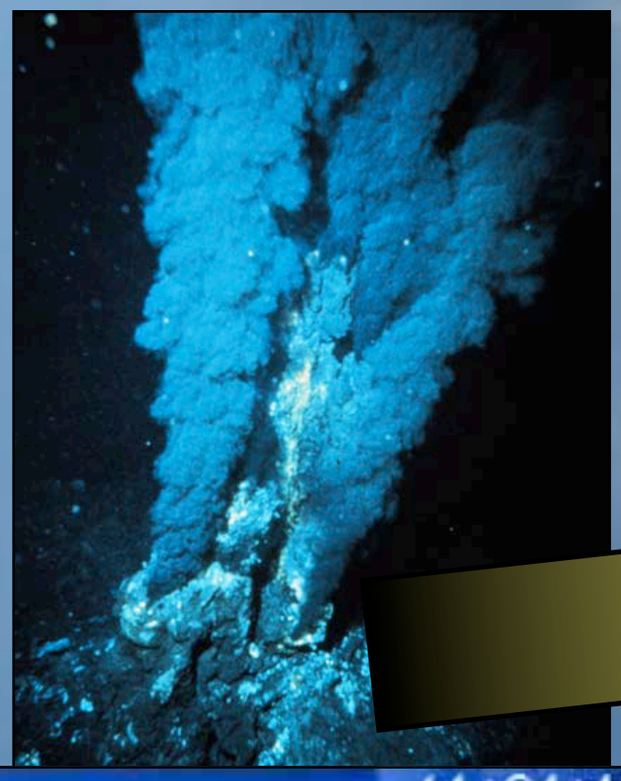
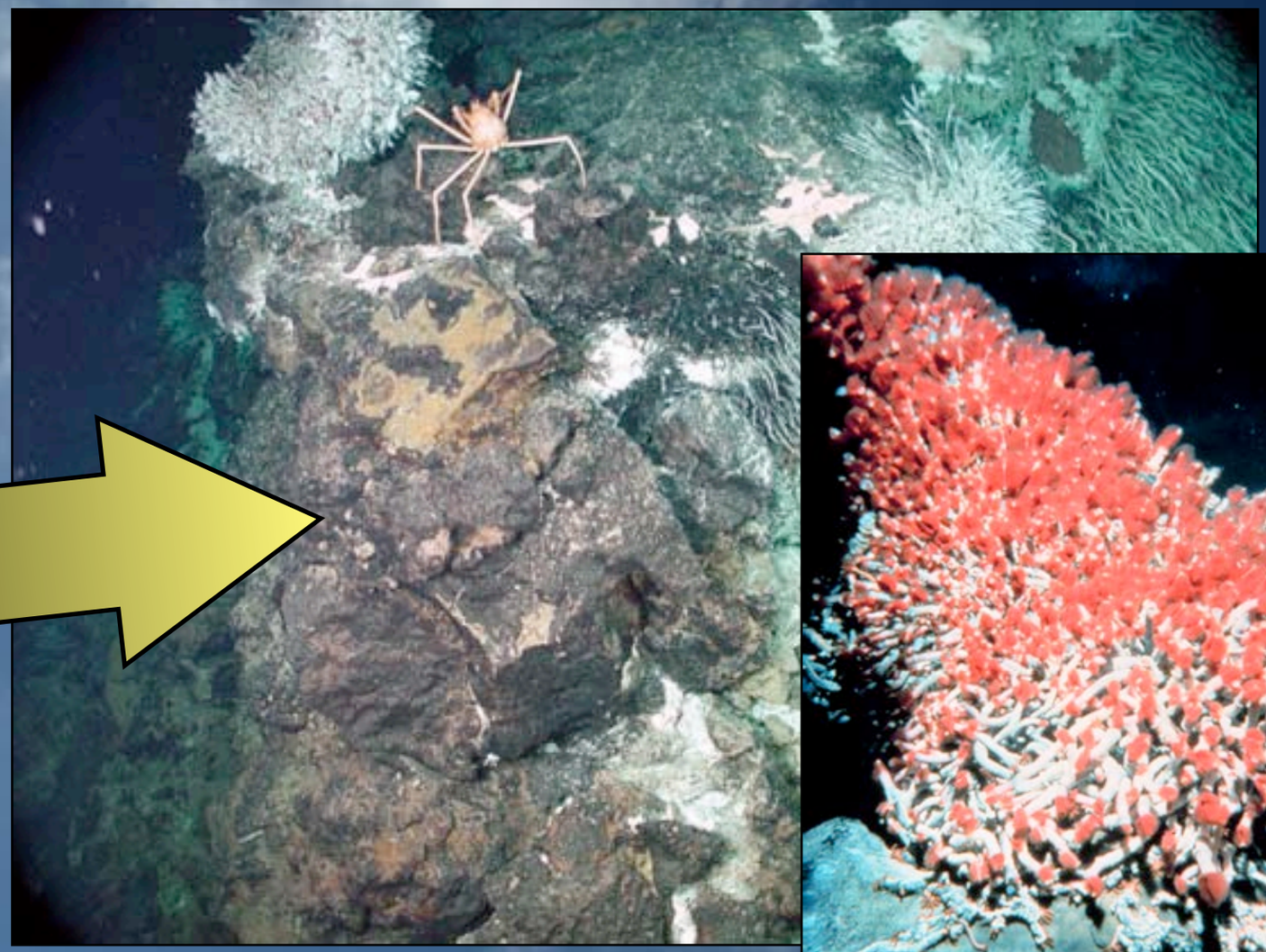
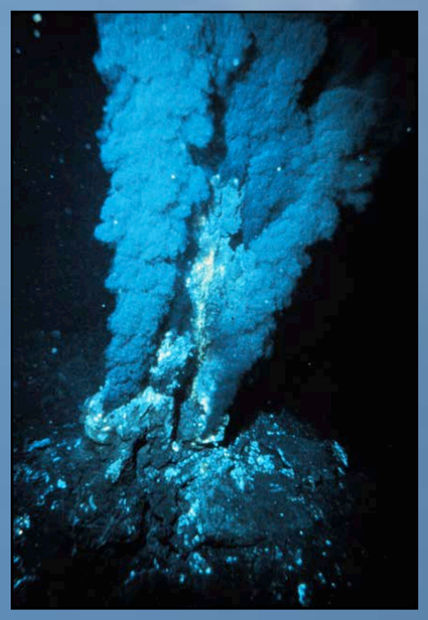




Chemotrophs

Sources: 4, 5, 6

The problem with chemotrophy:



Sources: 4, 5, 6, 7, 8

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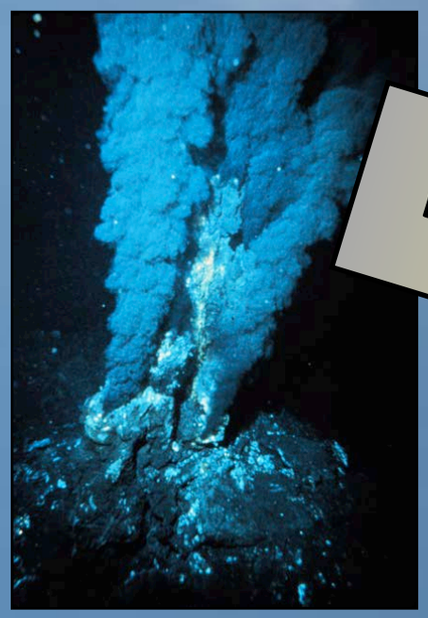

Matter & Energy

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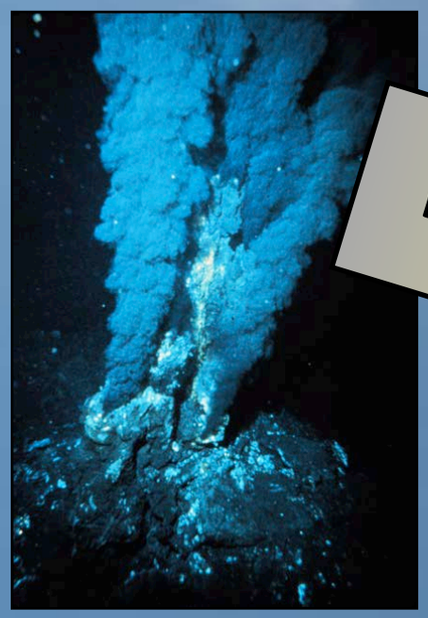
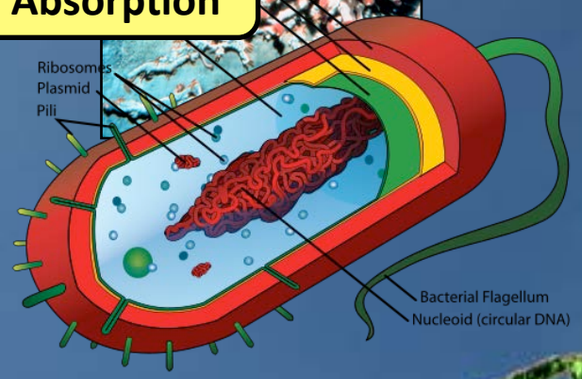


Matter & Energy

Metabolism

Absorption



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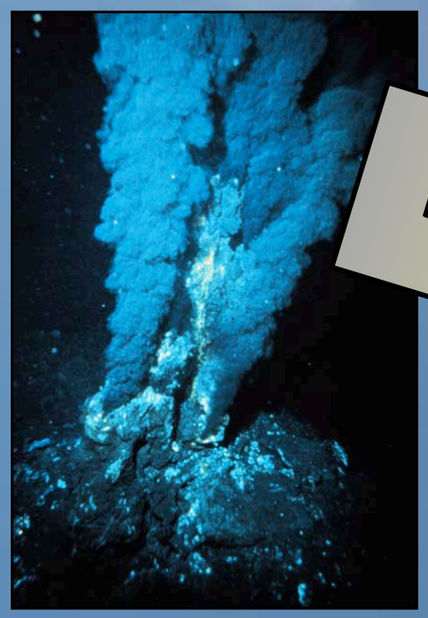

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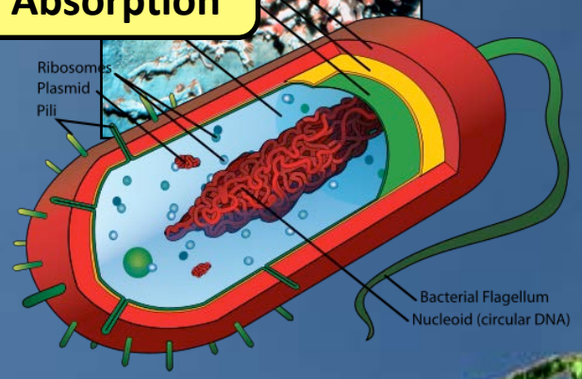

Chemoautotrophs

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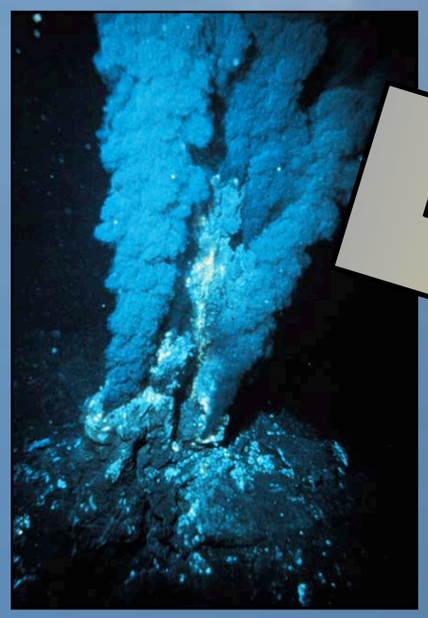

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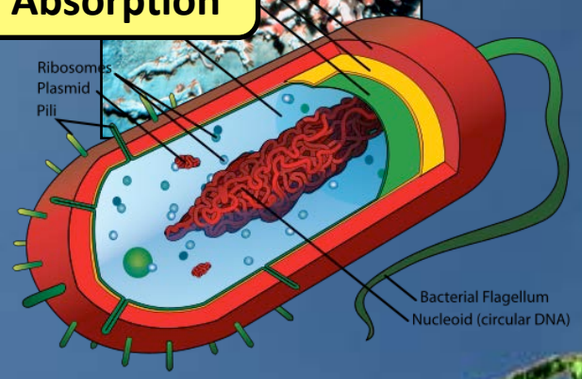

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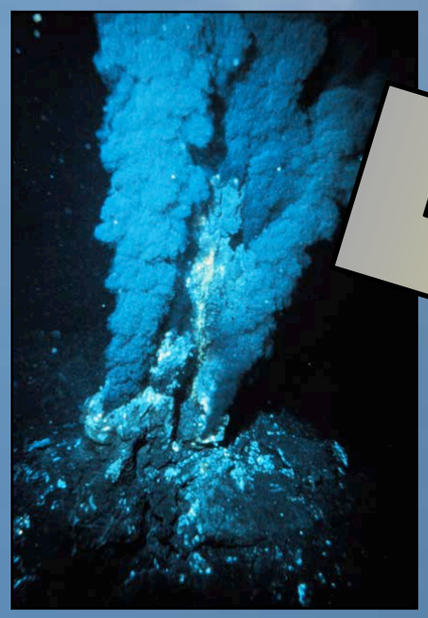

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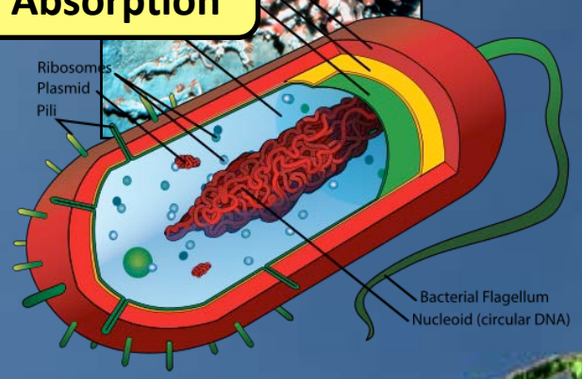

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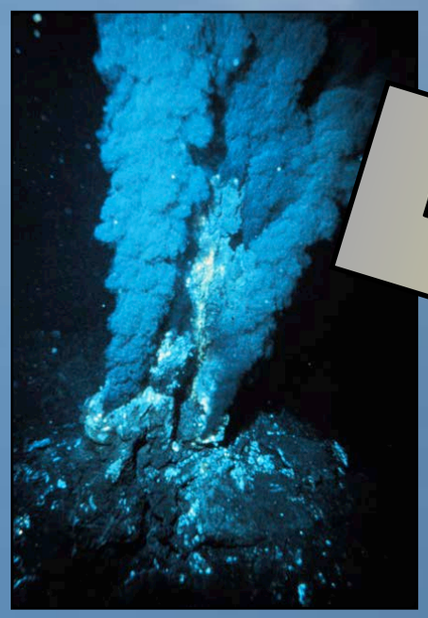

Matter & Energy

Metabolism

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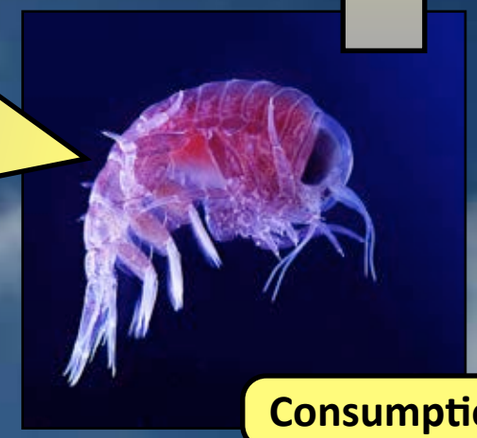

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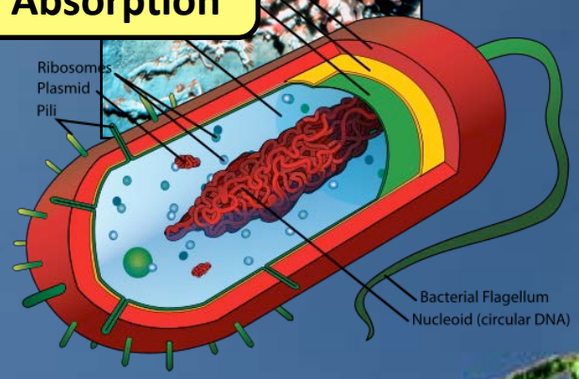

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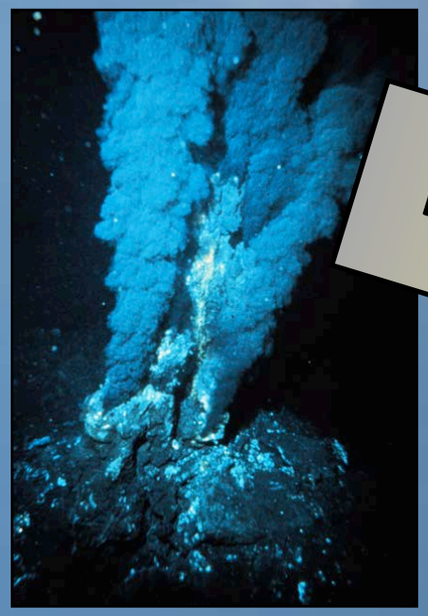
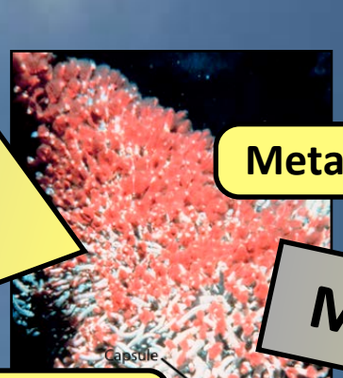
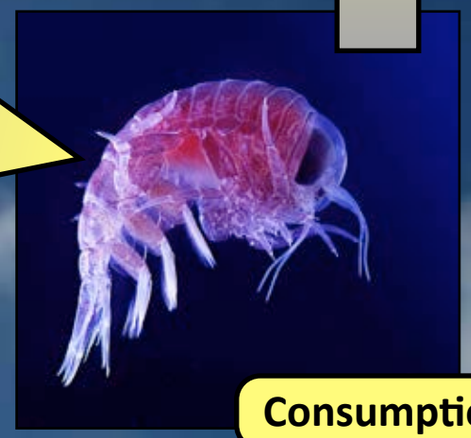


Matter & Energy



Metabolism

Matter & Energy

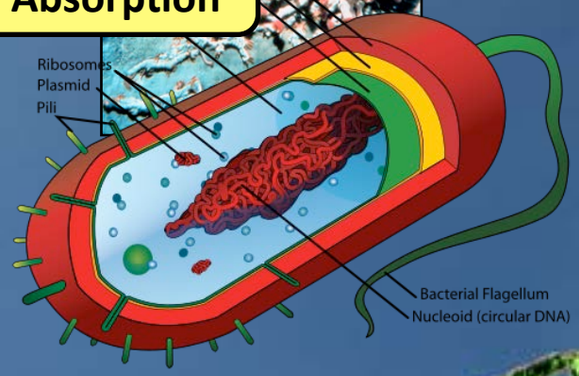


Consumption

Matter & Energy

Consumption

Absorption

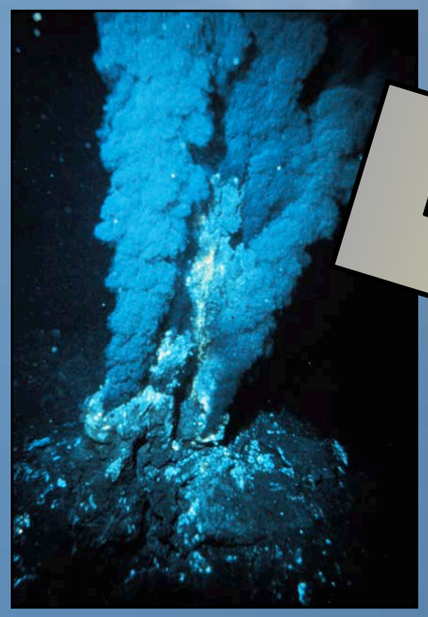


Chemoautotrophs

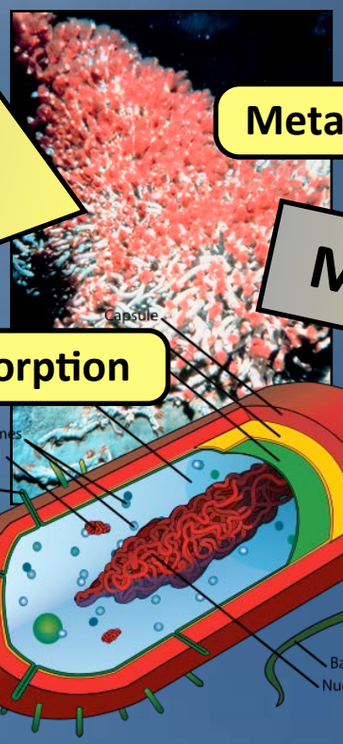
Sources: 4, 5, 6, 7, 8

Christopher X Jon Jensen
Pratt

The problem with chemotrophy:



Matter & Energy

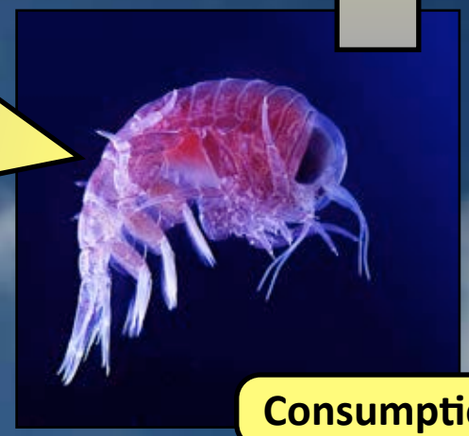


Metabolism

Absorption

Chemoautotrophs

Matter & Energy



Consumption

Chemoheterotrophs

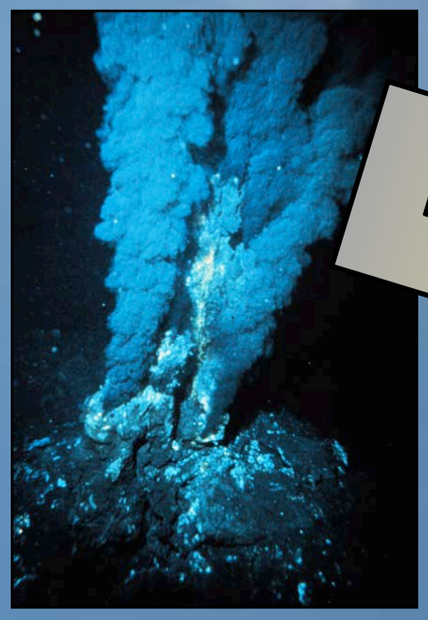
Consumption

Matter & Energy

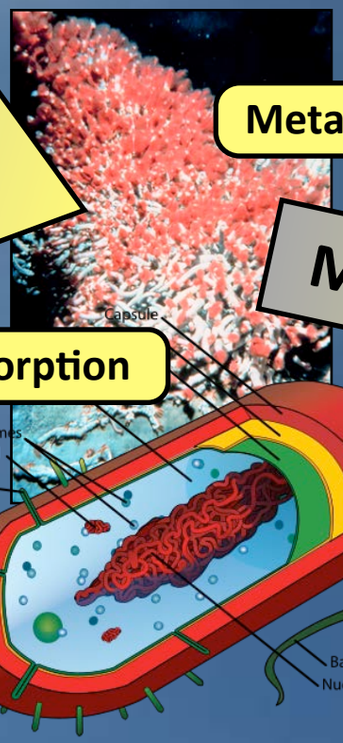
Sources: 4, 5, 6, 7, 8

Christopher X Jon Jensen
Pratt

The problem with chemotrophy:



Matter & Energy

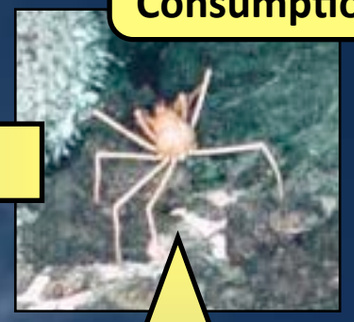


Metabolism

Absorption

Chemoautotrophs

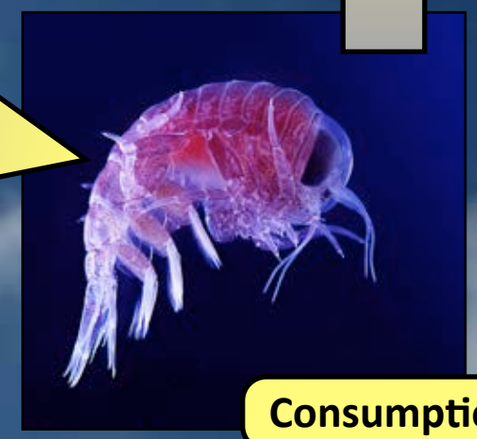
Matter & Energy



Consumption

Chemoheterotrophs

Matter & Energy



Consumption

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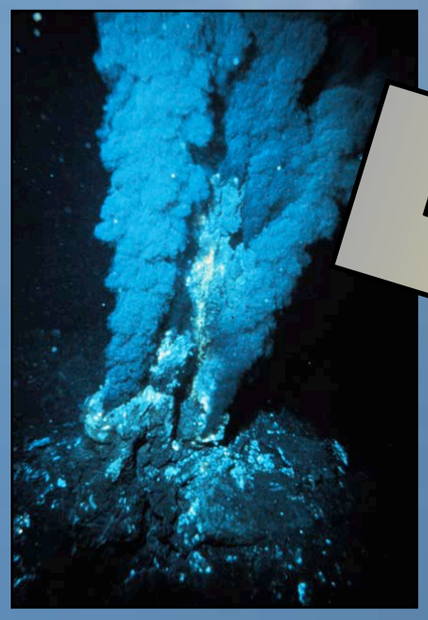
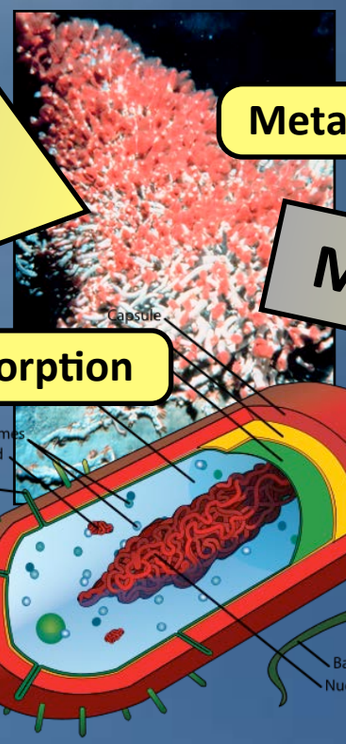


Matter & Energy

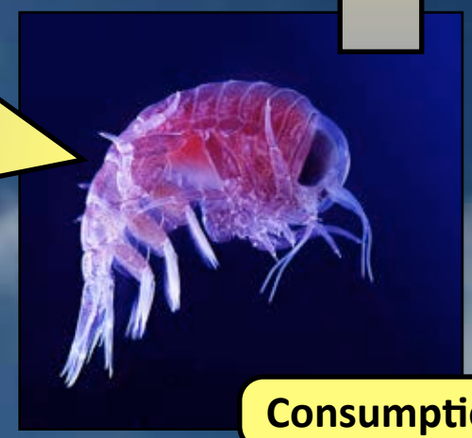


Metabolism

Absorption

Chemoautotrophs

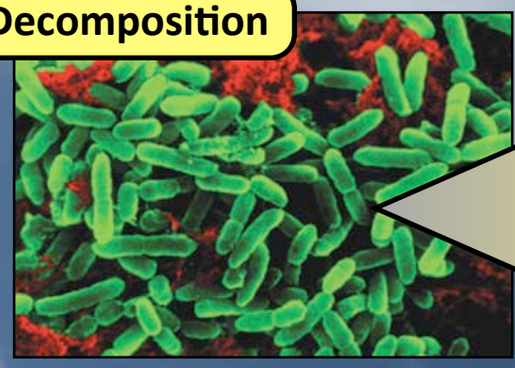
Matter & Energy



Consumption

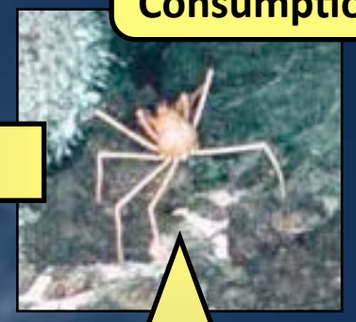
Chemoheterotrophs

Matter & Energy



Decomposition

Matter & Energy

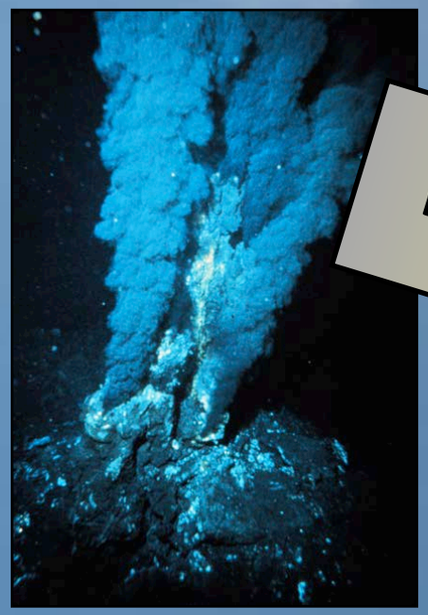


Consumption

Sources: 4, 5, 6, 7, 8

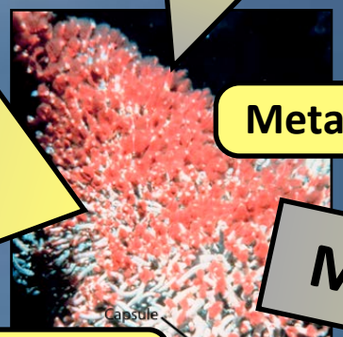
Christopher X Jon Jensen
Pratt

The problem with chemotrophy:



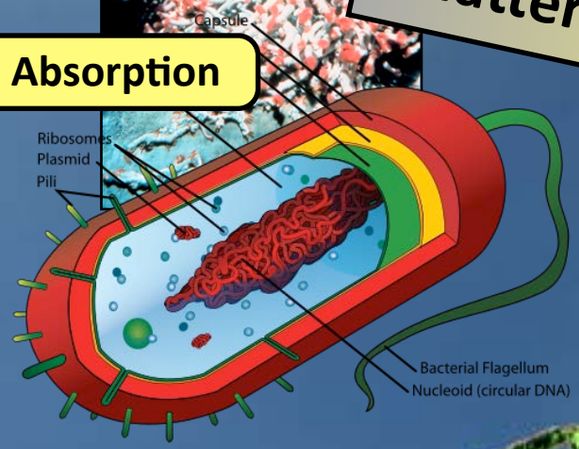
Matter & Energy

Chemoautotrophs

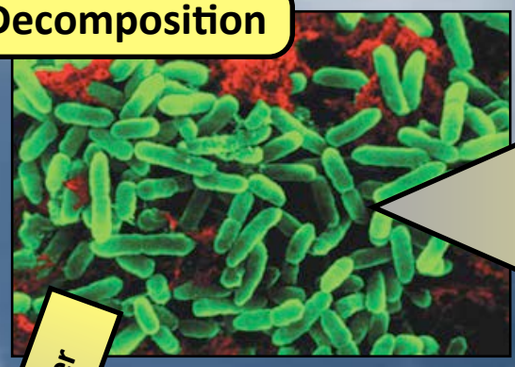


Metabolism

Absorption

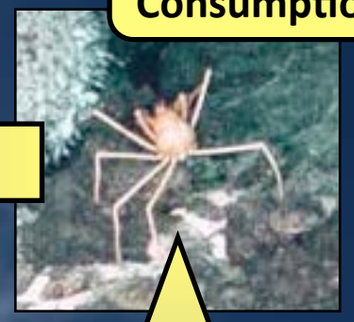


Matter



Decomposition

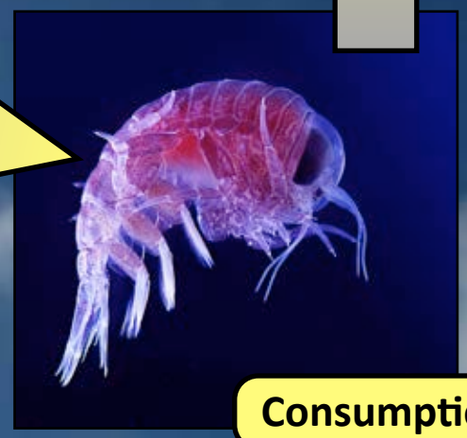
Matter & Energy



Consumption

Chemoheterotrophs

Matter & Energy



Consumption

Sources: 4, 5, 6, 7, 8

Christopher X Jon Jensen
Pratt

Moving beyond chemotrophy:

Sources: 9, 10

Christopher X Jon Jensen
Pratt

Moving beyond chemotrophy:

Sources: 9, 10

Christopher X Jon Jensen
Pratt

Moving beyond chemotrophy:

Photosynthesis

Sources: 9, 10

Christopher X Jon Jensen
Pratt

Moving beyond chemotrophy:

Photosynthesis

Photoautotrophs

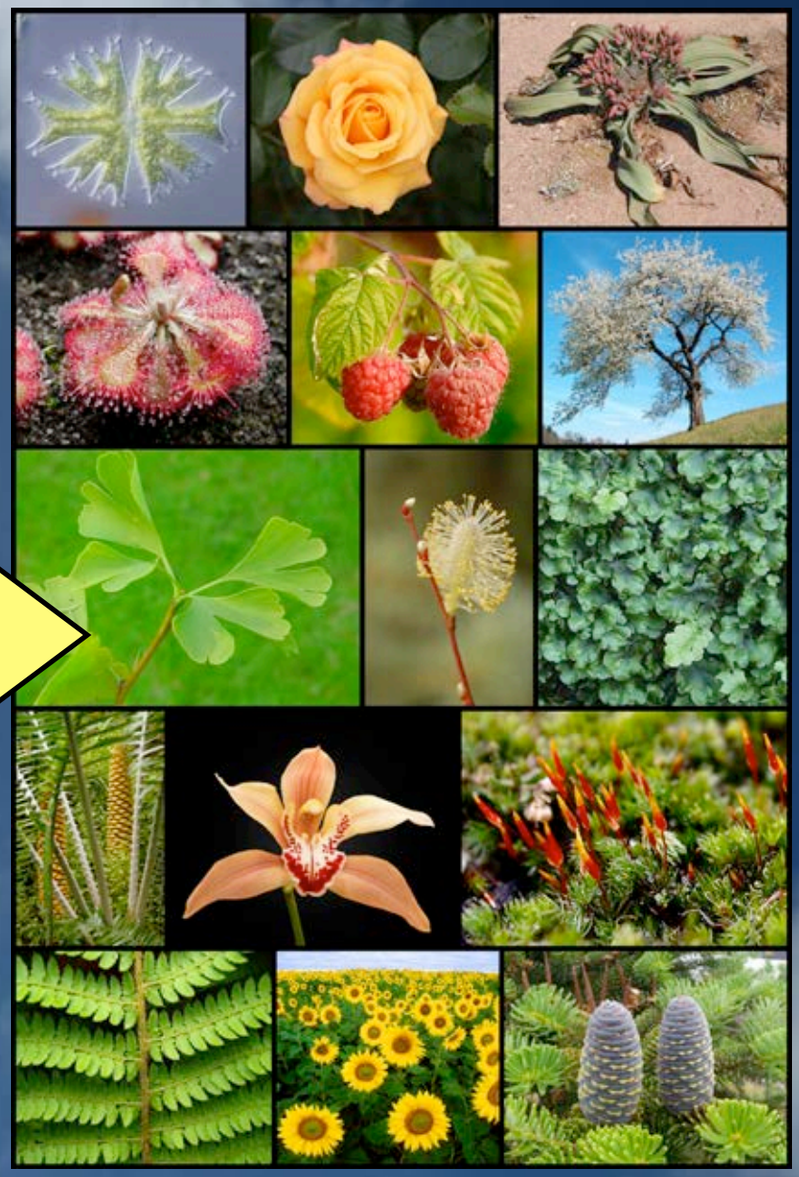
Sources: 9, 10

Christopher X Jon Jensen
Pratt

Moving beyond chemotrophy:

Photosynthesis

Symbiosis



Photoautotrophs

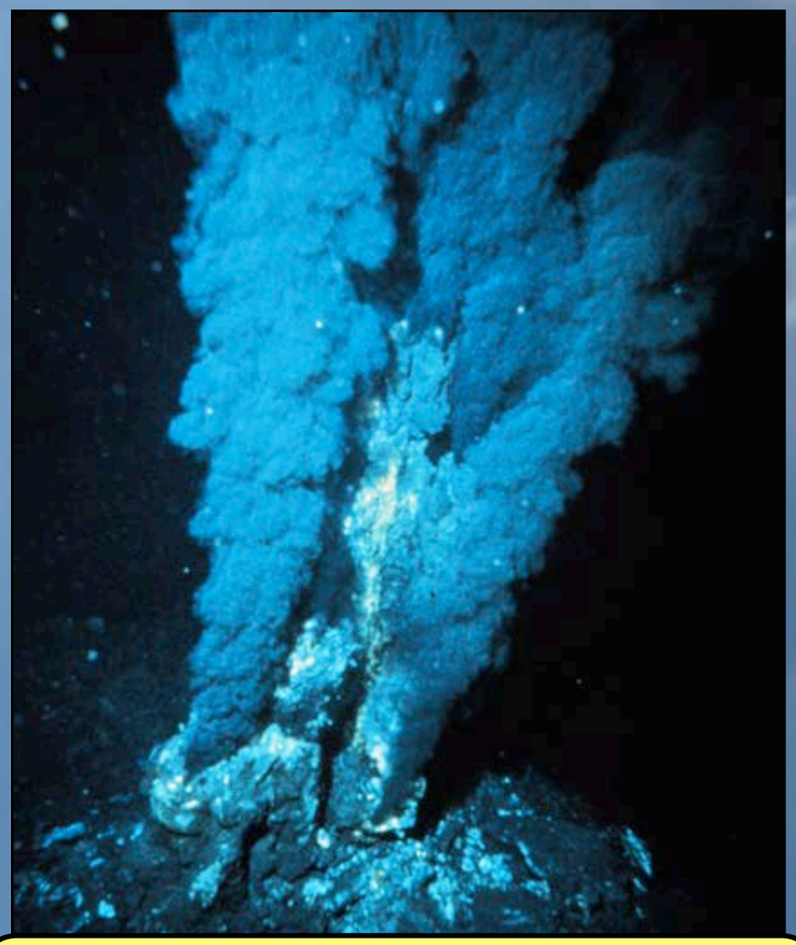
Sources: 9, 10

Christopher X Jon Jensen
Pratt

Moving beyond chemotrophy:

Sources: 4, 11

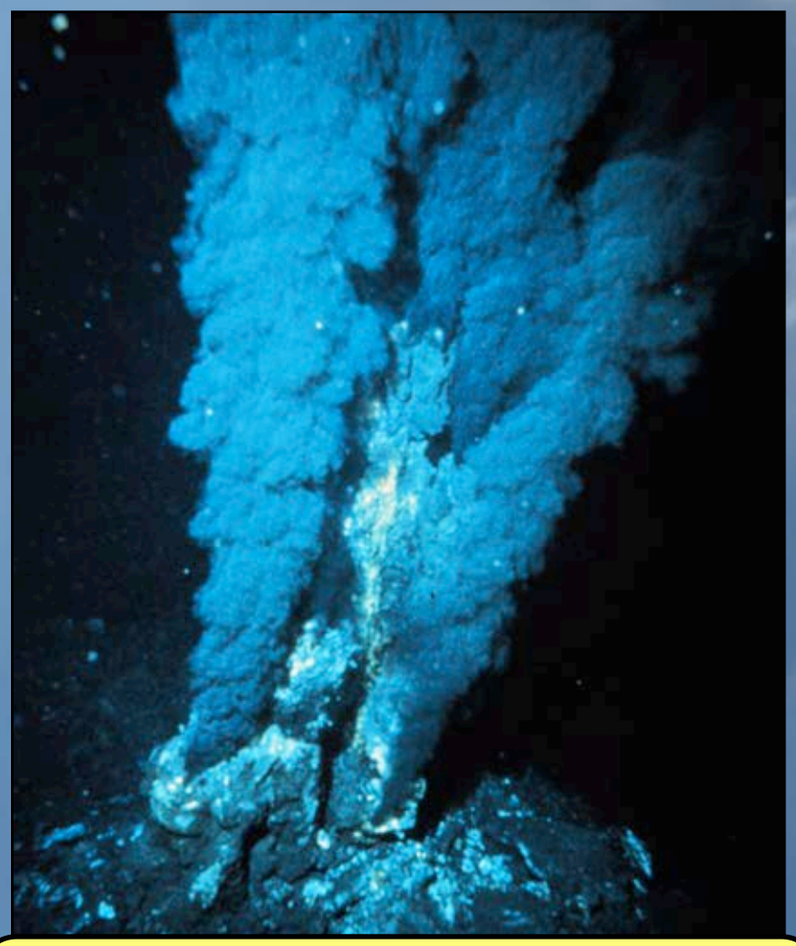
Moving beyond chemotrophy:



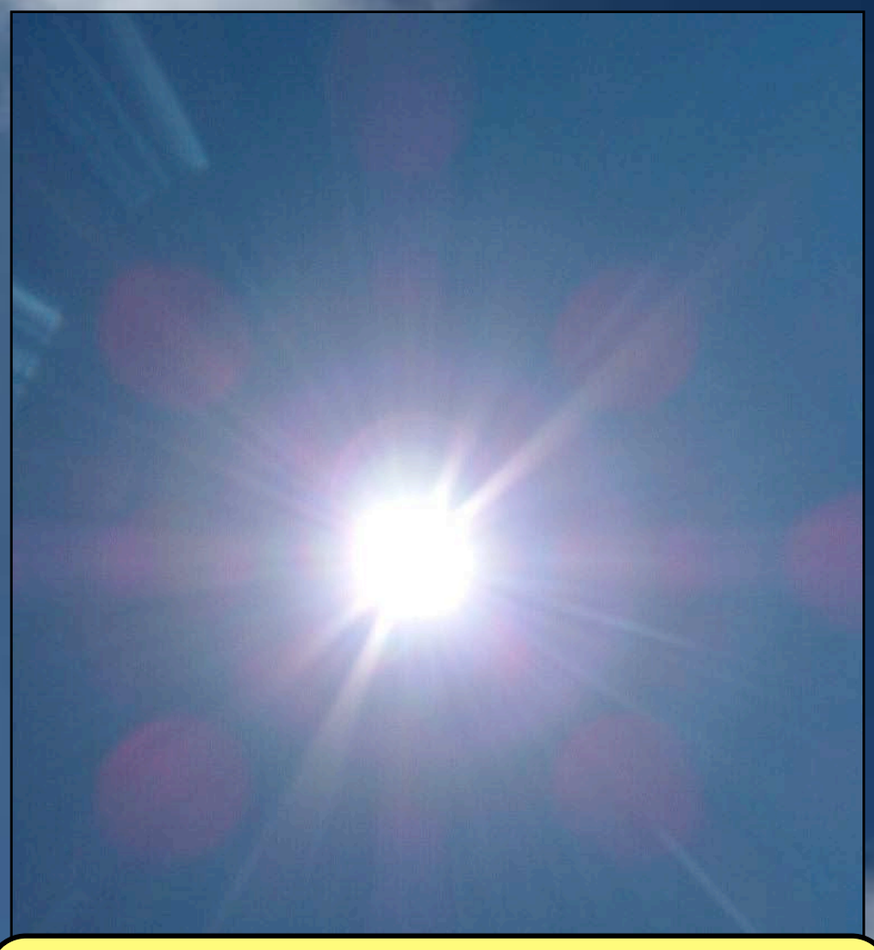
Inconsistent, sporadic source of low-quantity energy

Sources: 4, 11

Moving beyond chemotrophy:



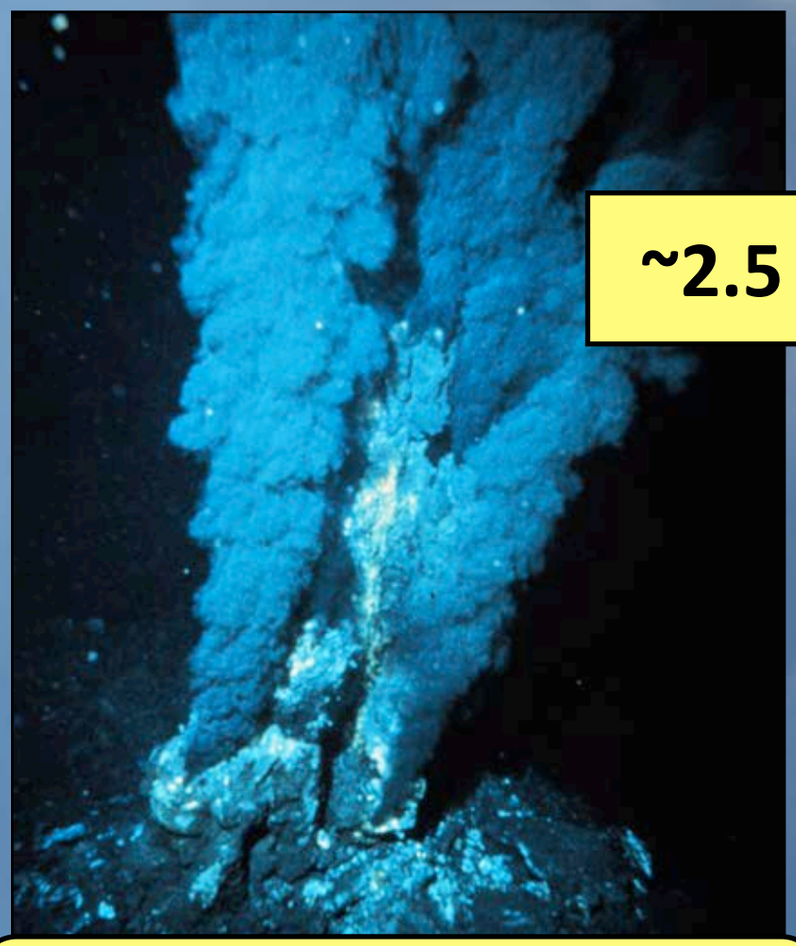
Inconsistent, sporadic source of low-quantity energy



Consistent, widespread source of high-quantity energy

Sources: 4, 11

Moving beyond chemotrophy:



~2.5 billion years ago

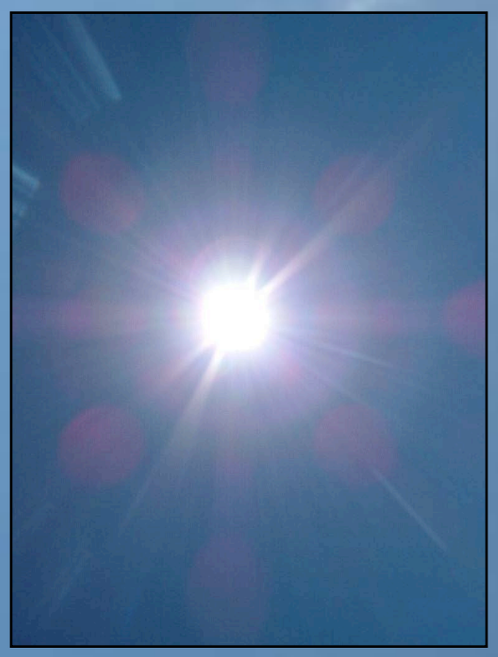
Inconsistent, sporadic source of low-quantity energy

Consistent, widespread source of high-quantity energy

Sources: 4, 11

Christopher X Jon Jensen
Pratt

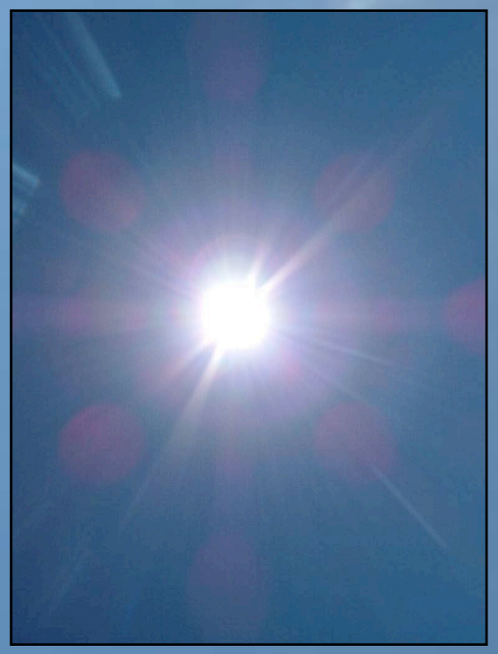
The triumph of phototrophy:

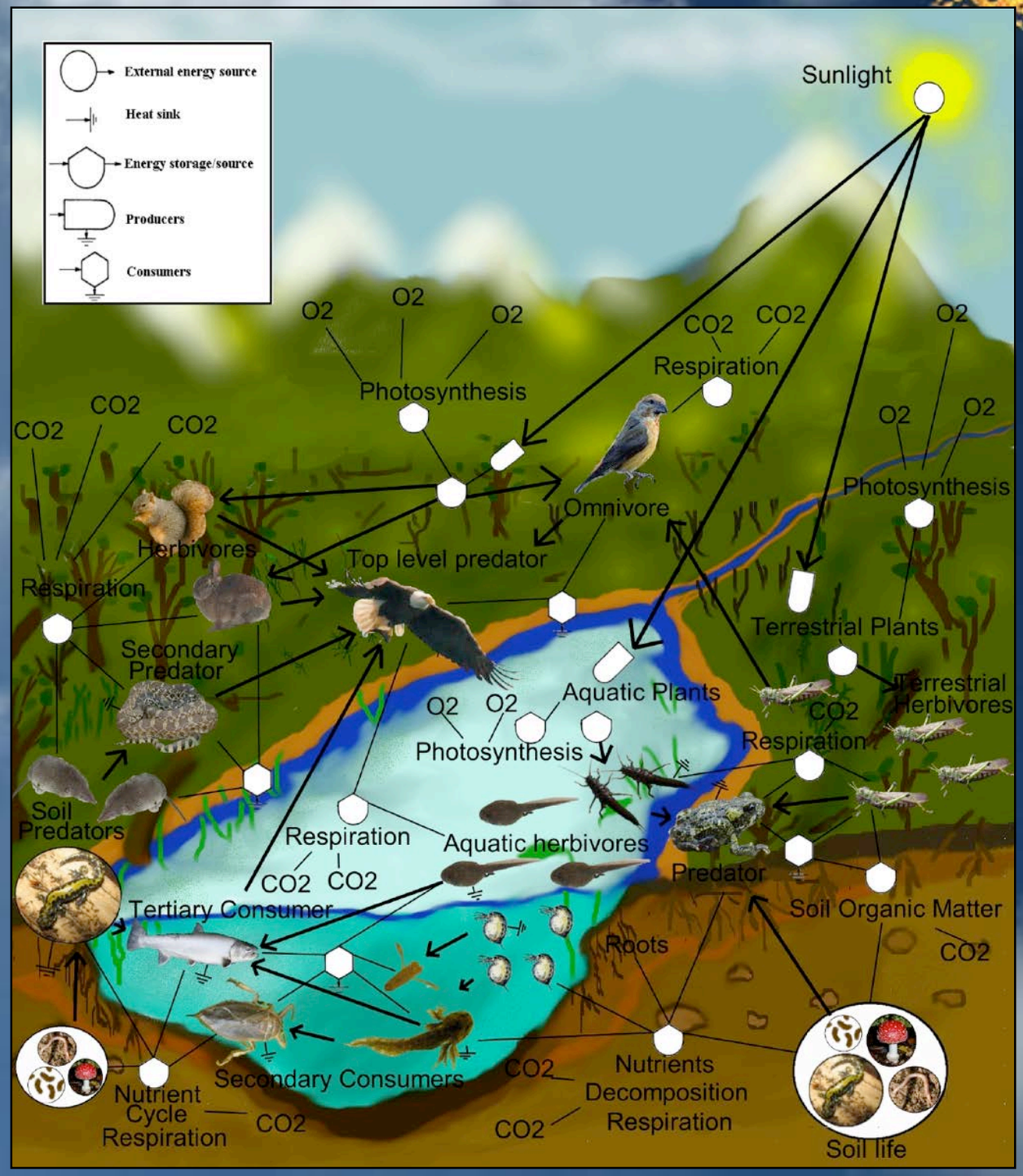


Sources: 12, 13

Christopher X Jon Jensen
Pratt

The triumph of phototrophy:





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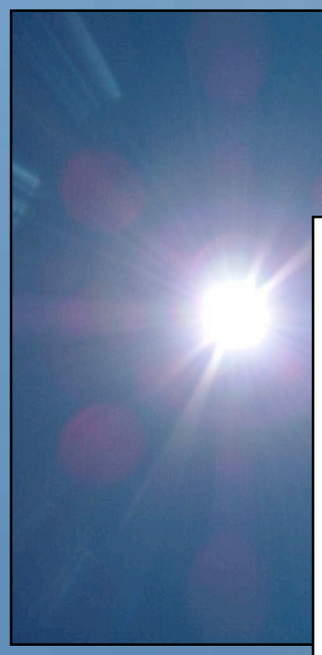
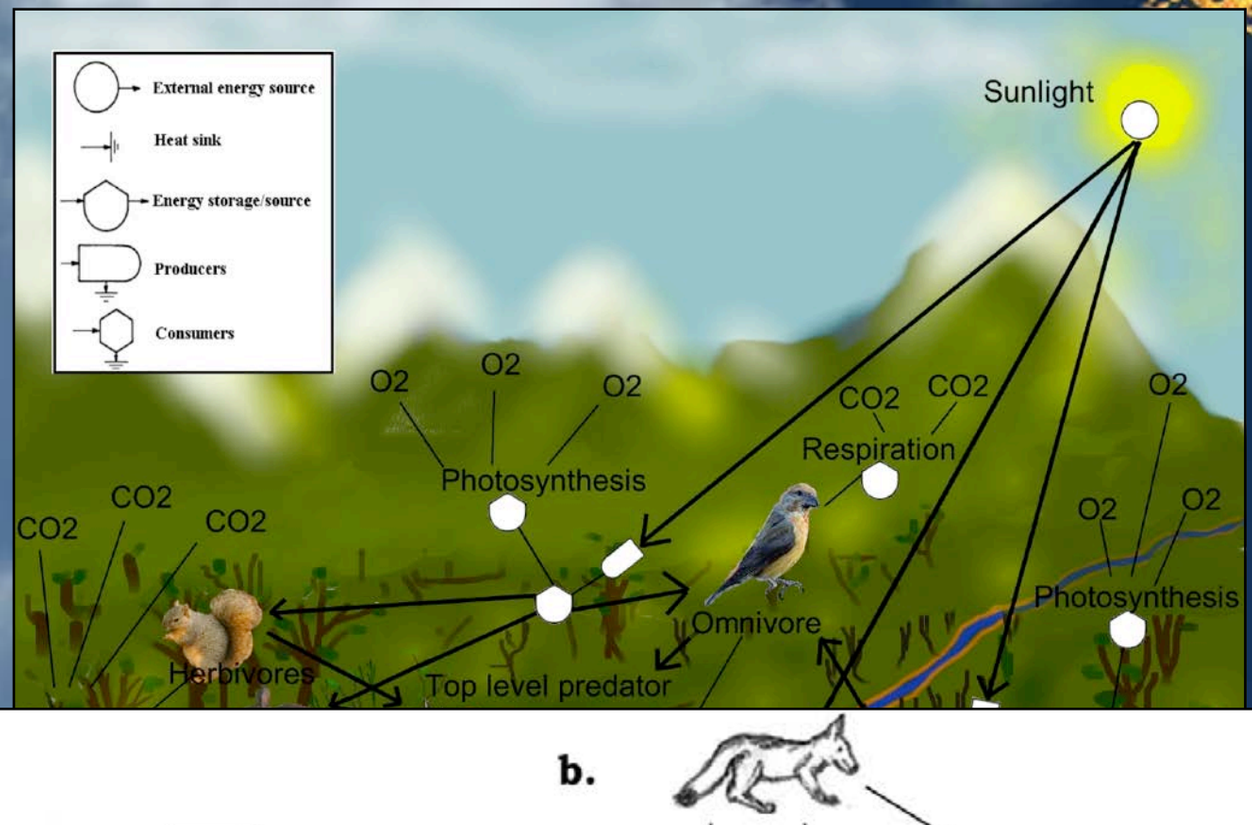
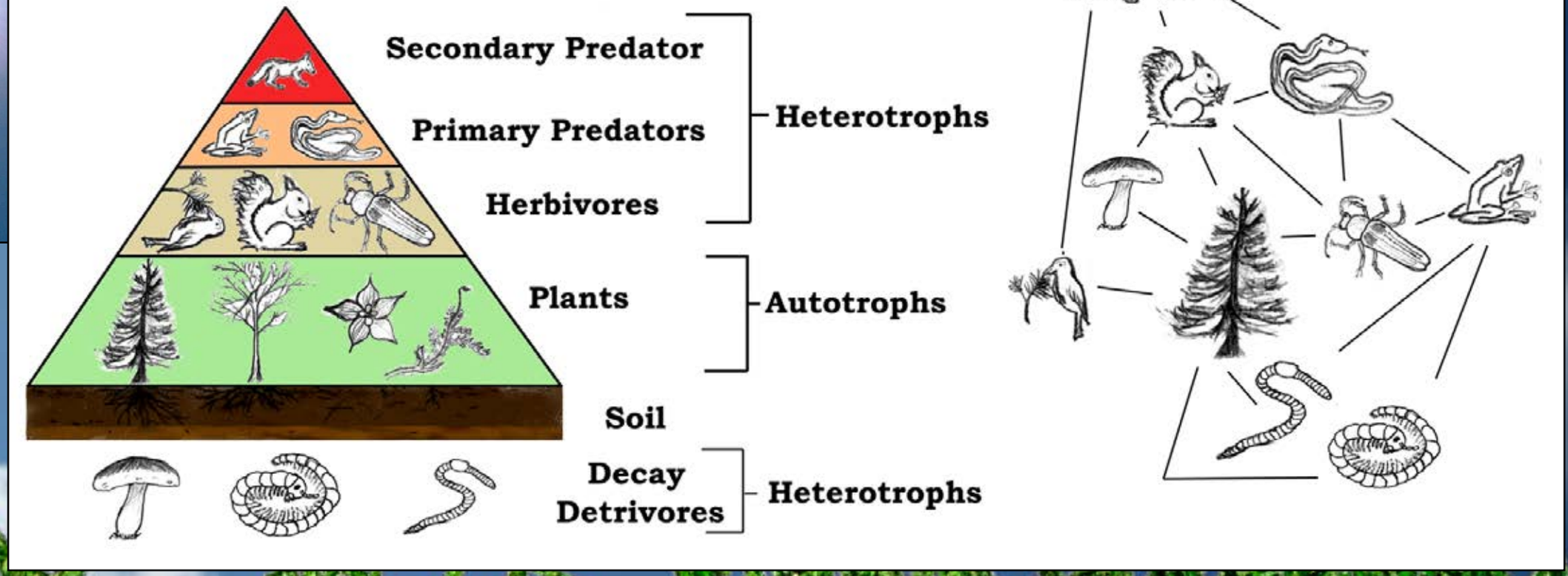






Sources: 12, 13

Christopher X Jon Jensen
Pratt

How well do we understand how ecosystems work?

Christopher X Jon Jensen
Pratt

How well do we understand how ecosystems work?

- Natural History

How well do we understand how ecosystems work?

- Natural History
- Testable Hypotheses

How well do we understand how ecosystems work?

- Natural History
- Testable Hypotheses
- Experimental Tests

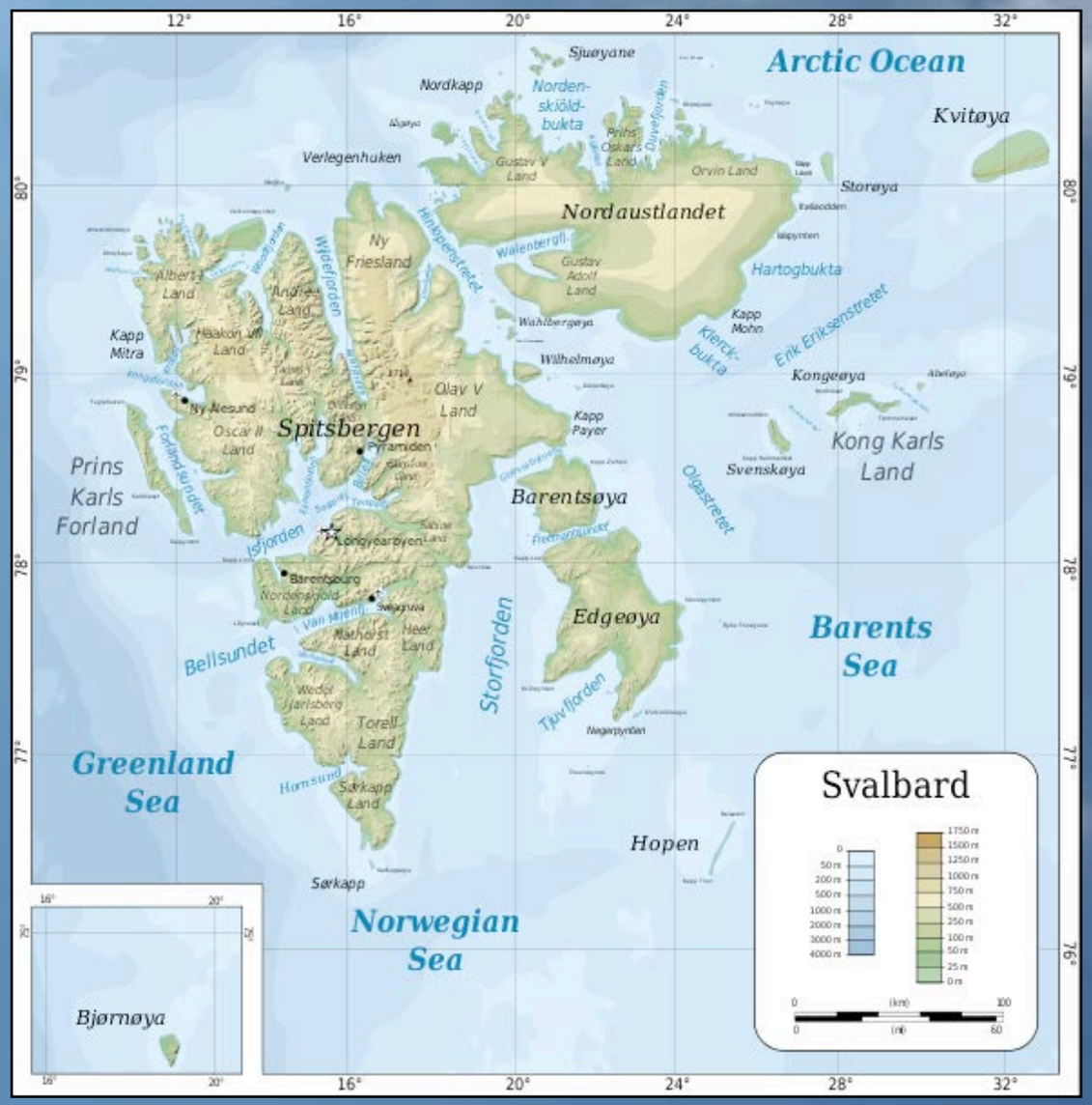
Christopher X Jon Jensen
Pratt

How well do we understand how ecosystems work?

- Natural History
- Testable Hypotheses
- Experimental Tests
- Usable Theory

Christopher X Jon Jensen
Pratt

Natural History:



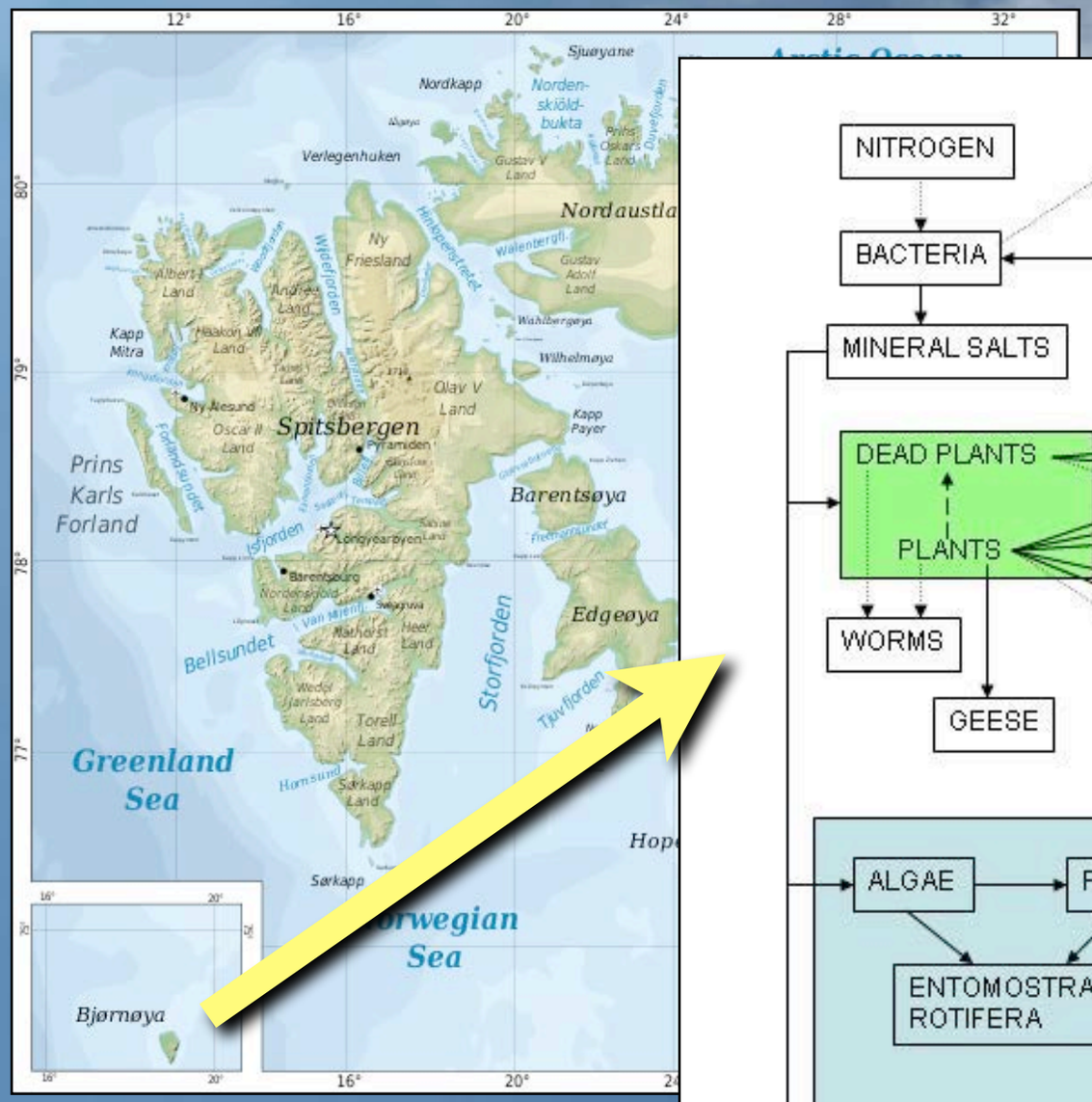
“Bear Island”

1923

Sources: 14, 15

Christopher X Jon Jensen
Pratt

Natural History:



"Bear Island"

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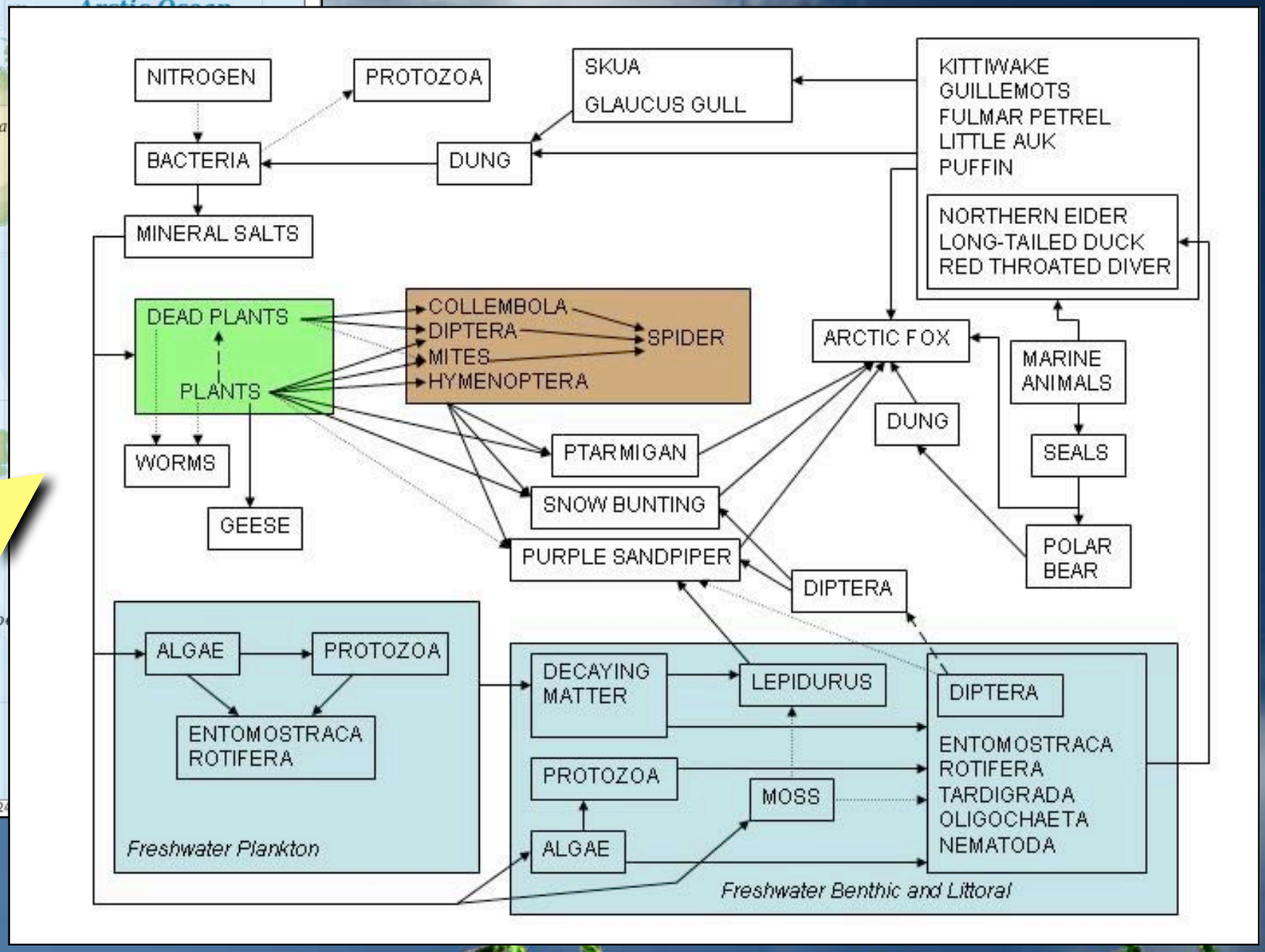
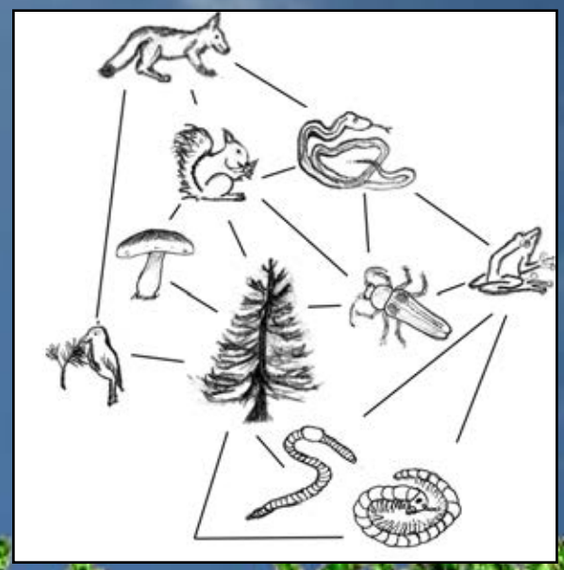


Sources: 14, 15

Christopher X Jon Jensen
Pratt

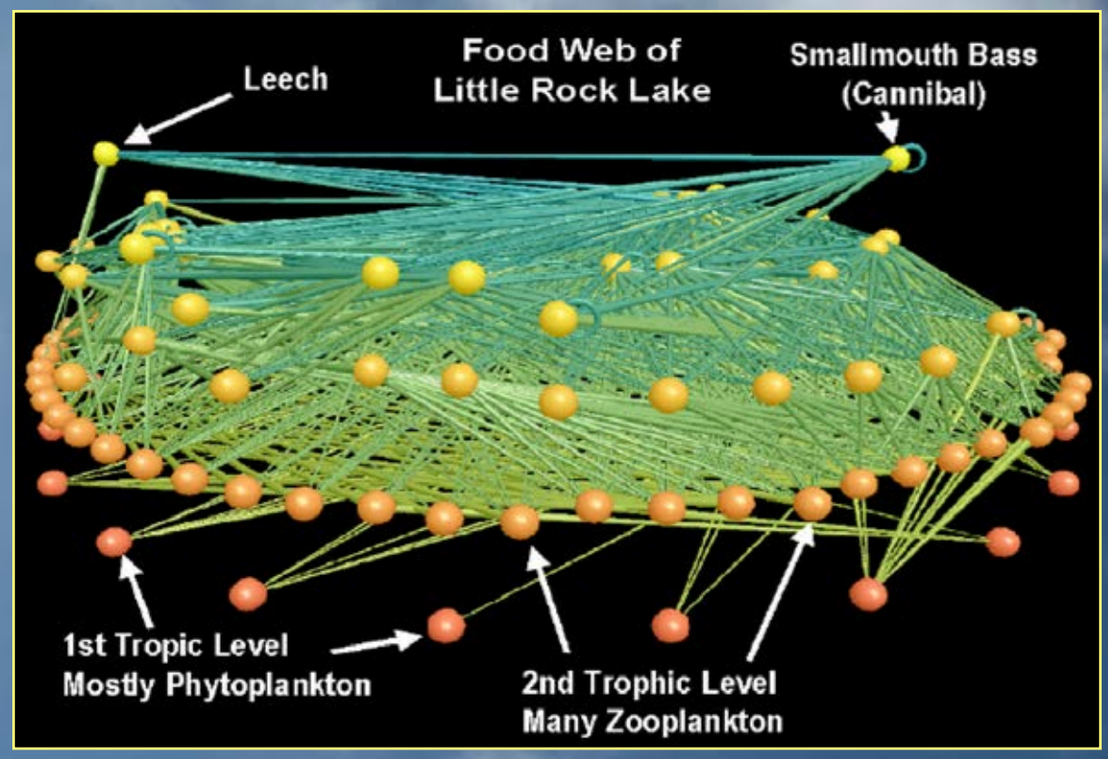
Modern Understanding of Food Webs:



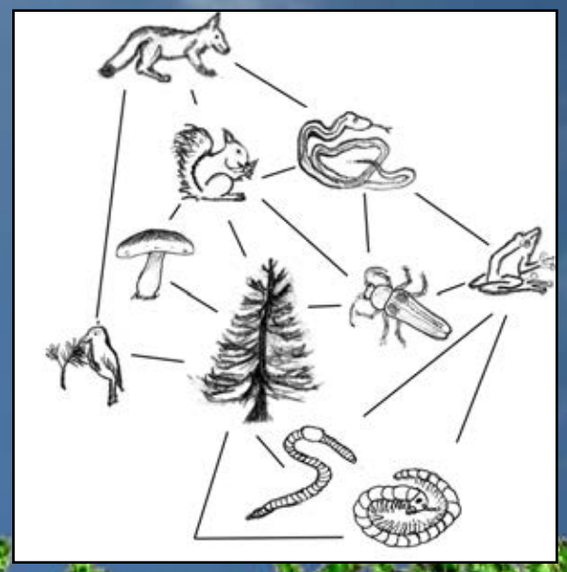
Sources: 16

Christopher X Jon Jensen
Pratt

Modern Understanding of Food Webs:



Wisconsin Lake



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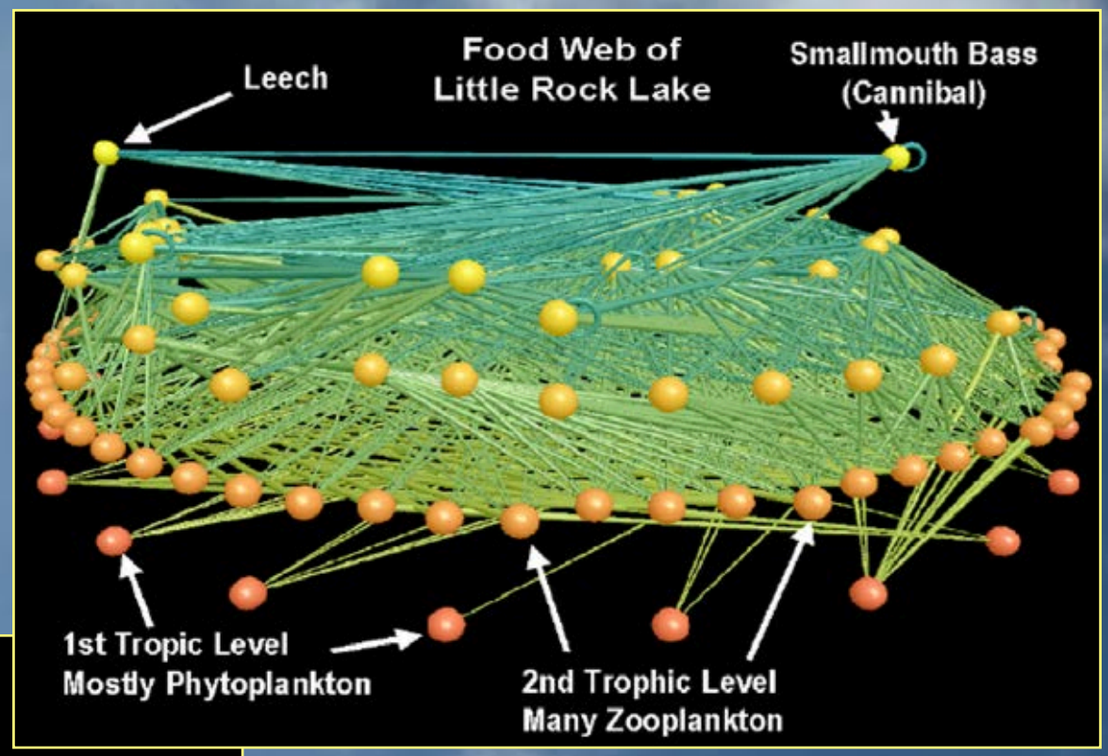
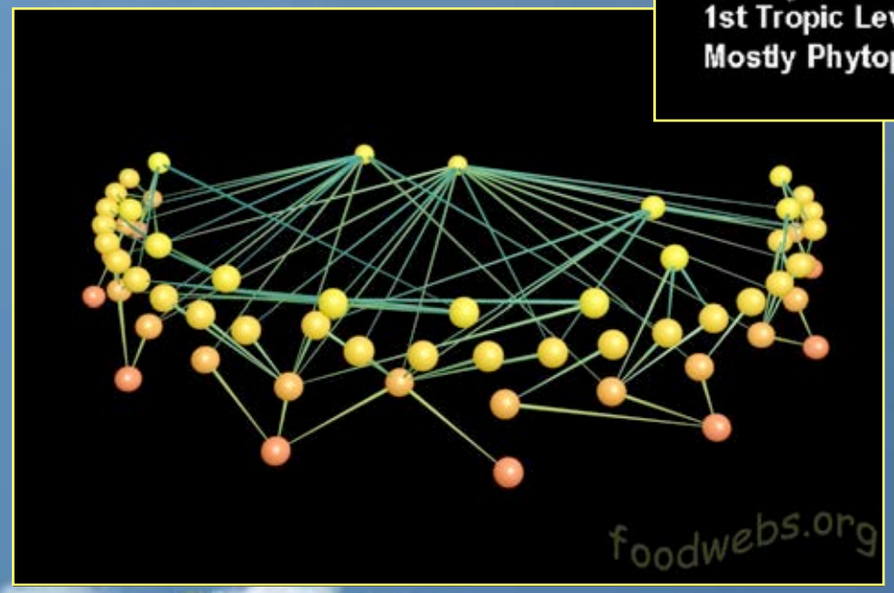
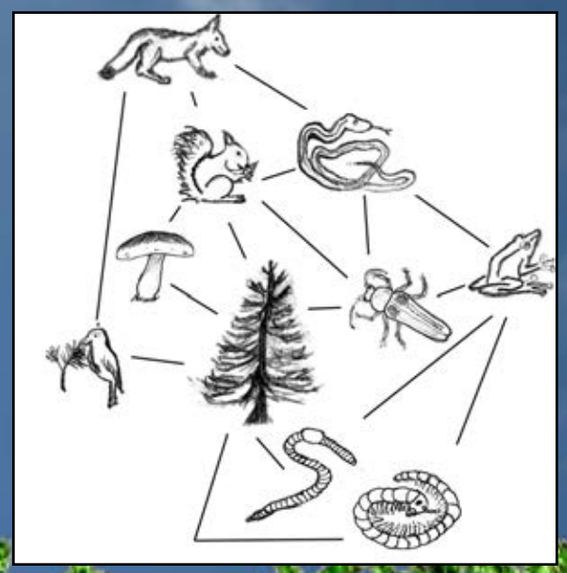


Wisconsin Lake

UK Grassland





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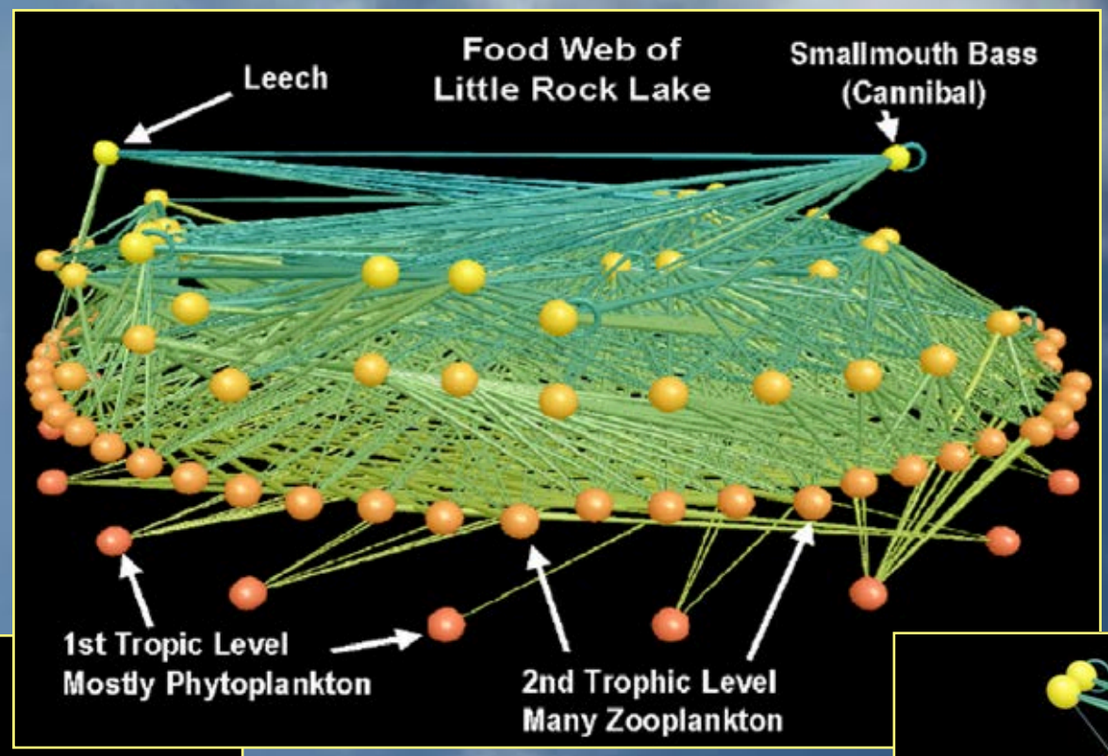

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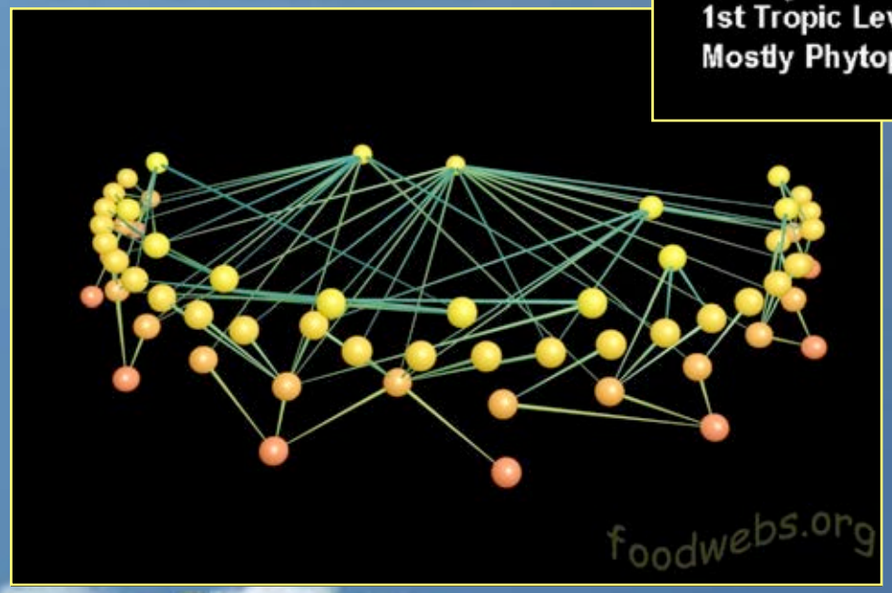
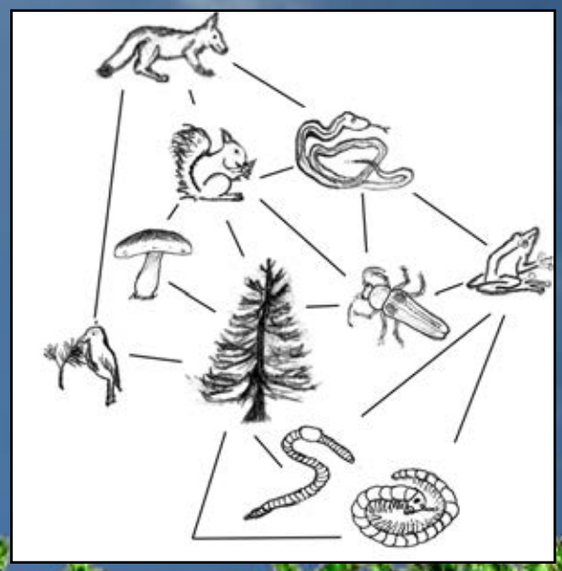
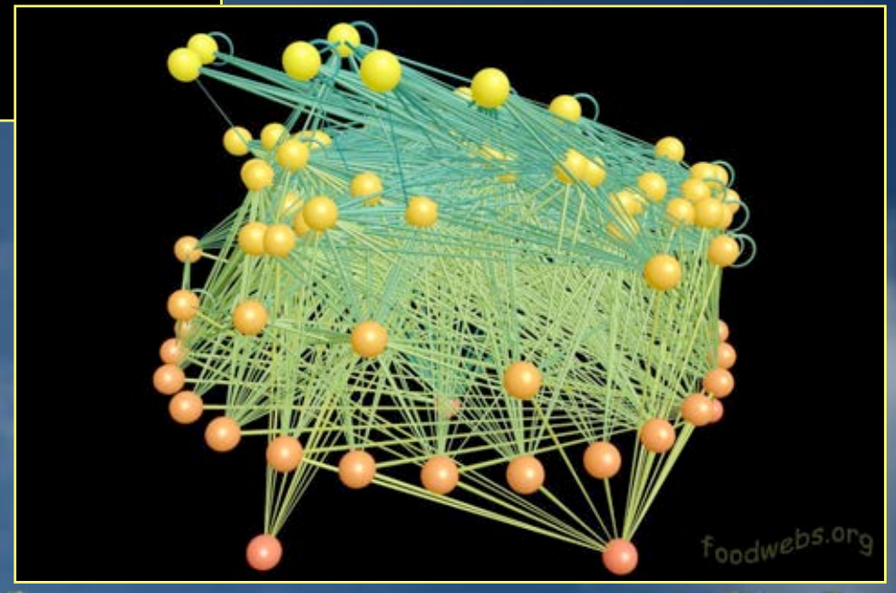
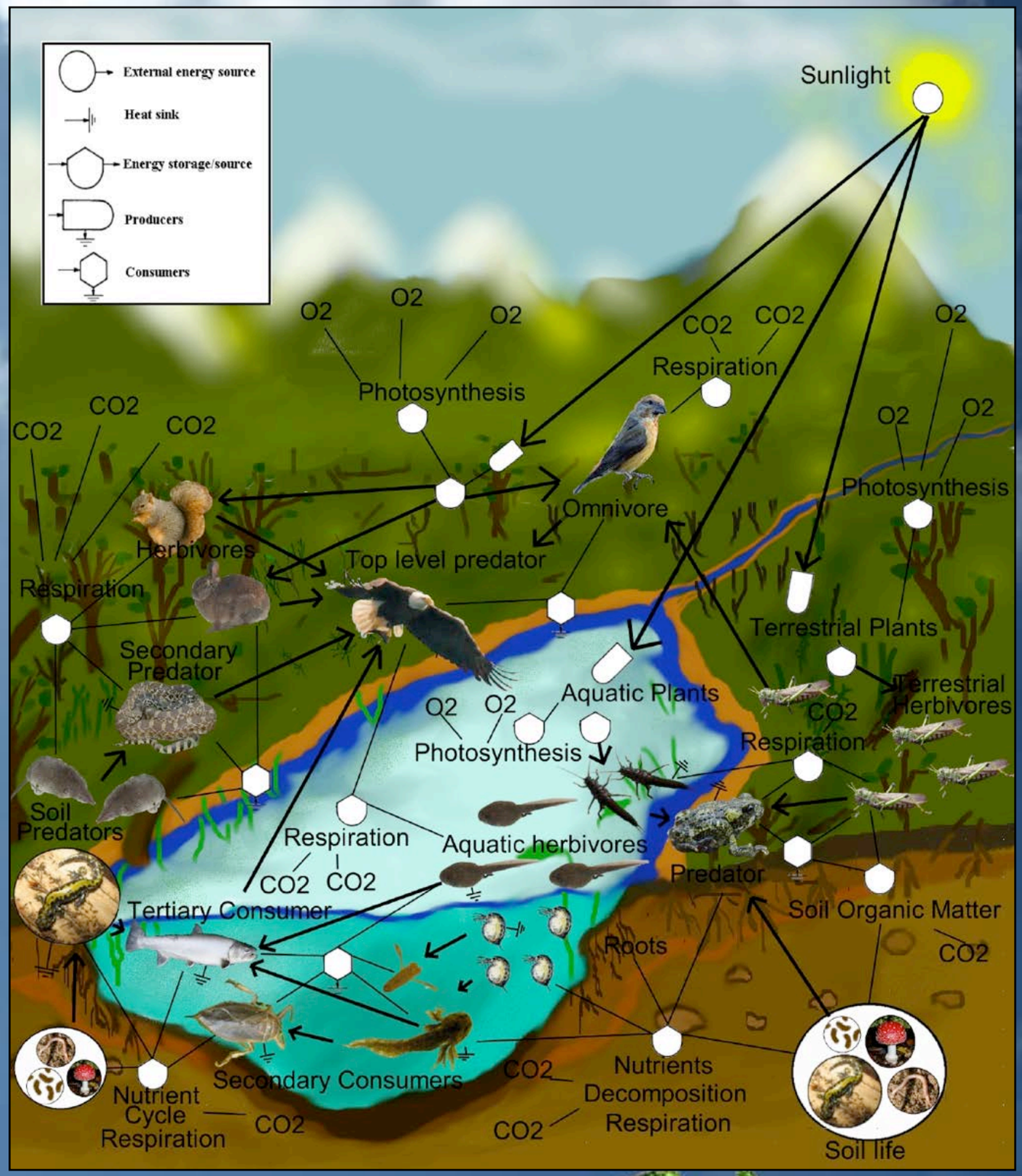




Caribbean Reef

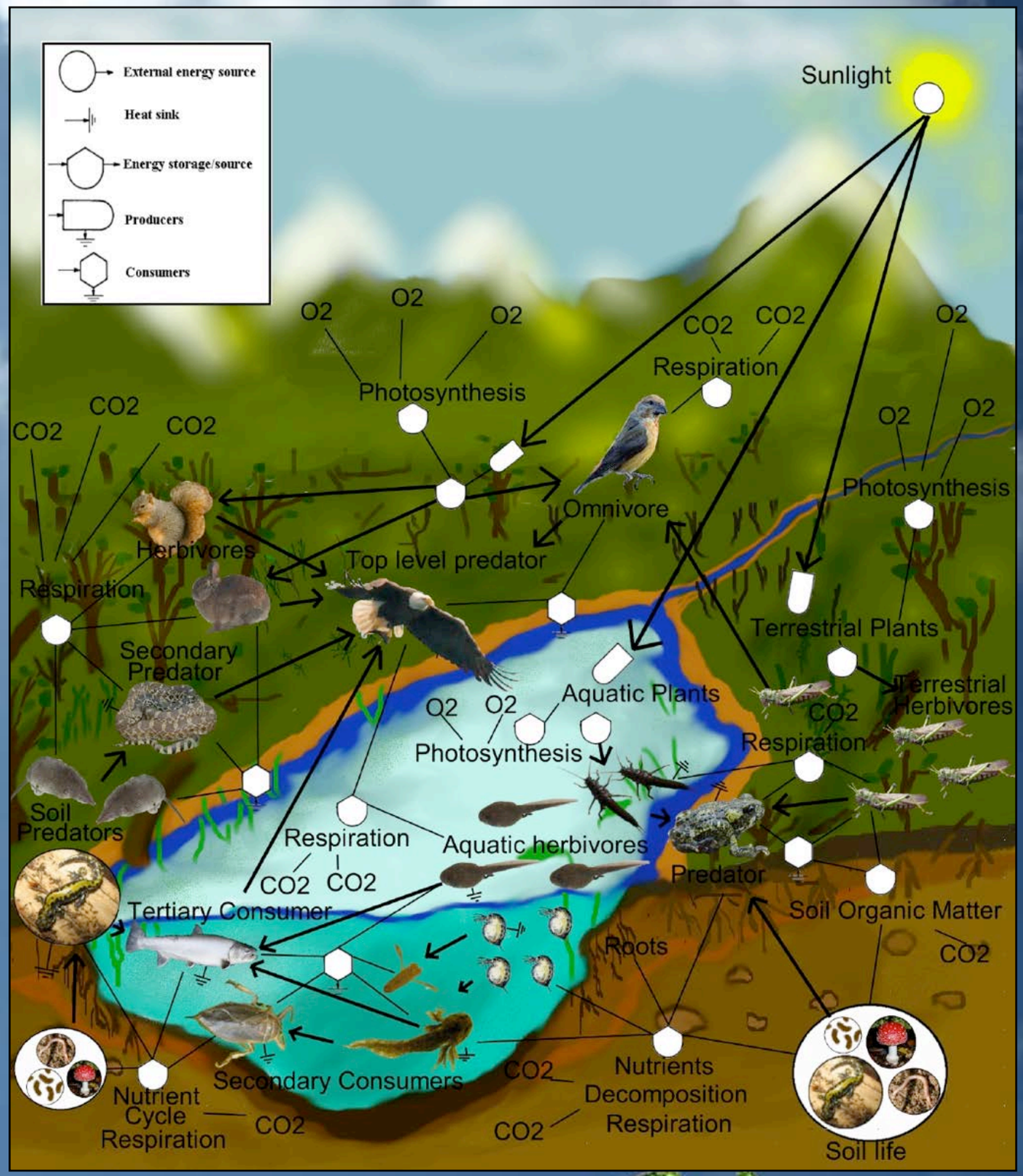


Sources: 16


External energy source
Heat sink
Energy storage/source
Producers
Consumers
Sunlight
O2
O2
O2
Photosynthesis
CO2
CO2
Respiration
O2
O2
Photosynthesis
CO2
CO2
CO2
Herbivores
Respiration
Omnivore
Top level predator
Terrestrial Plants
Secondary Predator
Aquatic Plants
O2
O2
Photosynthesis
Terrestrial Herbivores
CO2
Respiration
Soil Predators
Respiration
CO2
CO2
Aquatic herbivores
Predator
Tertiary Consumer
Soil Organic Matter
CO2
Roots
Secondary Consumers
Nutrient Cycle Respiration
CO2
CO2
Nutrients Decomposition Respiration
Soil life

Sources: 12

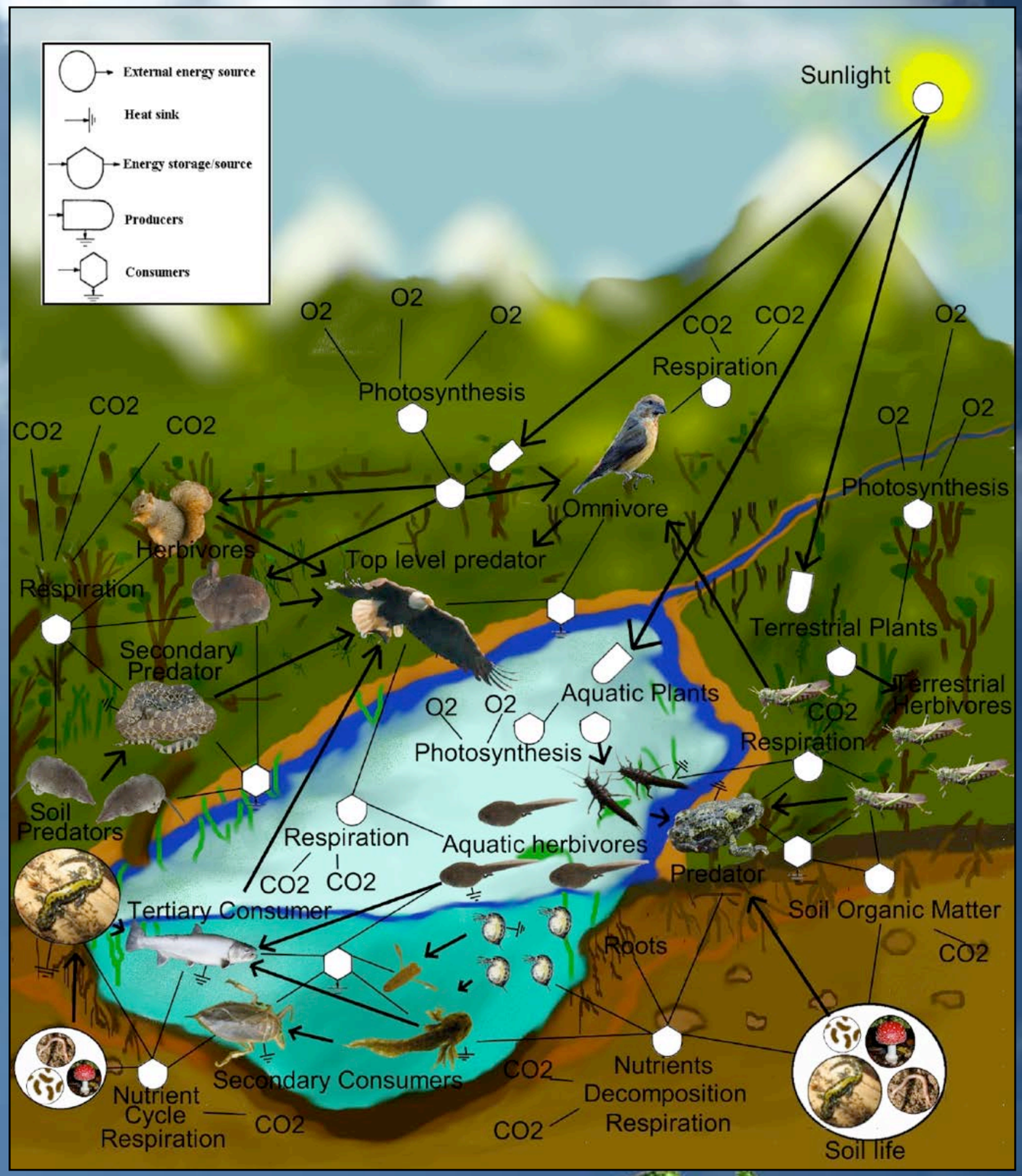
Nutrient flows



Sources: 12

Christopher X Jon Jensen
Pratt

Nutrient flows



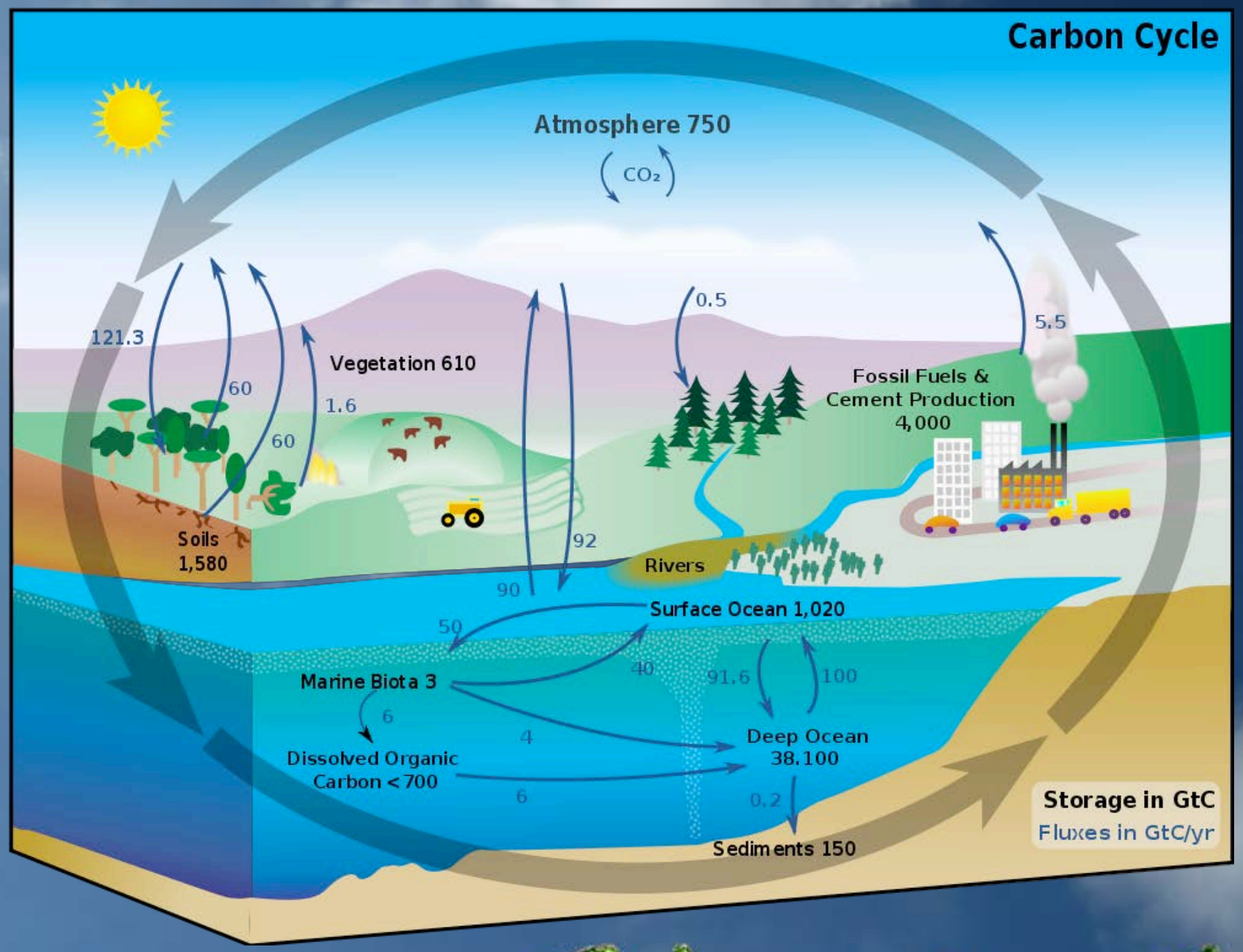
Energy flows

Sources: 12

Christopher X Jon Jensen
Pratt

Nutrient Cycling:

Carbon

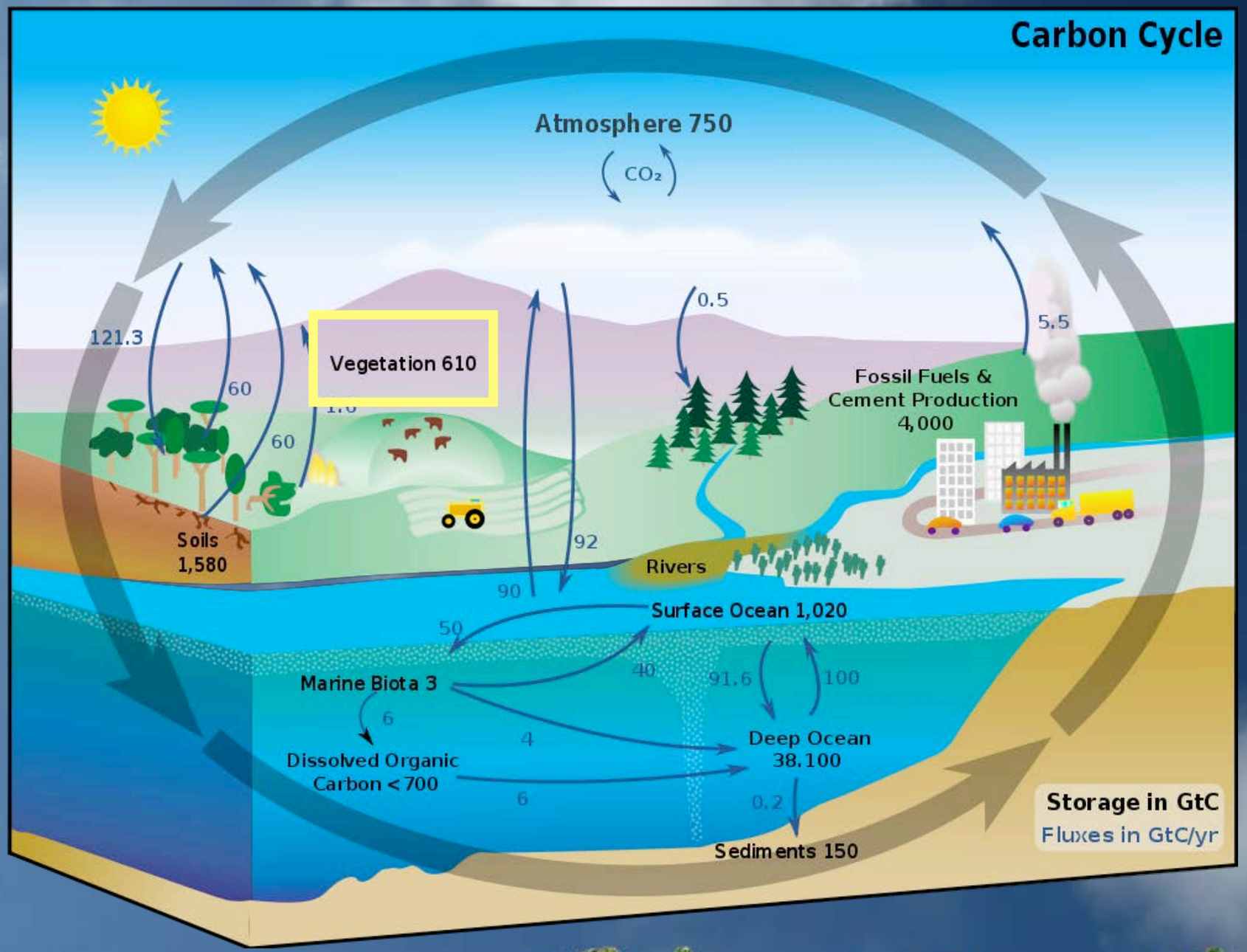


Sources: 17

Christopher X Jon Jensen
Pratt

Nutrient Cycling:

Carbon



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Pratt

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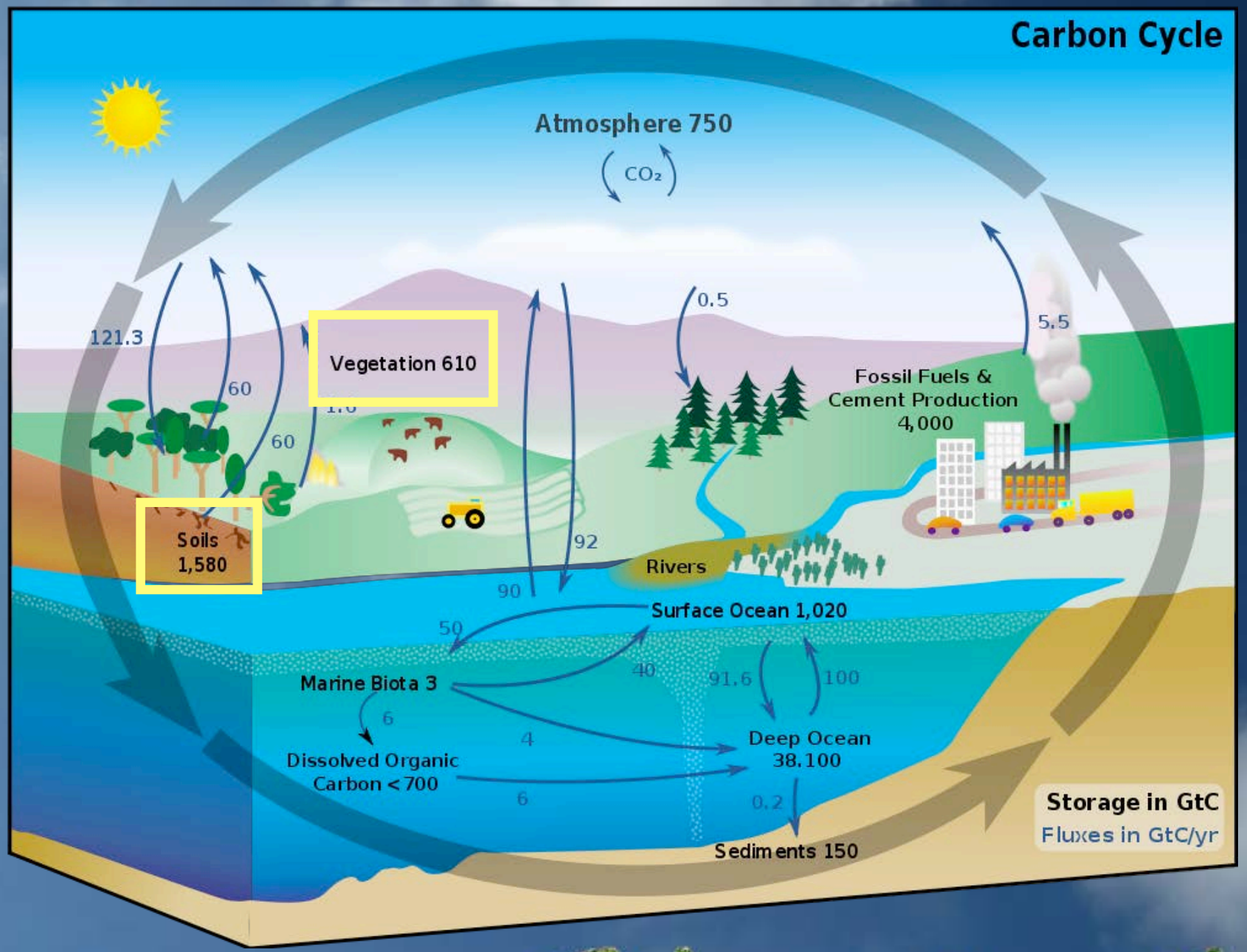
Carbon

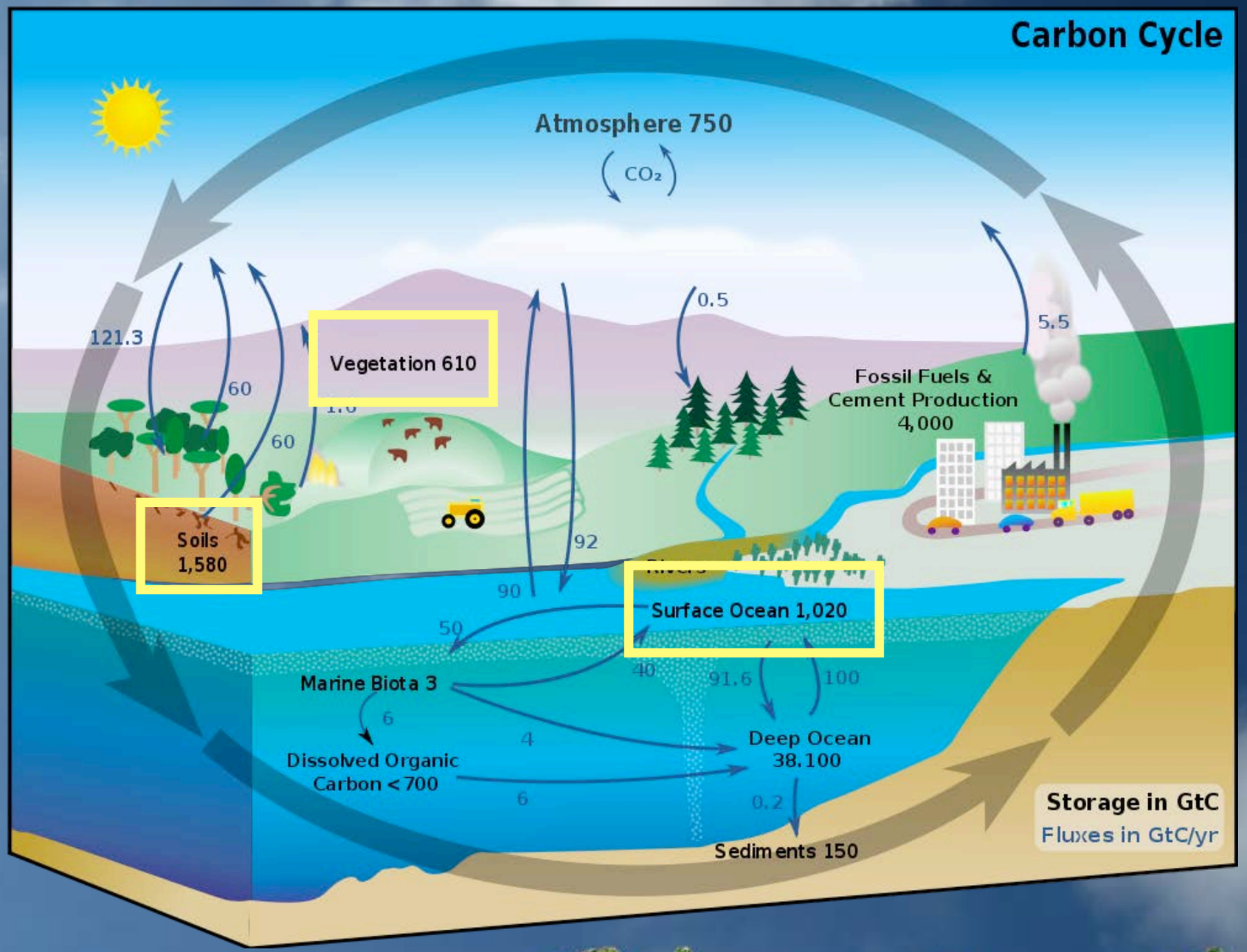


Sources: 17

Christopher X Jon Jensen
Pratt

Nutrient Cycling:

Carbon

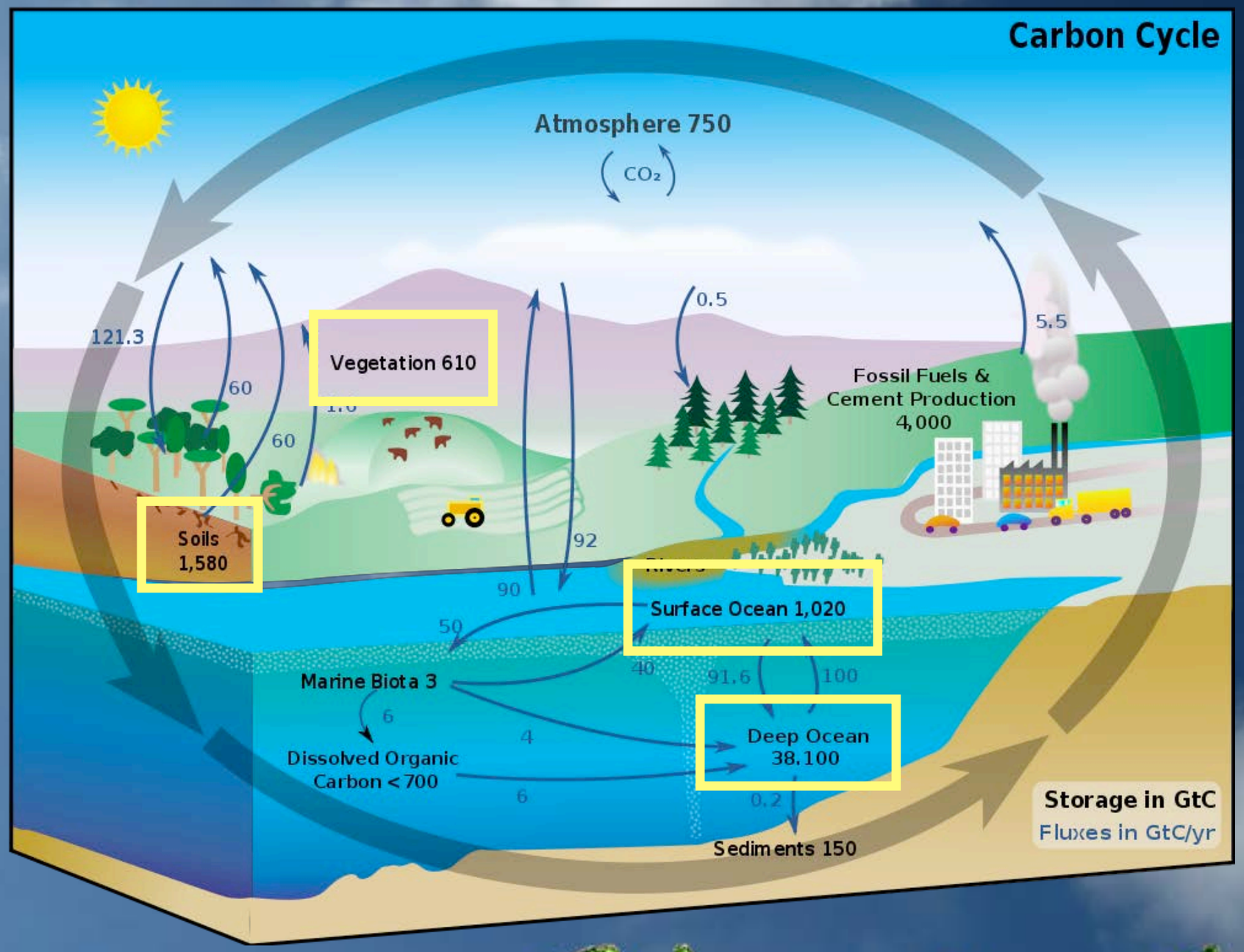


Sources: 17

Christopher X Jon Jensen
Pratt

Nutrient Cycling:

Carbon

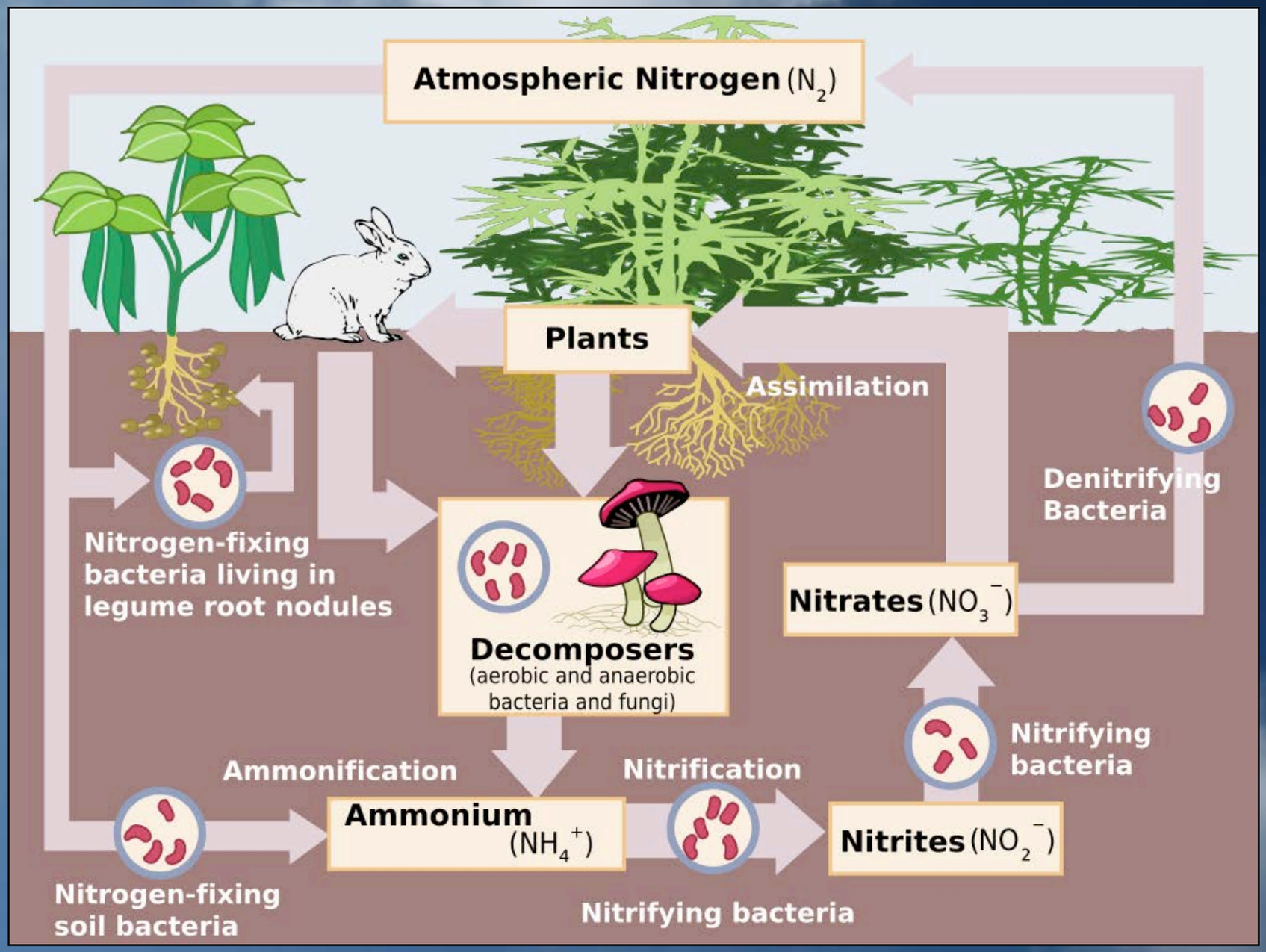


Sources: 17

Christopher X Jon Jensen
Pratt

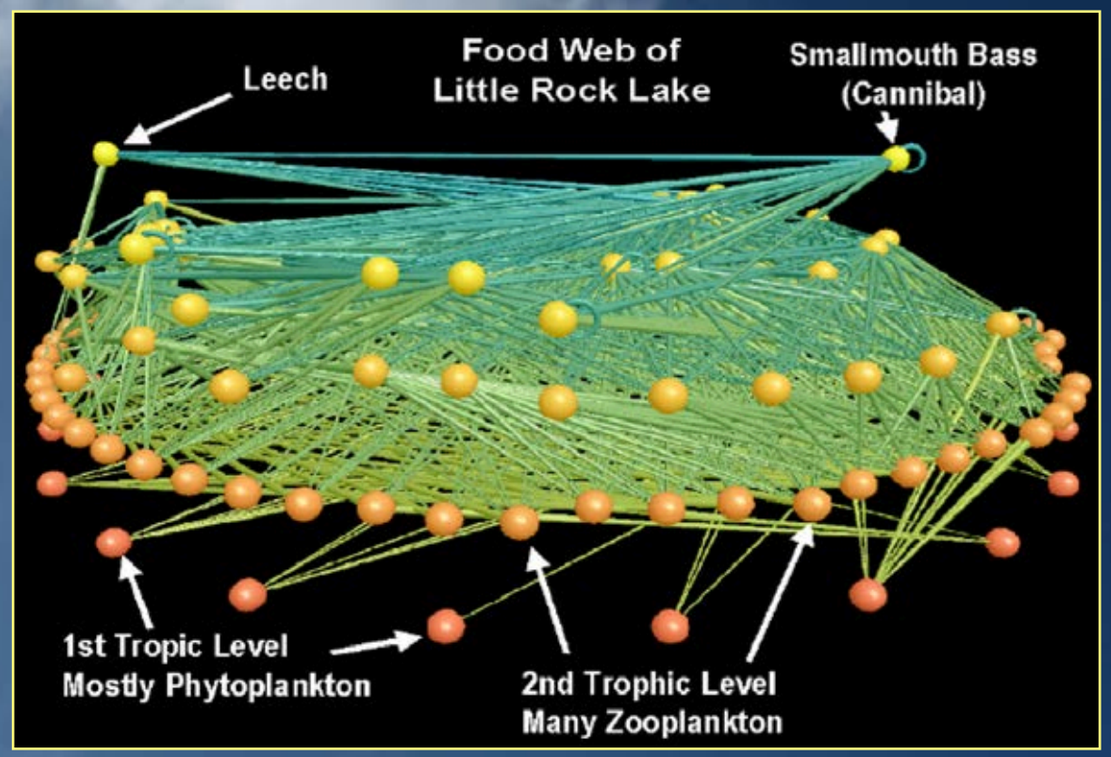
Nutrient Cycling:

Nitrogen



Sources: 18

Understanding Networks:



Sources: 19, 20

Christopher X Jon Jensen
Pratt

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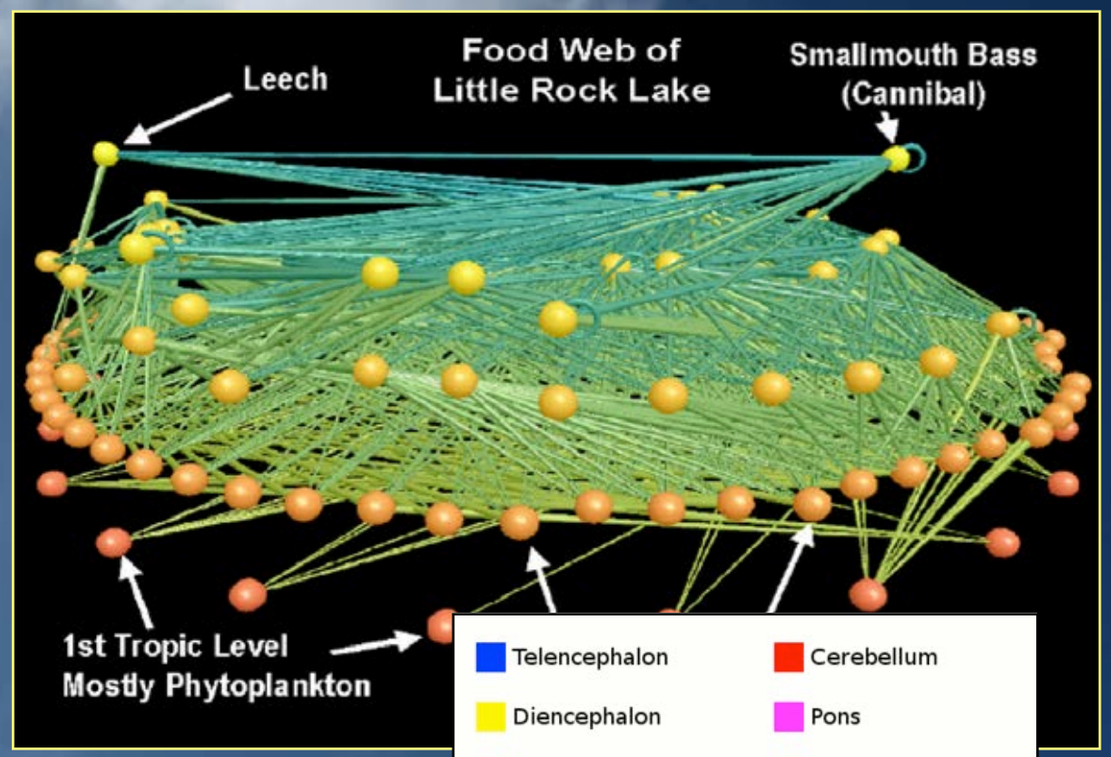

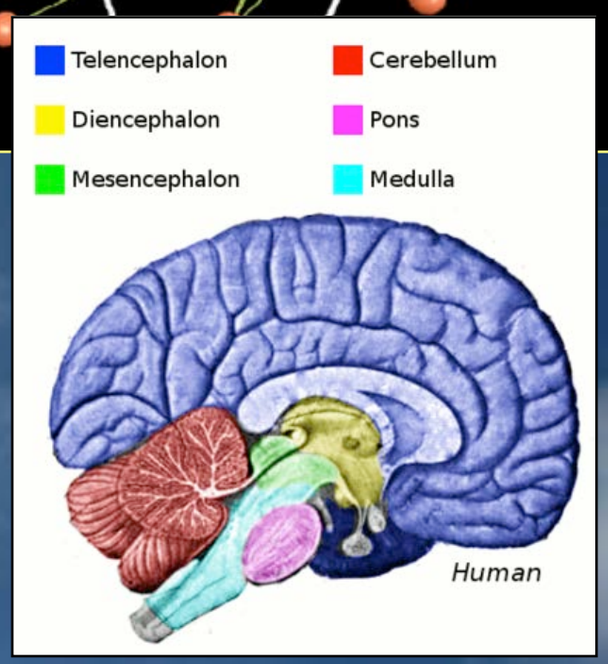

Sources: 19, 20

Christopher X Jon Jensen
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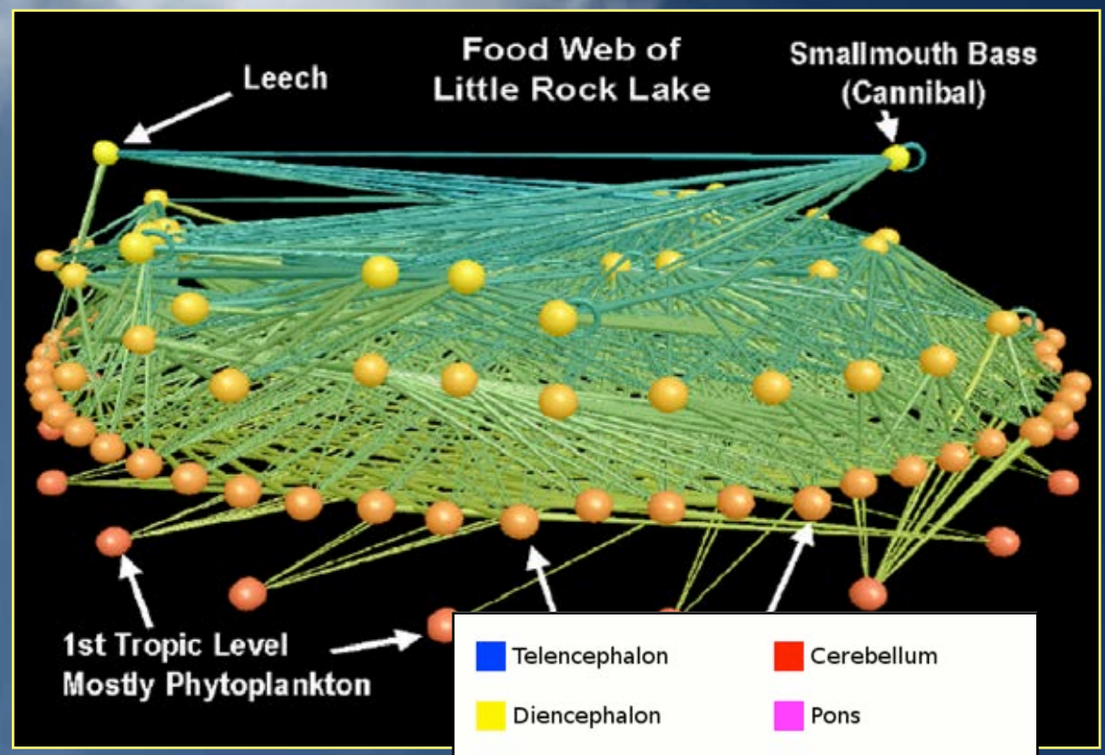

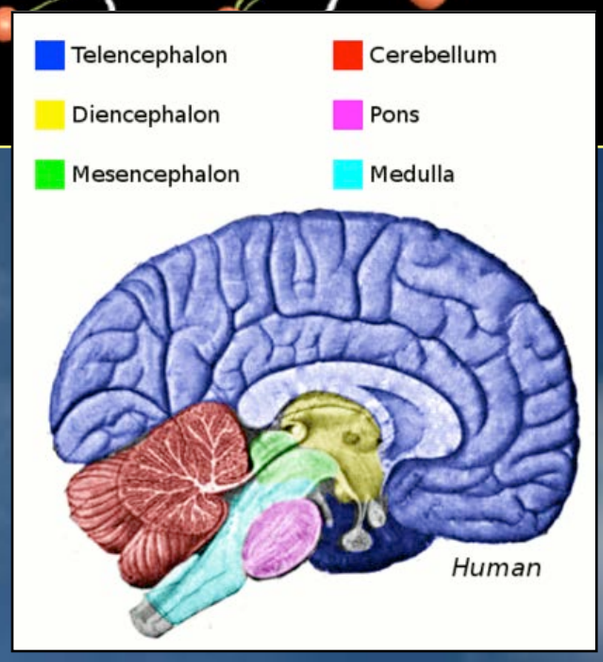

Sources: 19, 20

Christopher X Jon Jensen
Pratt

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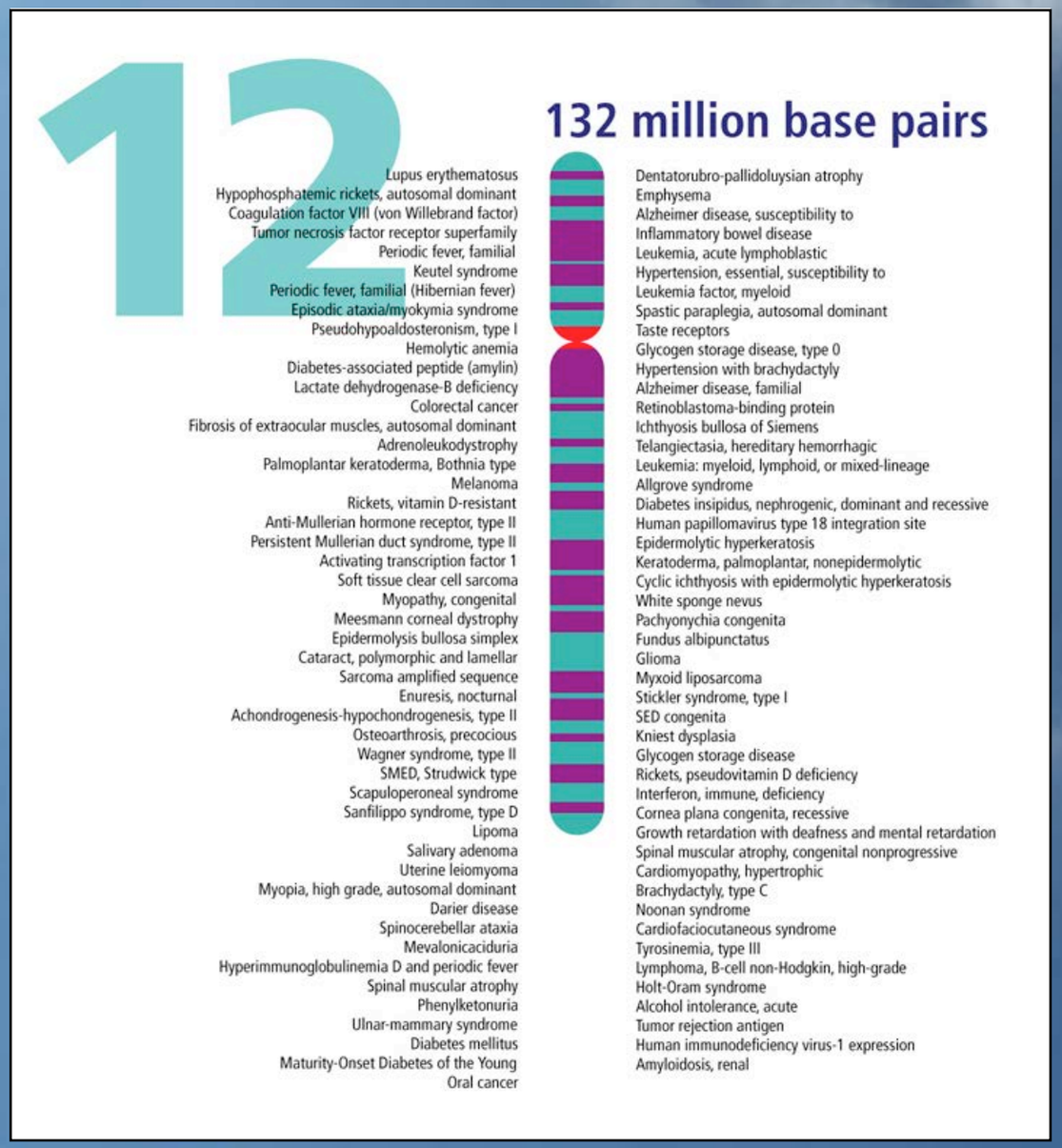
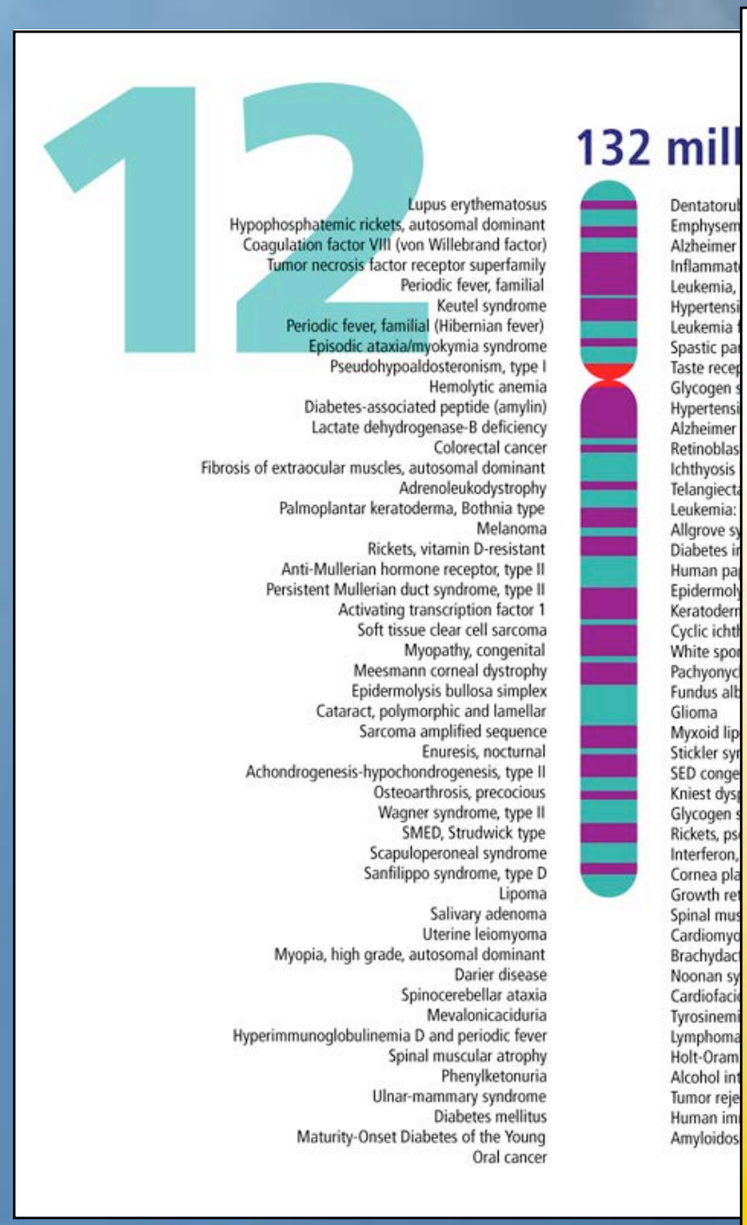
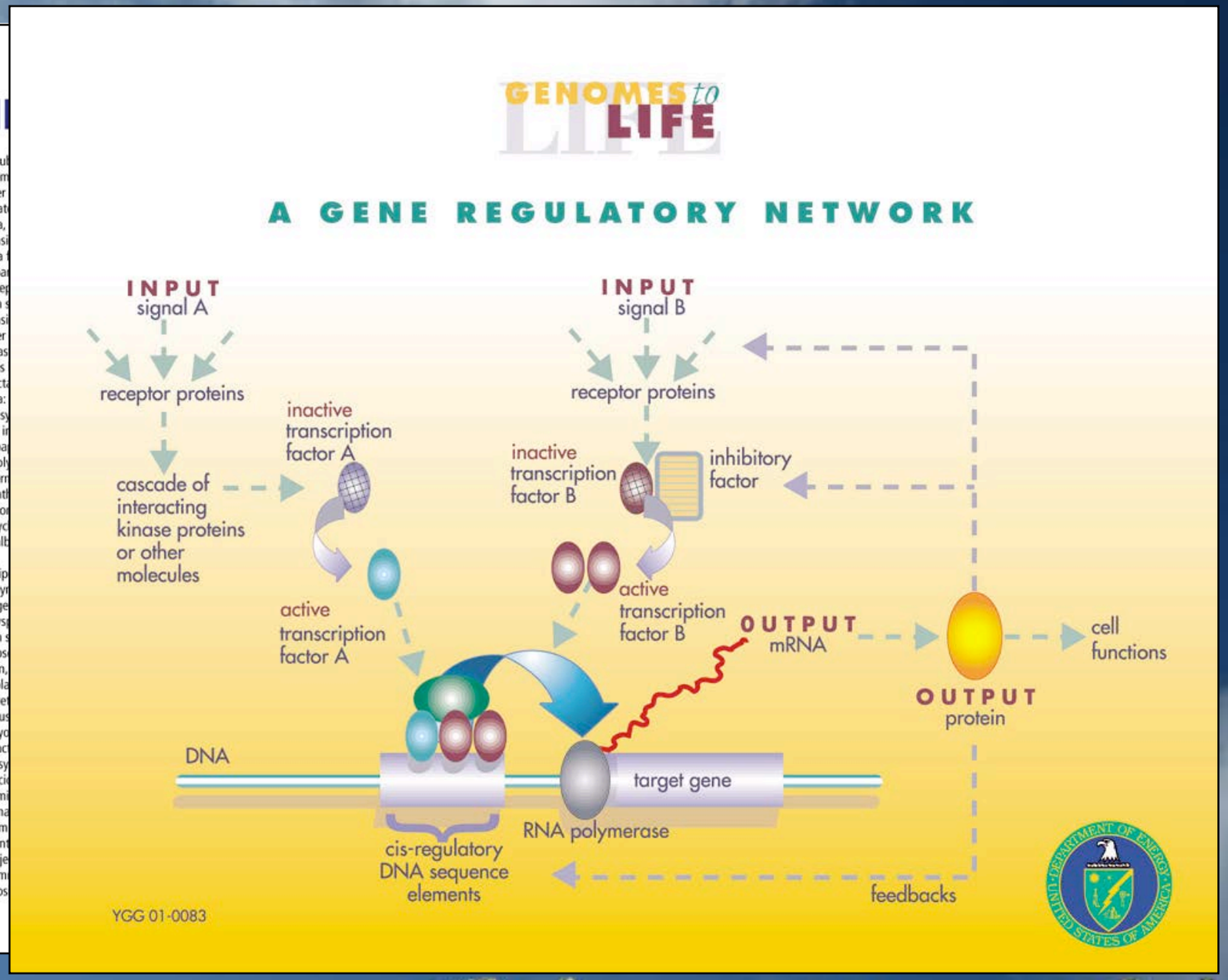


Sources: 21, 22

Christopher X Jon Jensen
Pratt

Understanding Networks:





Sources: 21, 22

Christopher X Jon Jensen
Pratt

Patterns in the networking of ecosystems:

Sources: 23, 24

Christopher X Jon Jensen
Pratt

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Sources: 23, 24

Christopher X Jon Jensen
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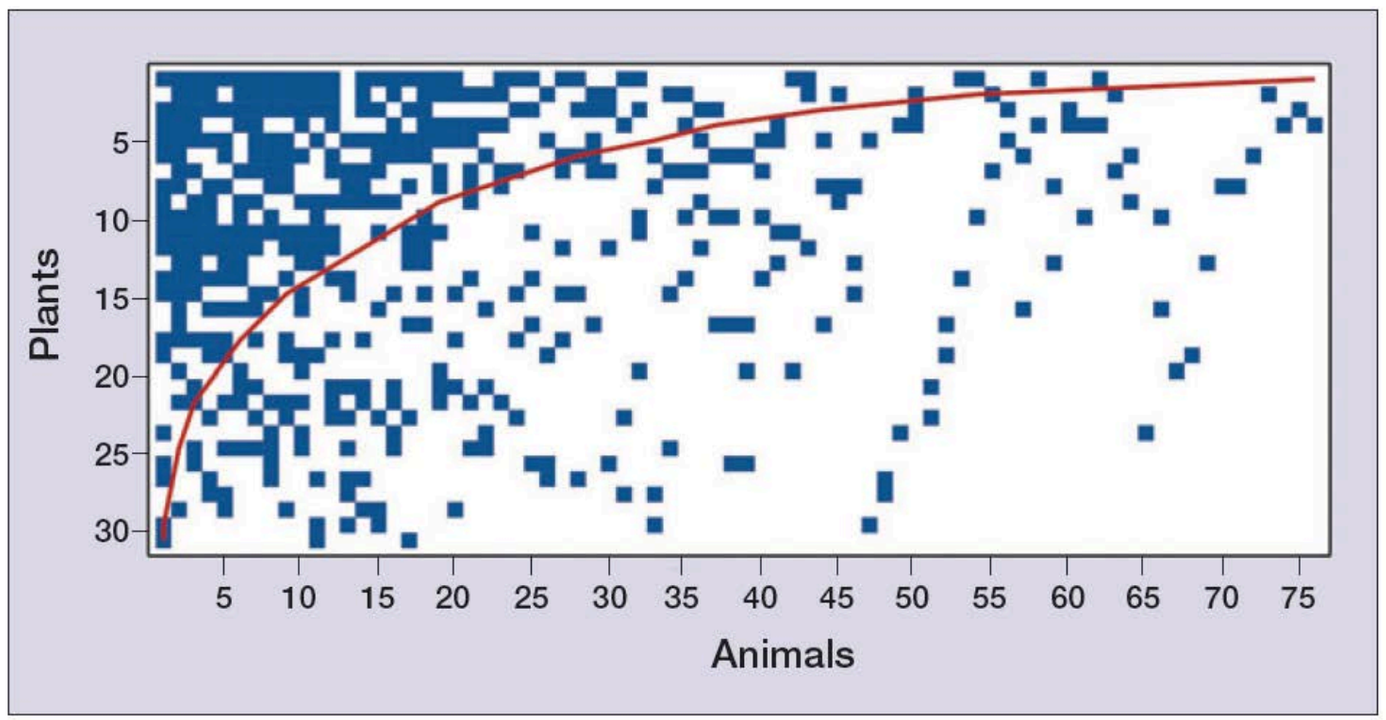
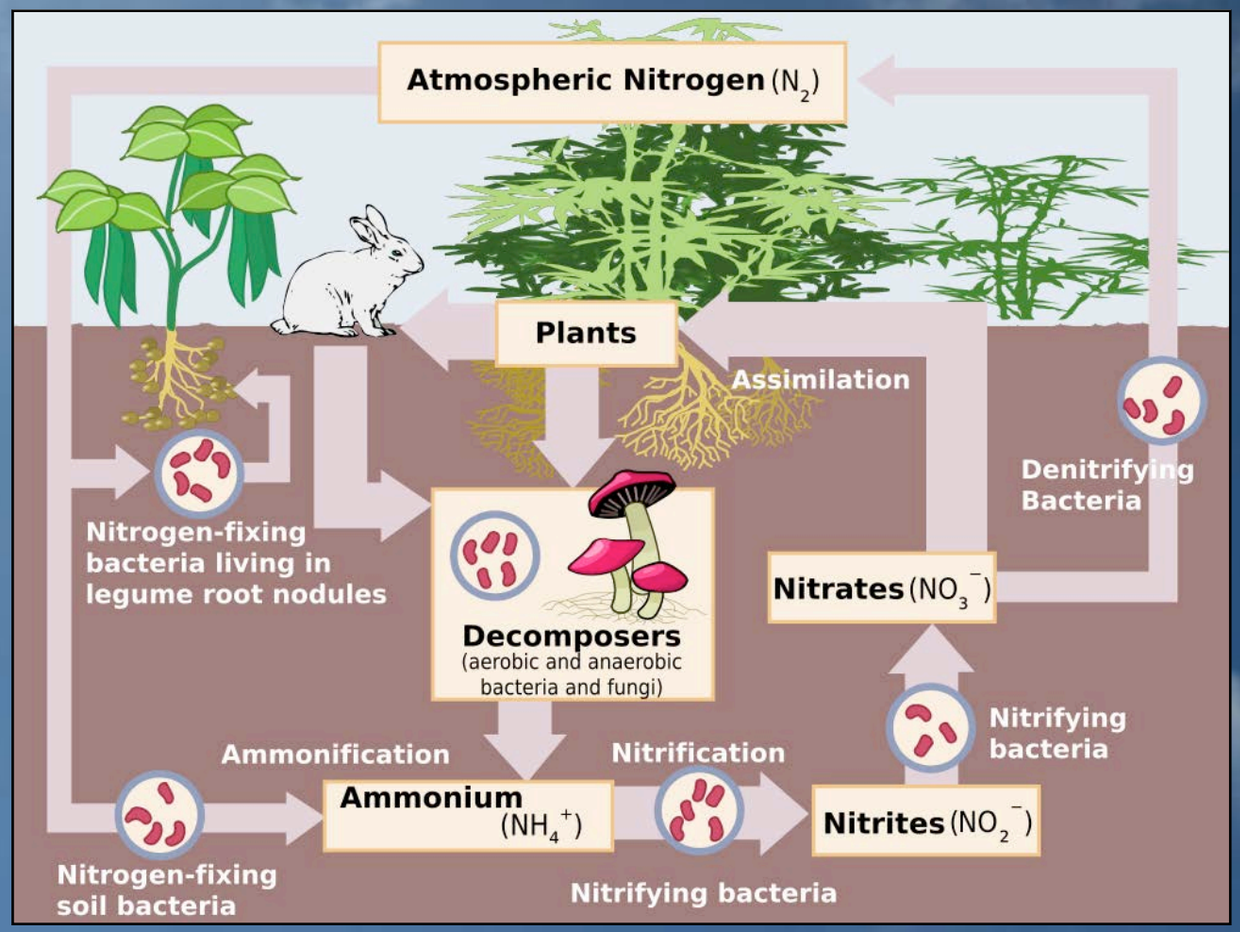


Figure 4. *Mutualistic networks are nested: species interacting with the specialists form well-defined subsets of the species that generalists interact with. This results in a cohesive network (generalist plants and animals interact among themselves) with asymmetric specialization (specialists interact with the most generalist species). Rows represent plants, columns represent animals, and a blue square indicates that the plant in the row and the animal in the column interact. This matrix representation is equivalent to a network representation. Community is the same as that depicted in Figure 2.*

Sources: 23, 24

Christopher X Jon Jensen
Pratt

How does evolution produce sustainable ecosystems?



Sources: 18

Christopher X Jon Jensen
Pratt

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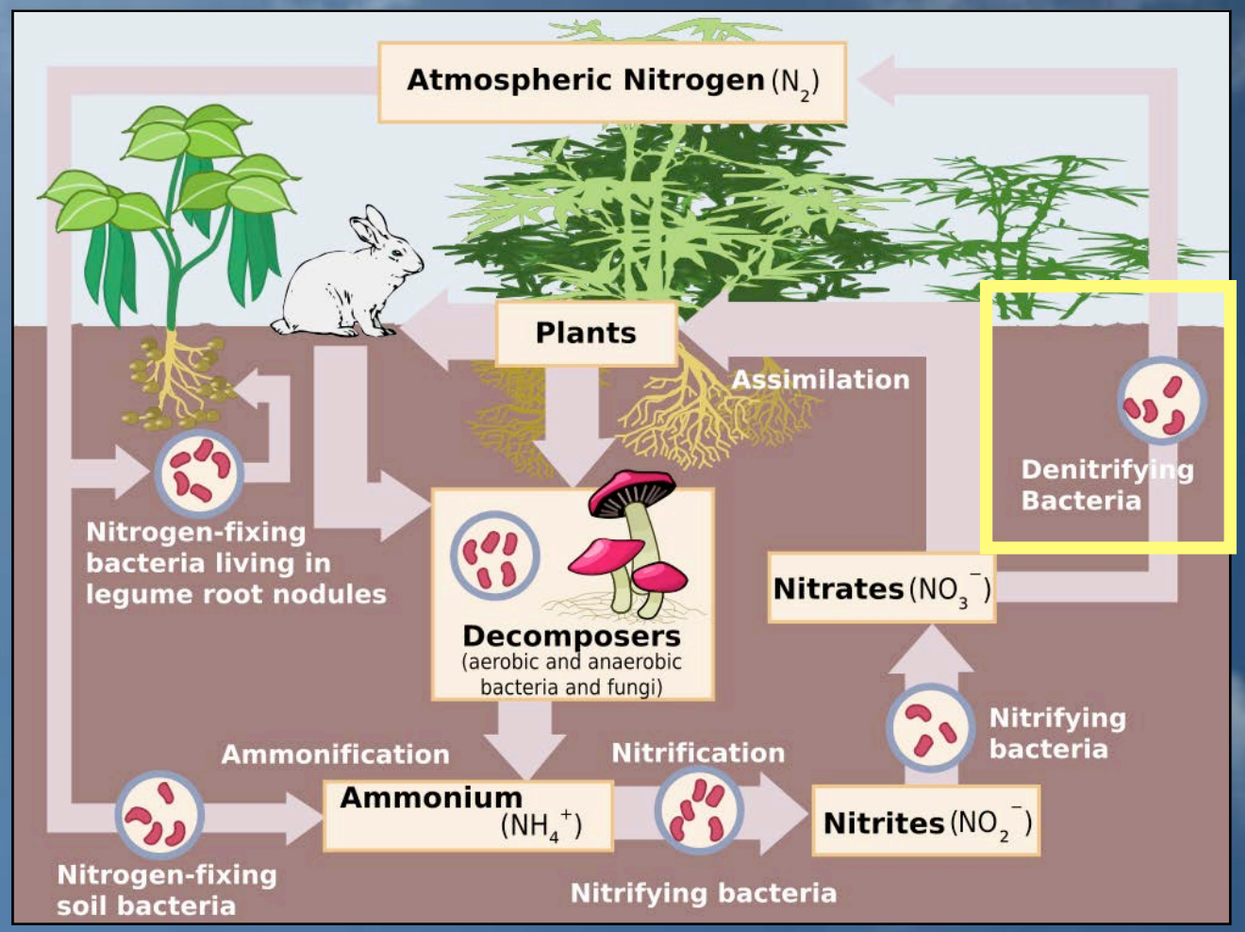
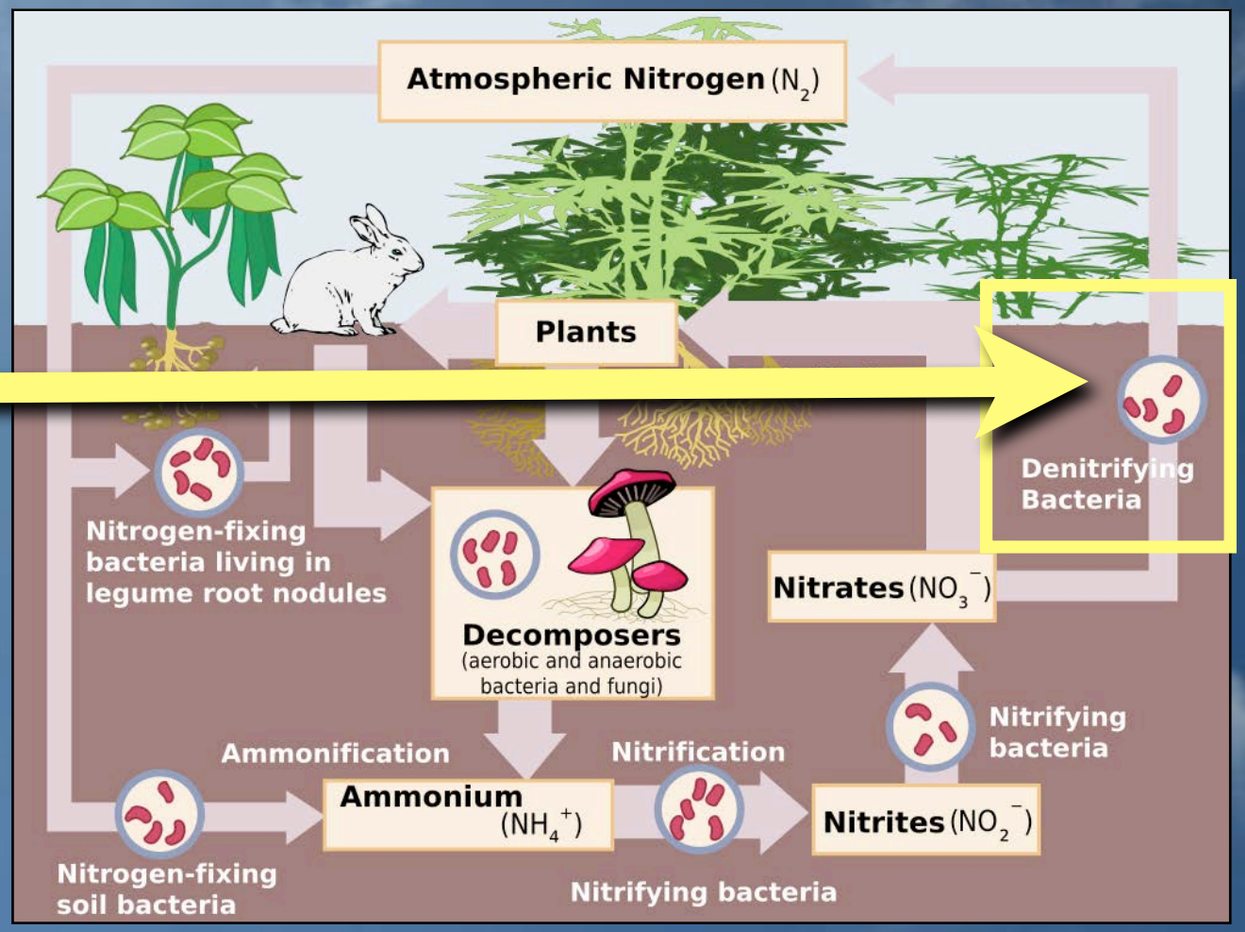


Sources: 18

Christopher X Jon Jensen
Pratt

How does evolution produce sustainable ecosystems?

"Free Market"
Hypothesis:
Dynamic selection on individual traits makes small adjustments to population-wide characteristics, leading to a self-adjusting, balanced ecosystem



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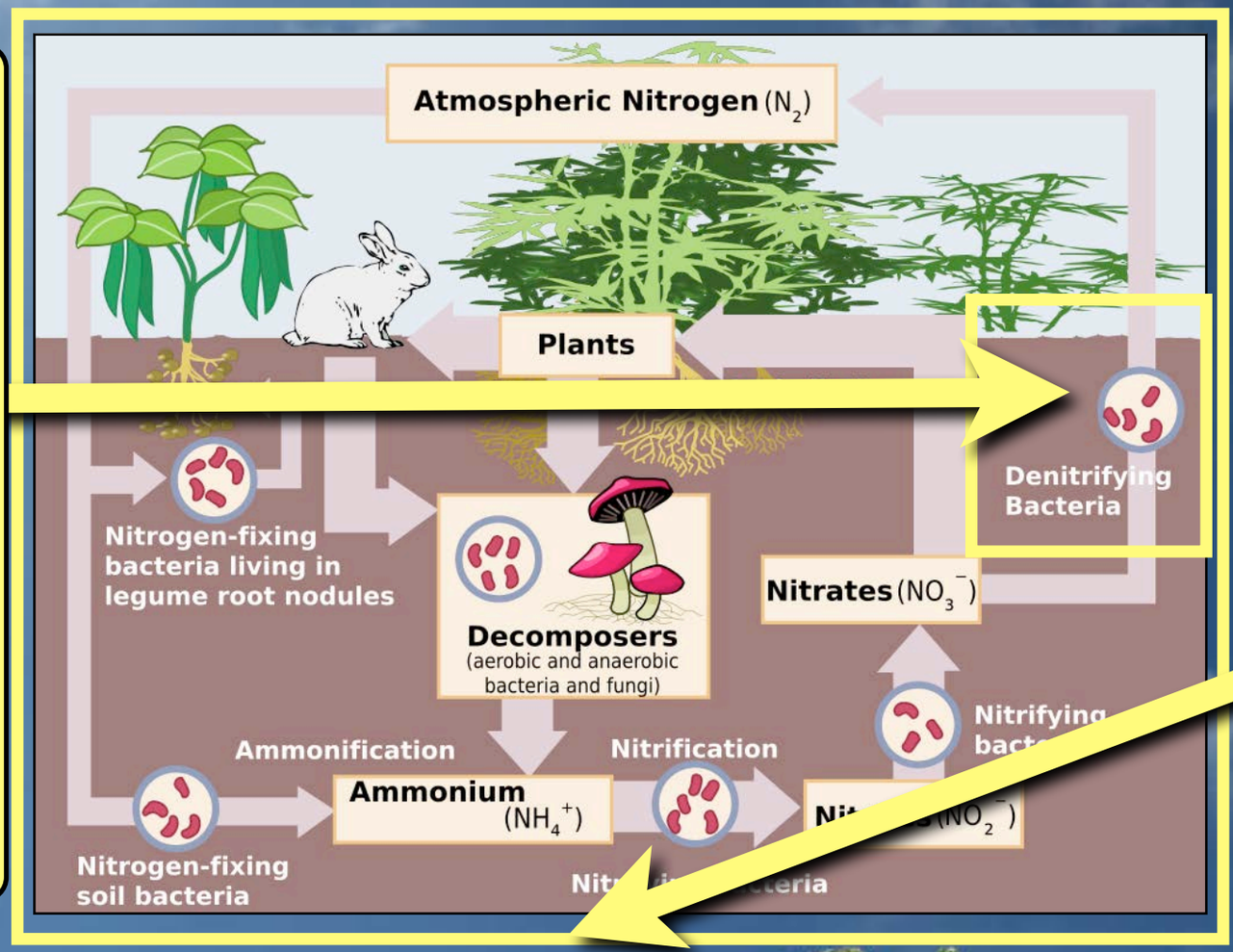

"Ecological Exclusion"

Hypothesis:
Ecosystems that go out of balance collapse, leading to the local loss of all species; the ecosystems we see today are those which have maintained stability.

Sources: 18

Christopher X Jon Jensen
Pratt

Testable Hypotheses:

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- Ecosystems are composed of “functional guilds”, each of which performs a critical function.

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- Ecosystems respond to external changes through a series of compensatory changes in populations and/or structure.

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- Ecosystems are composed of "functional guilds", each of which performs a critical function.
- Ecosystems respond to external changes through a series of compensatory changes in populations and/or structure.
- Diversity makes ecosystems more resilient.

Experimental Tests:

[AIR]

CO_2: GREATER GROWTH FOR SOME

Issue: Scientists estimate that the oceans and terrestrial ecosystems soak up at least half of the CO_2 released by burning fossil fuels. Plants do it by using the gas to produce carbohydrates during photosynthesis. But will that conversion continue at higher CO_2 concentrations? And will more CO_2 alter the sugars, carbohydrates and protective compounds in plants, in turn helping or hindering insects and pathogens?

Experiment: The Free-Air CO_2 Enrichment (FACE) experiment has been running at Oak Ridge National Laboratory for more than 10 years, under Richard Norby. It consists of four study areas ringed by vent pipes suspended from towers (*photograph* and *illustration*). The pipes release CO_2 such that the trees all receive a selected amount. Similar FACE experiments operate at almost 35 other natural and managed ecosystems worldwide, ranging from one-meter-diameter plots in bogs, 23-meter plots on croplands and 30-meter plots on forest plantations.

Results: The data confirm that higher CO_2 levels stimulate photosynthesis, which incorporates more carbon into plant tissues. This net primary production (NPP) is also sustained over multiple growing seasons. NPP in forest experiments in Wisconsin, North Carolina, Tennessee and Italy has increased 23 percent annually when CO_2 is raised from the ambient level of 388 parts per million (ppm) to 550 ppm—a level that could arise within 100 years if nations do nothing to curb emissions. Recent modeling results suggest that plants will respond positively to elevated CO_2 levels, although gains may be tempered where soil contains insufficient nutrients such as nitrogen.

Increased NPP has been consistent across the FACE plots worldwide. But NPP indicates only the amount of carbon added to a plant; it does not reflect the long-term fate of that carbon. In the North Carolina loblolly pine forest, the additional carbon was stored primarily in stems and branches, where it might persist for decades. In Tennessee's sweetgum forest, however, the carbon appeared mostly in new, small roots. Such roots are advantageous, of course, but live for only a few weeks to a year; much of the carbon returns to the atmosphere as microbes decompose the roots. Scientists are trying to understand what drives carbon to one destination or another; we will learn more as trees are harvested and soils are excavated in the coming months at various sites.

FACE experiments have already paid off. James Randerson of the University of California, Irvine, and scientists at Oak Ridge, the National Center for Atmospheric Research in Boulder, Colo., and other institutions have used the data to evaluate and improve the Community Climate System Model, which simulates the physical, chemical and biological processes that drive the earth's climate system.

FREE-AIR CO_2 ENRICHMENT EXPERIMENT

RINGS of vent pipes at the Free-Air CO_2 Enrichment experiment simulate heightened emissions by pumping the gas through trees.

Sources: 25, 26

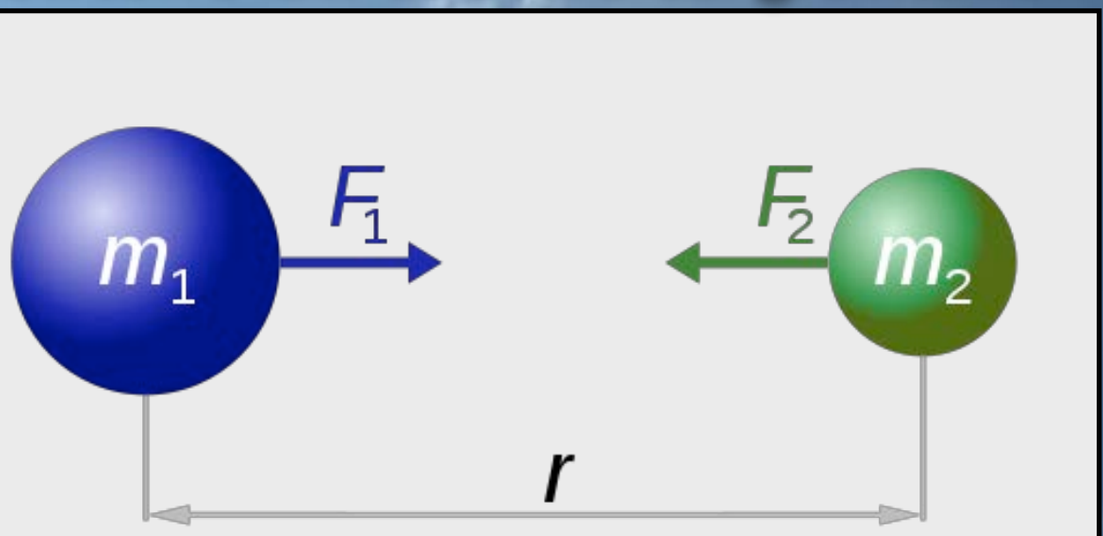
Christopher X Jon Jensen
Pratt

Usable Theory:

Sources: 27, 28

Usable Theory:

Newton's law of universal gravitation



$$F_1 = F_2 = G\frac{m_1 \times m_2}{r^2}$$

Sources: 27, 28

Usable Theory:

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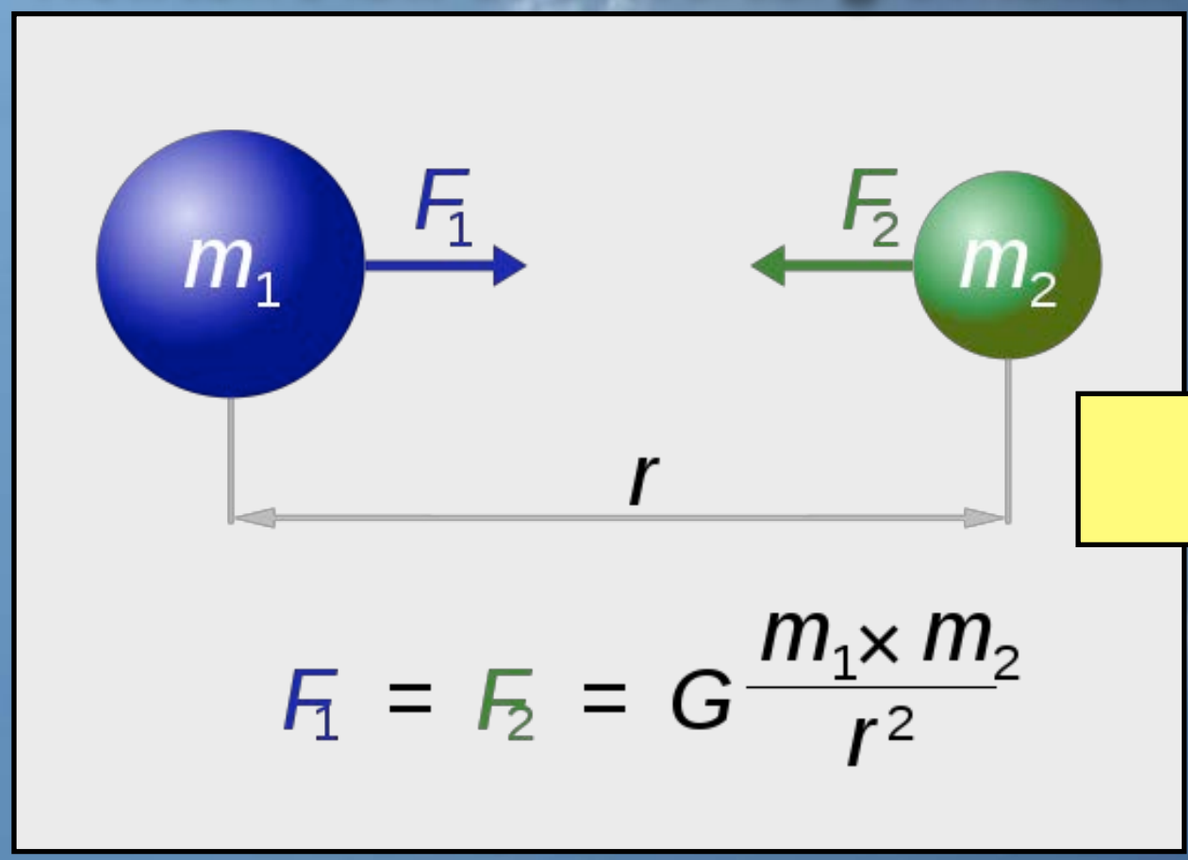
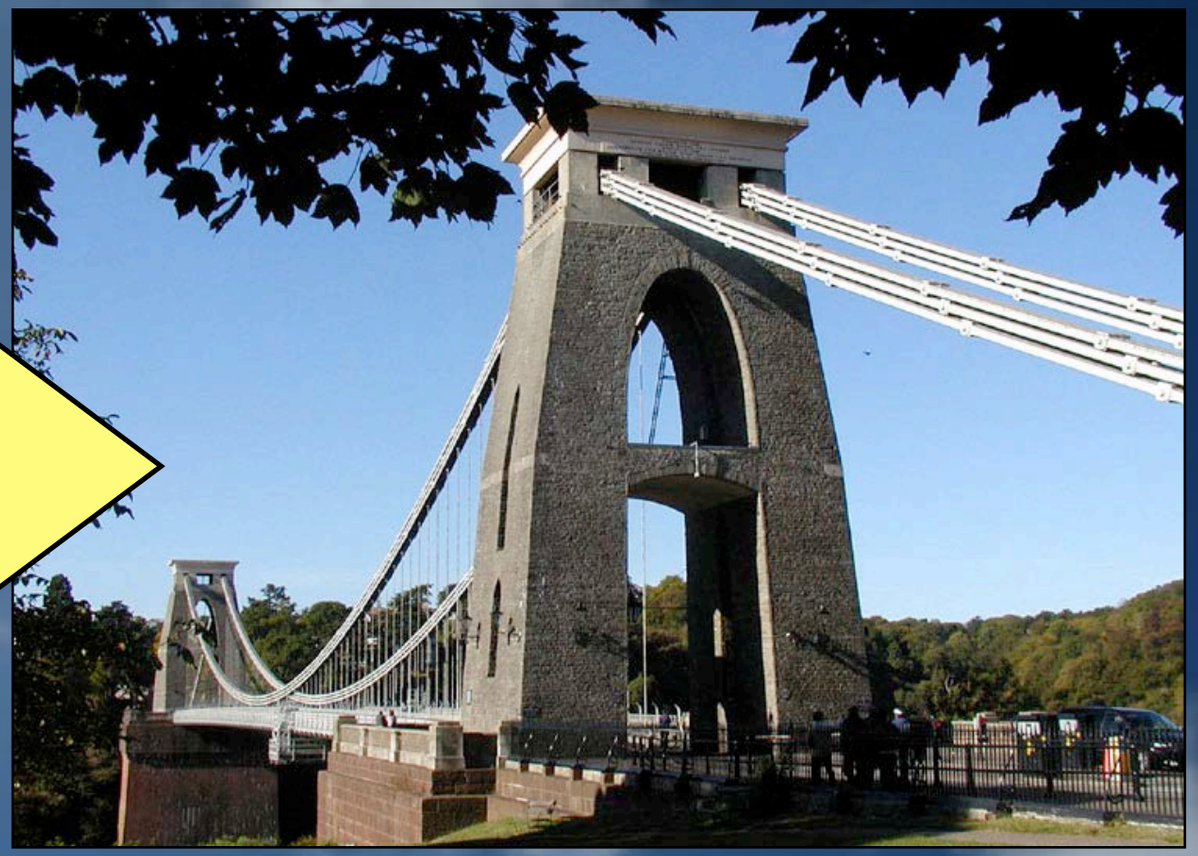


Clifton Suspension Bridge, completed 1864



Sources: 27, 28

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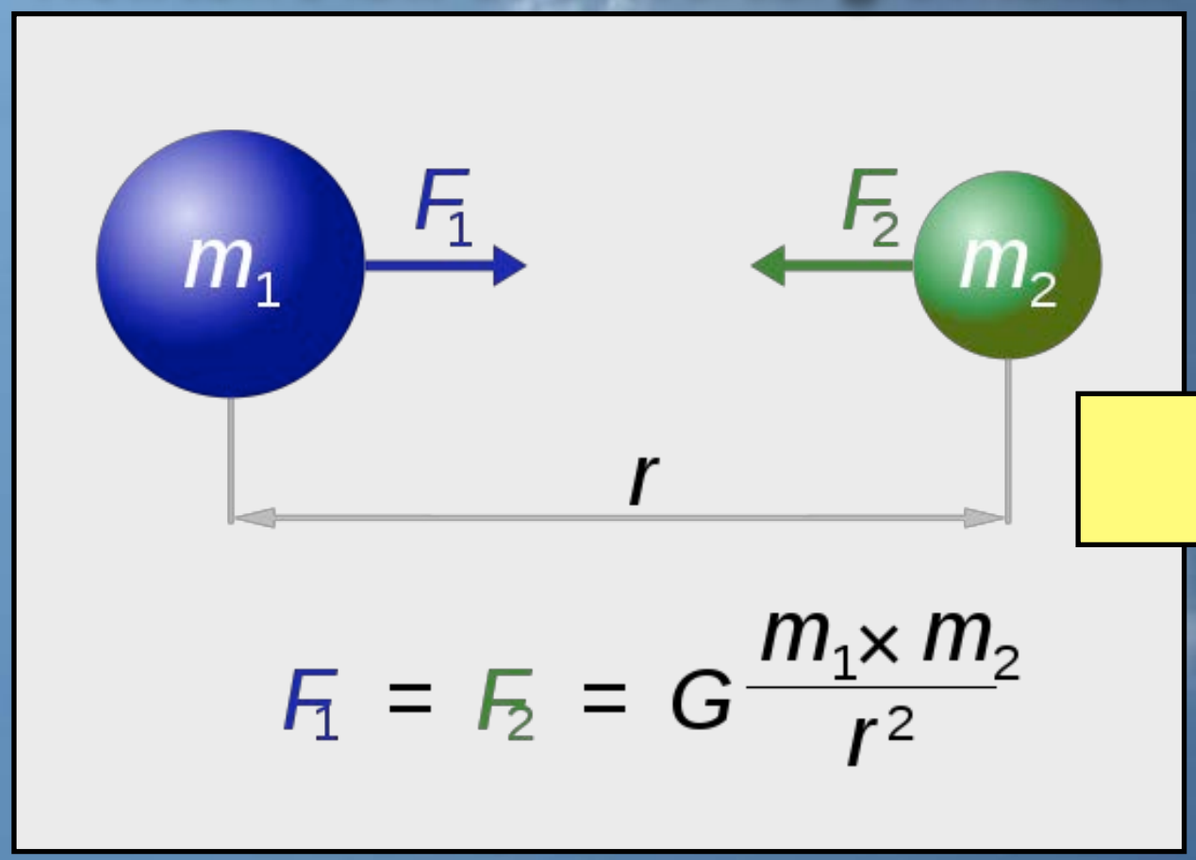

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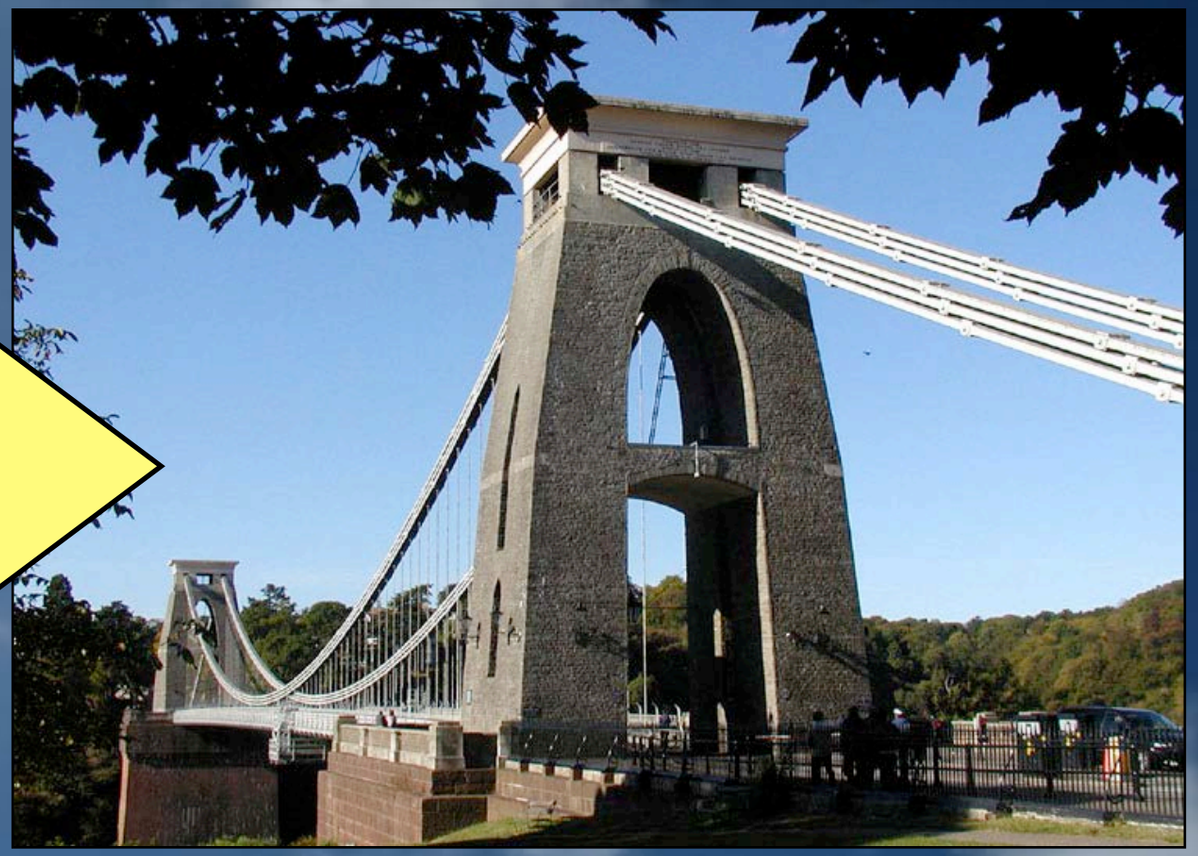

"physics envy"

Sources: 27, 28

Christopher X Jon Jensen
Pratt

Biosphere 2 Experiments:

Sources: 29

Christopher X Jon Jensen
Pratt

Biosphere 2 Results:

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- Oxygen levels plunged from 20.9% to 14.5% in 16 months

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- Oxygen levels plunged from 20.9% to 14.5% in 16 months
- Carbon dioxide levels fluctuated wildly
- Most vertebrates and all pollinating insects died
- Insect pests boomed and invasive ant species took over

Christopher X Jon Jensen
Pratt

Biosphere 2 was cheater!

Sources: 29

Christopher X Jon Jensen
Pratt

Biosphere 2 was cheater!

External energy used for cooling (3:1 inefficiency)

Sources: 29

Christopher X Jon Jensen
Pratt

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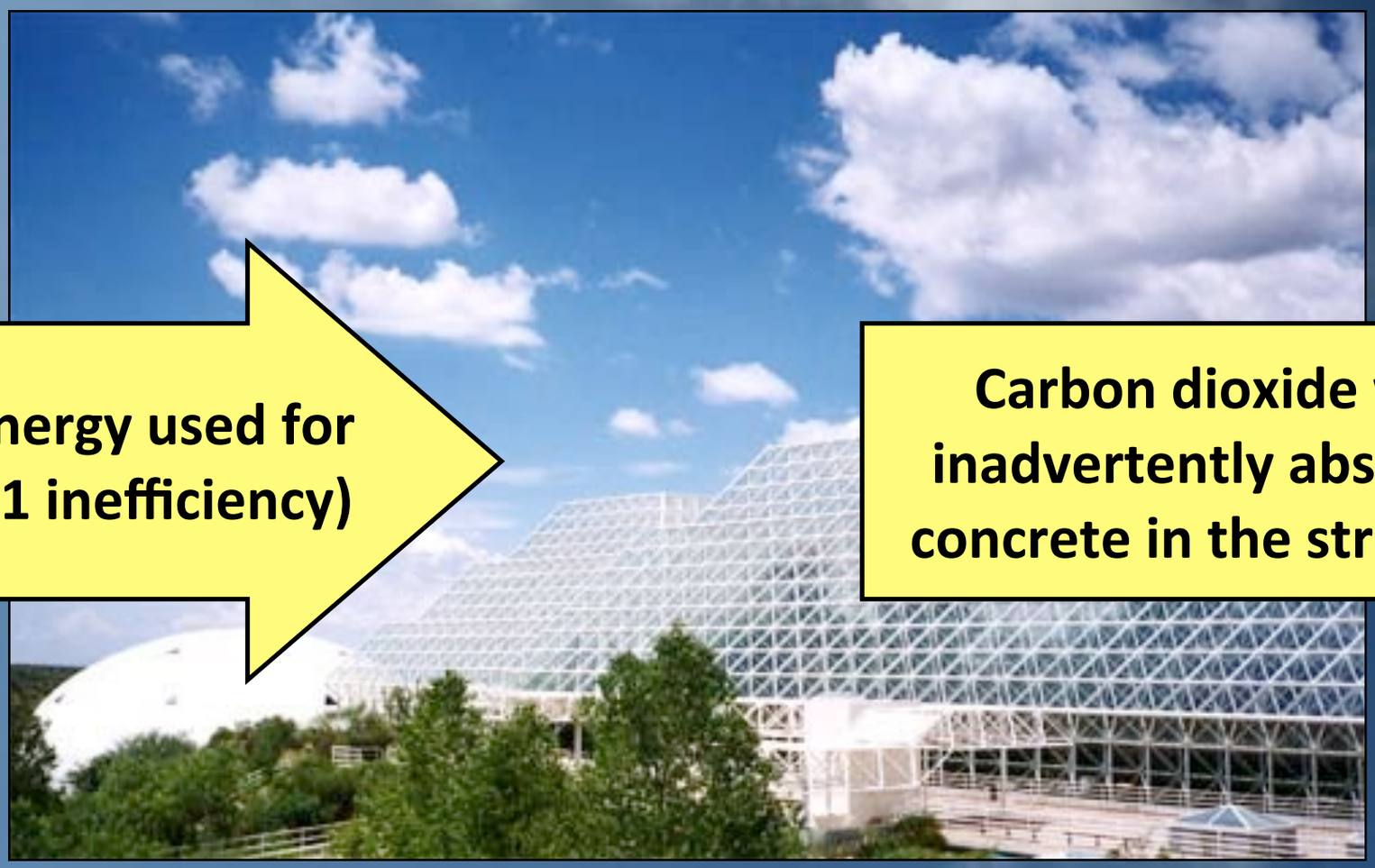


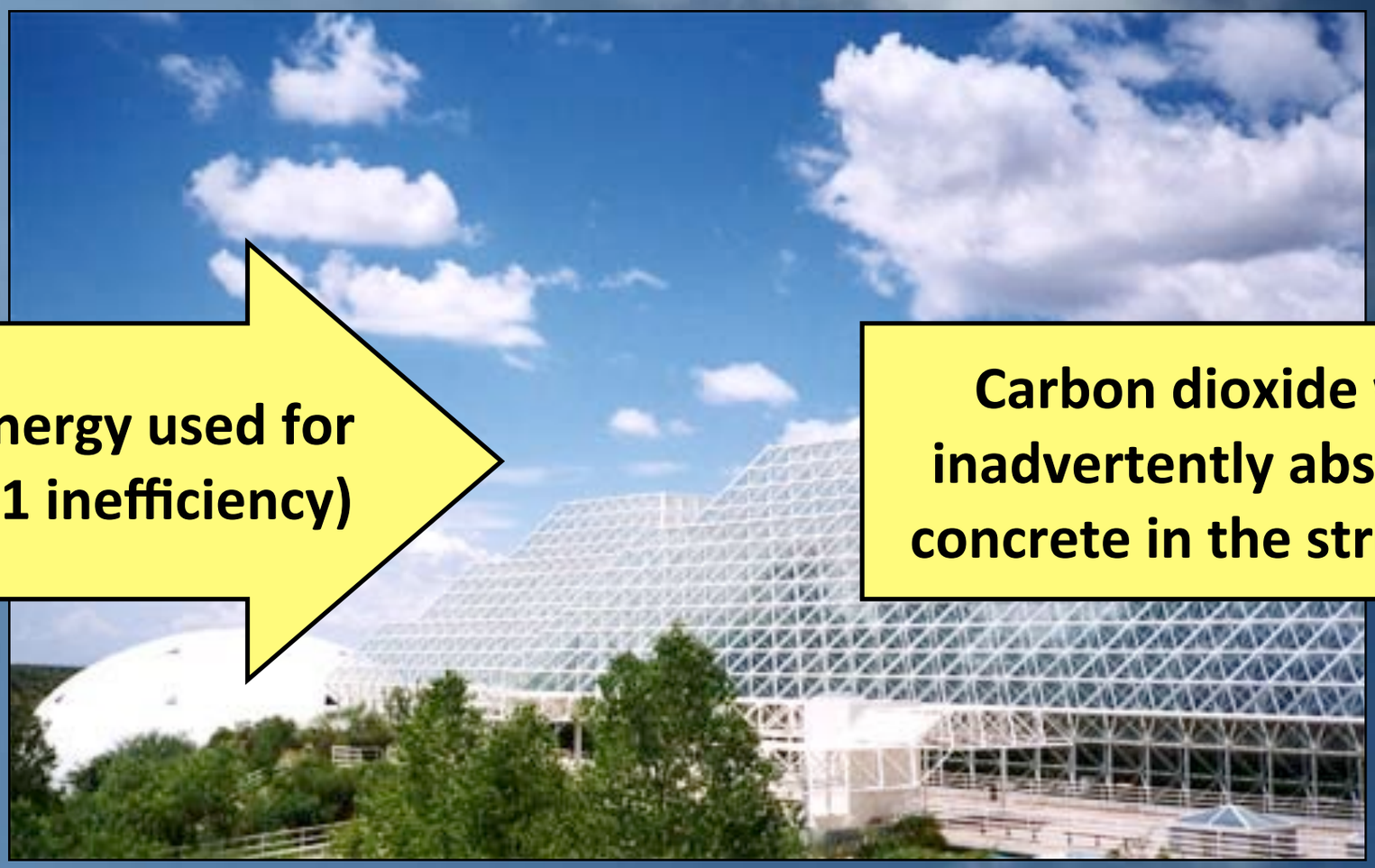
External energy used for cooling (3:1 inefficiency)

Carbon dioxide was inadvertently absorbed by concrete in the structure

Sources: 29

Christopher X Jon Jensen
Pratt

Biosphere 2 was cheater!



External energy used for cooling (3:1 inefficiency)

Carbon dioxide was inadvertently absorbed by concrete in the structure

the system was not truly closed

Sources: 29

Humans:
a chemotrophic species?

Sources: 30, 31, 32

Christopher X Jon Jensen
Pratt

Humans:
a chemotrophic species?

Sources: 30, 31, 32

Christopher X Jon Jensen
Pratt

Humans:
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Sources: 30, 31, 32

Christopher X Jon Jensen
Pratt

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Harnessing the energy produced over 100's of millions of years of photosynthesis in just a few hundred years

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Christopher X Jon Jensen
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Domesticating nature?

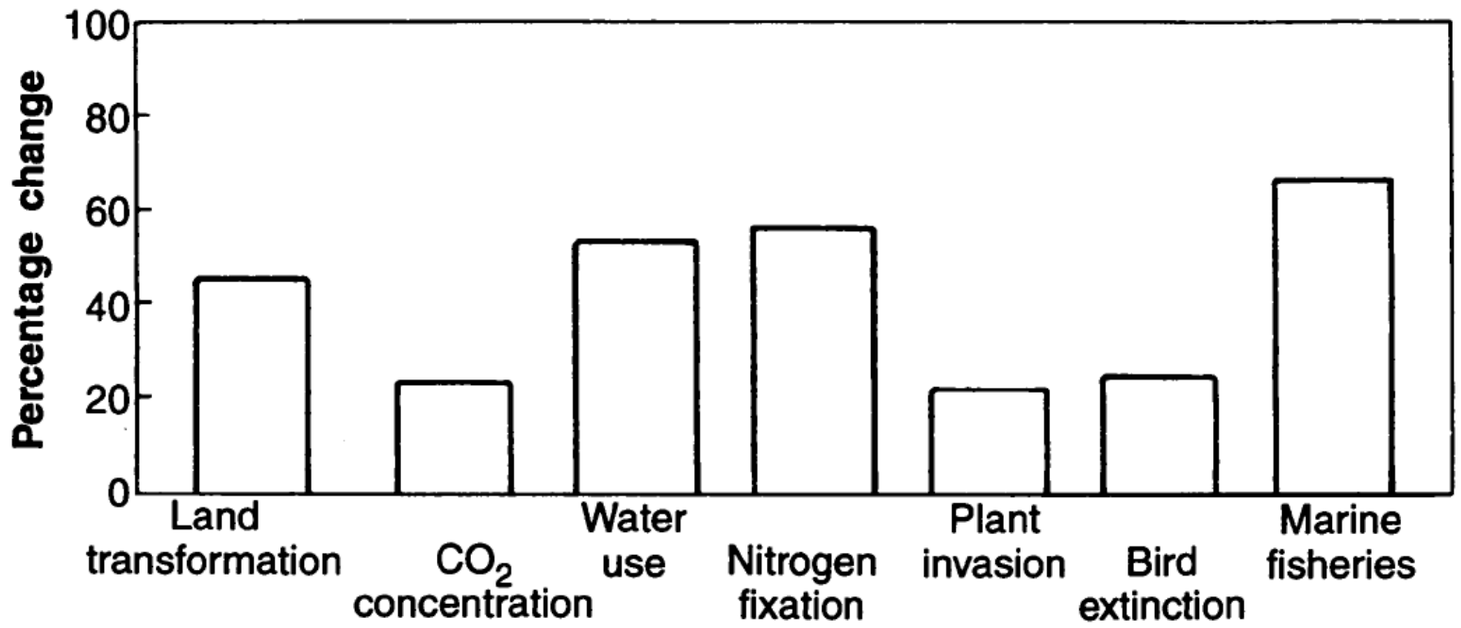


Fig. 2. Human dominance or alteration of several major components of the Earth system, expressed as (from left to right) percentage of the land surface transformed (5); percentage of the current atmospheric CO_2 concentration that results from human action (*17*); percentage of accessible surface fresh water used (*20*); percentage of terrestrial N fixation that is human-caused (*28*); percentage of plant species in Canada that humanity has introduced from elsewhere (*48*); percentage of bird species on Earth that have become extinct in the past two millennia, almost all of them as a consequence of human activity (*42*); and percentage of major marine fisheries that are fully exploited, overexploited, or depleted (*14*).

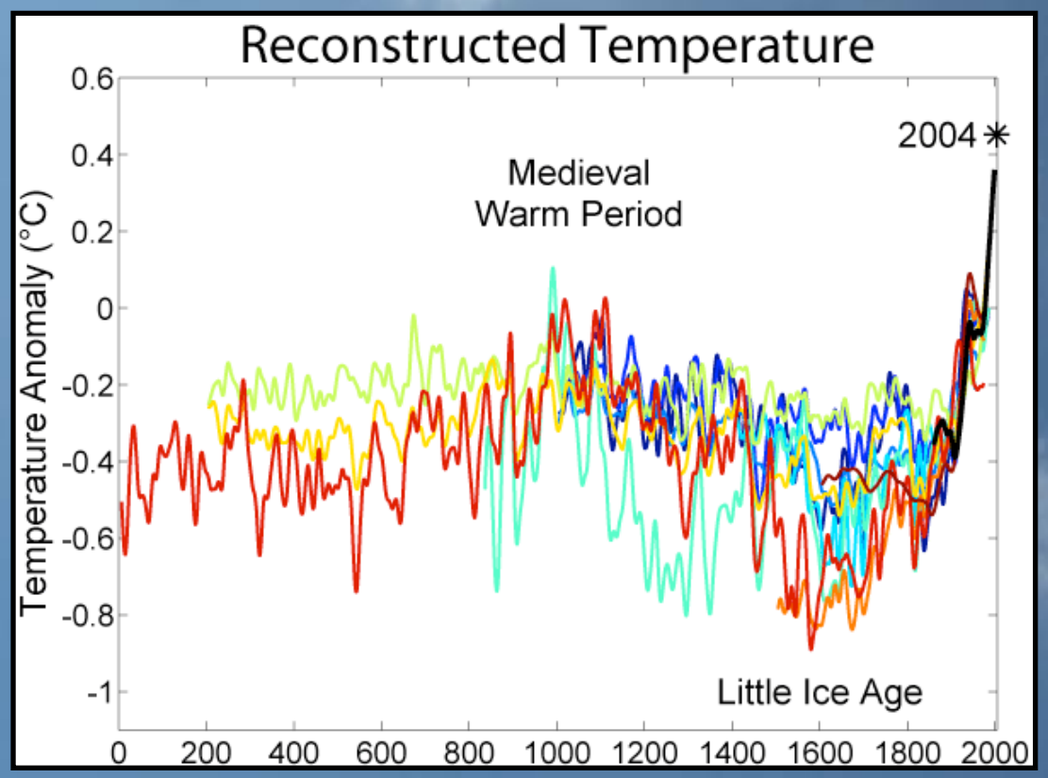
Sources: 33

Christopher X Jon Jensen
Pratt

Domesticating nature?

Sources: 34, 35

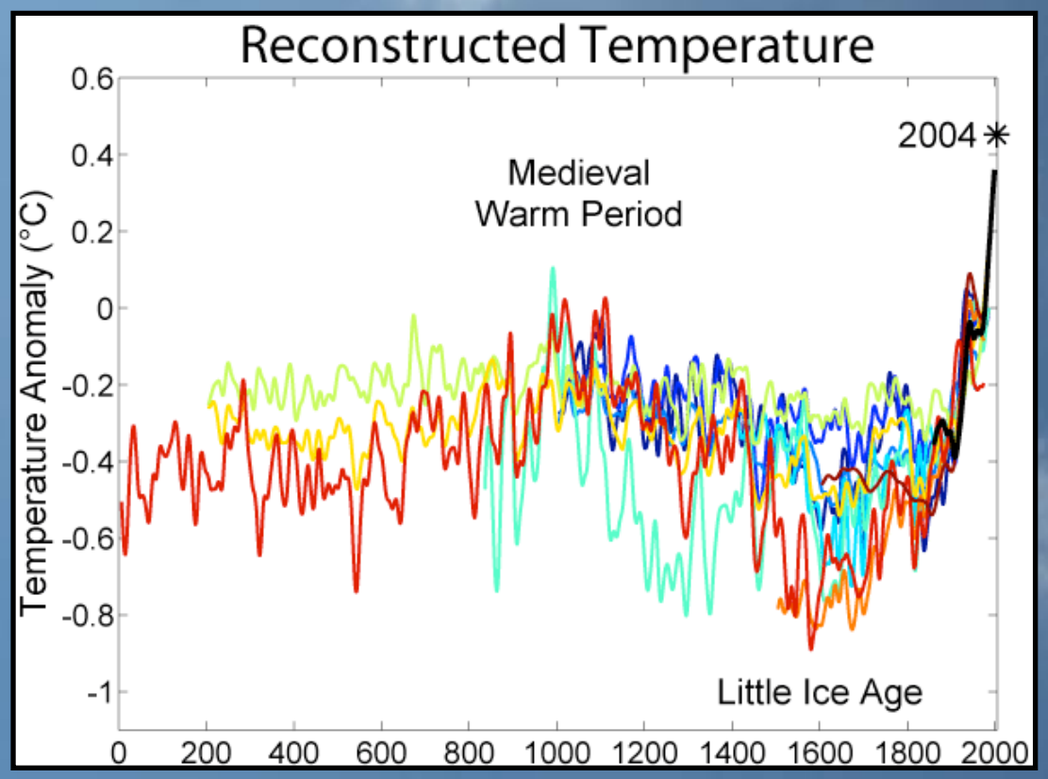
Domesticating nature?



Climate change

Sources: 34, 35

Domesticating nature?



Climate change

Eutrophication

Sources: 34, 35

Christopher X Jon Jensen
Pratt

Humans:
a chemotrophic species?

Sources: 36, 37

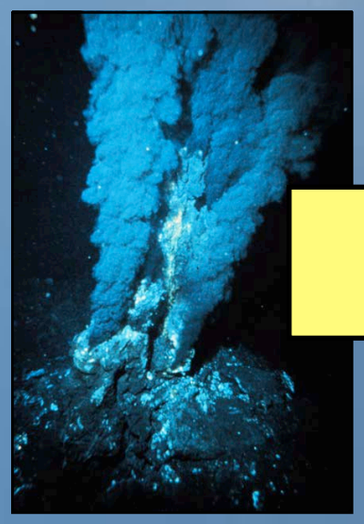
Christopher X Jon Jensen
Pratt

Humans:
a chemotrophic species?

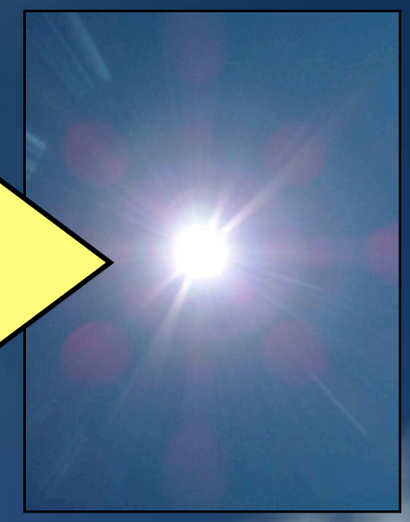
How can we mimic nature's sustainability?

Sources: 36, 37

Transitioning from chemotrophy to phototrophy:



~2.5 billion years ago



Sources: 4, 11, 38, 39, 40, 41

Christopher X Jon Jensen
Pratt

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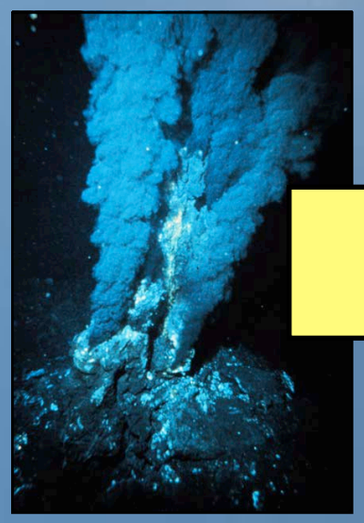

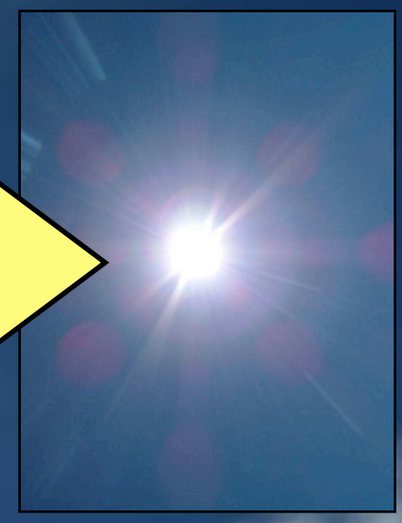

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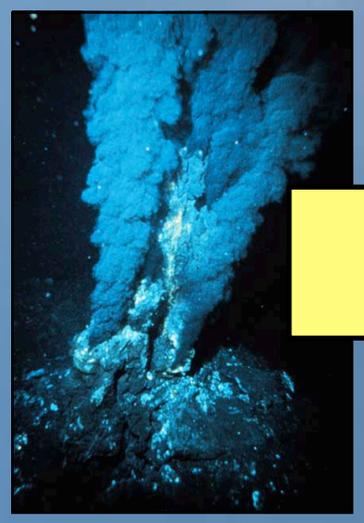

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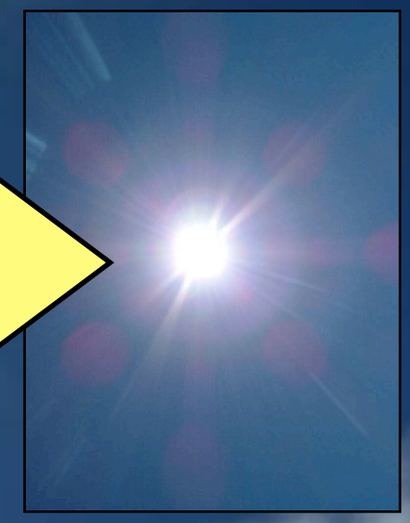

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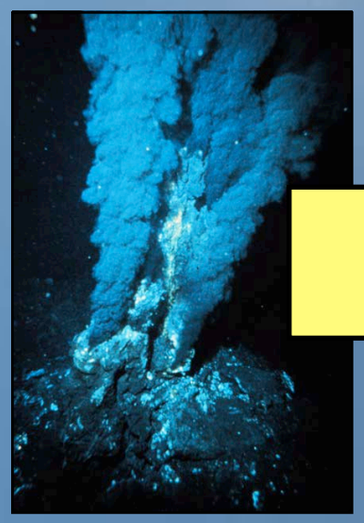

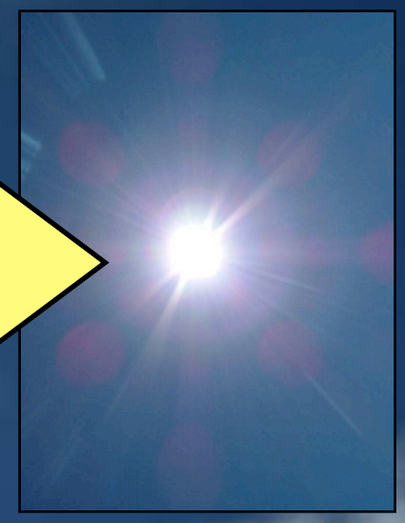

...s ago

Sources: 4, 11, 38, 39, 40, 41

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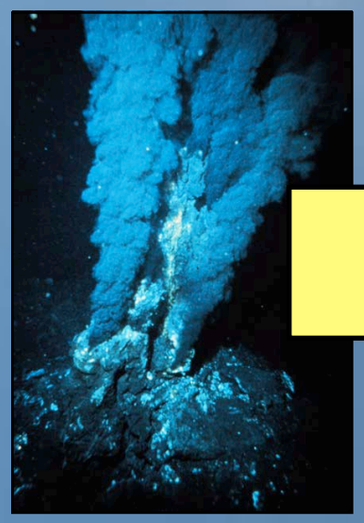

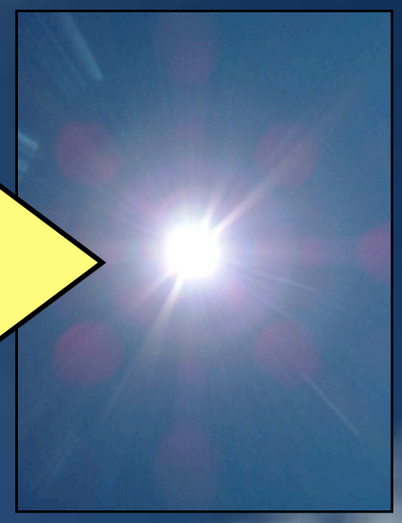

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Two reasons to worry that biological evolution won't save us:

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- The rate at which humans have changed ecosystems is greater than any rate previously recorded.

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- The rate at which humans have changed ecosystems is greater than any rate previously recorded.
- Ecosystems may evolve via periodic collapse: if this is the case, we will be the casualty of our own lack of sustainability.

What about cultural evolution?

Sources: 42, 43, 44

What about cultural evolution?

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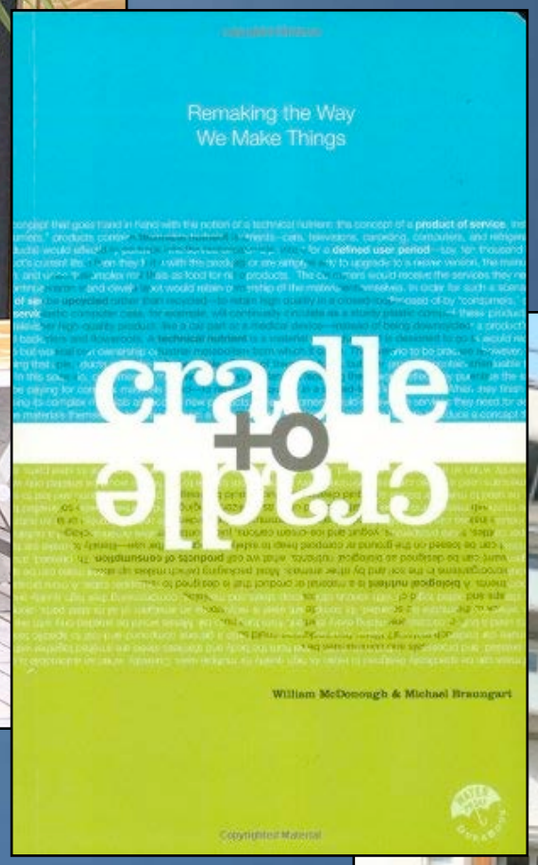
What about cultural evolution?

Sources: 42, 43, 44

Christopher X Jon Jensen
Pratt

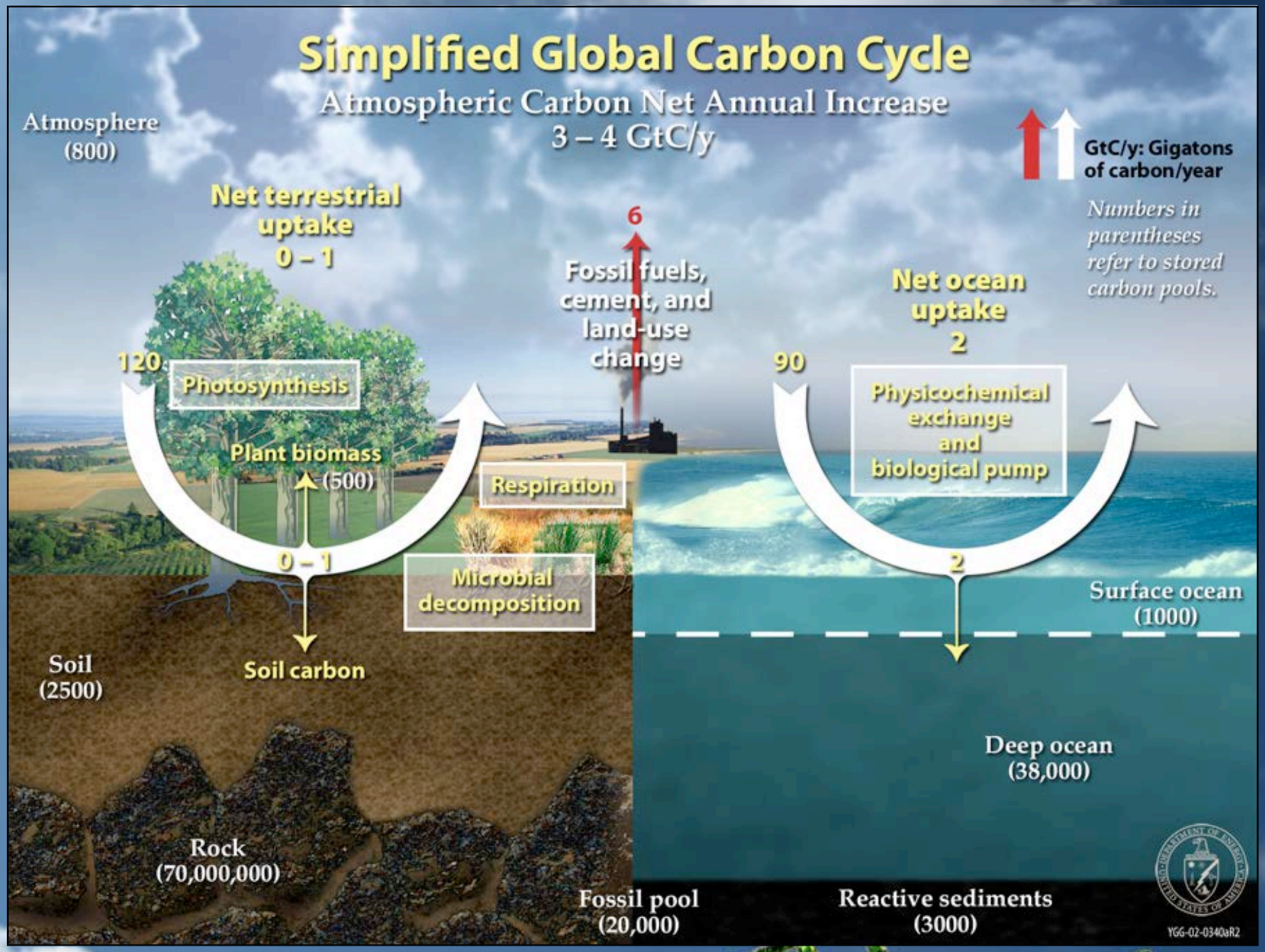
What about cultural evolution?



Sources: 42, 43, 44

Christopher X Jon Jensen
Pratt

Quantitative sustainability:



Sources: 45

Christopher X Jon Jensen
Pratt

The biofuel boondoggle:

Sources: 11, 46, 47, 48

Christopher X Jon Jensen
Pratt

The biofuel boondoggle:

Energy

Sources: 11, 46, 47, 48

Christopher X Jon Jensen
Pratt

The biofuel boondoggle:

Sources: 11, 46, 47, 48

Christopher X Jon Jensen
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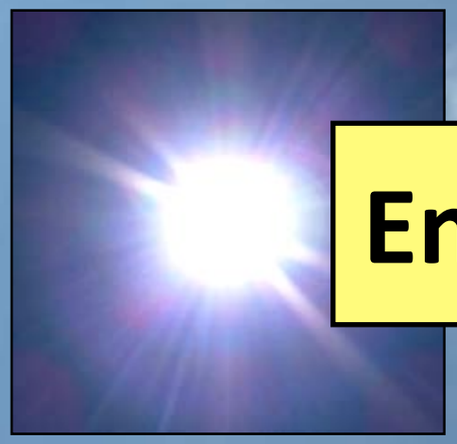


Energy

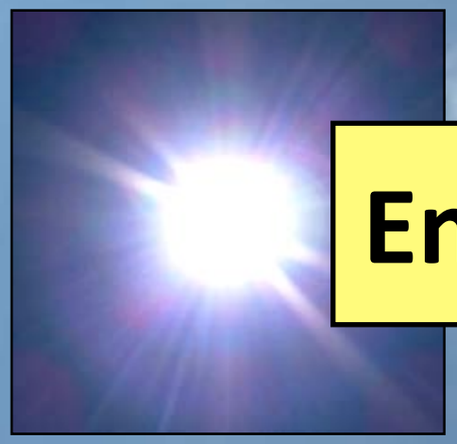
CO_2

Energy + C

Sources: 11, 46, 47, 48

Christopher X Jon Jensen
Pratt

The biofuel boondoggle:



Energy

CO_2

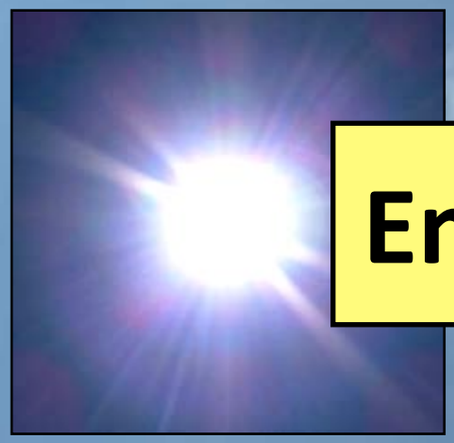
Energy + C

Energy + C

Sources: 11, 46, 47, 48

Christopher X Jon Jensen
Pratt

The biofuel boondoggle:



Energy

CO_2

CO_2

Energy + C

Energy + C

Sources: 11, 46, 47, 48

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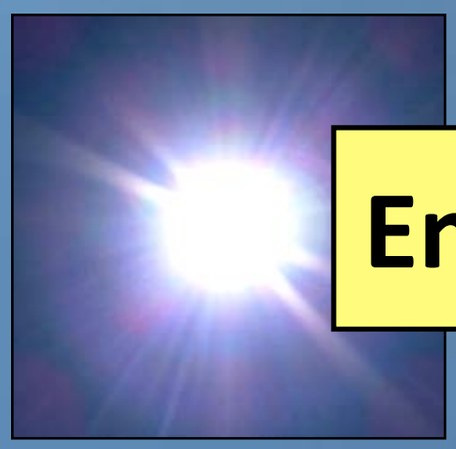

Energy

Outputs

Sources: 11, 47, 48, 49, 50, 51

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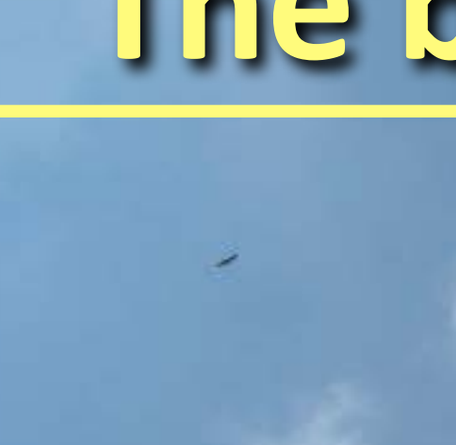
The biofuel boondoggle:



Energy

Inputs

Outputs

Sources: 11, 47, 48, 49, 50, 51

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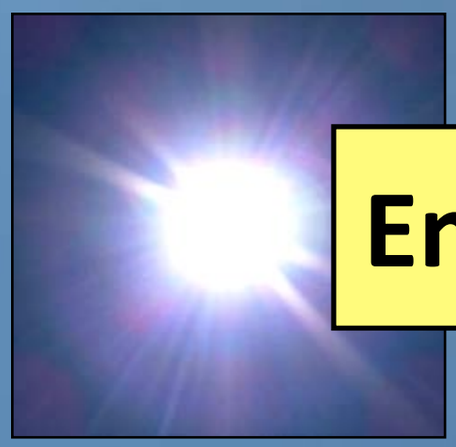
The biofuel boondoggle:

Cultivation

Inputs



Energy

Outputs

Sources: 11, 47, 48, 49, 50, 51

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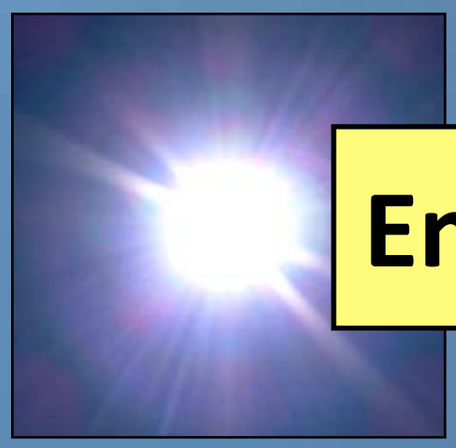
The biofuel boondoggle:

Cultivation

Fertilization

Inputs



Energy

Outputs

Sources: 11, 47, 48, 49, 50, 51

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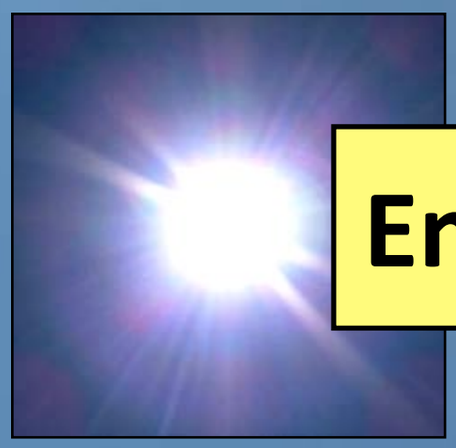
The biofuel boondoggle:

Cultivation

Fertilization

Transport

Inputs



Energy

Outputs

Sources: 11, 47, 48, 49, 50, 51

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Pratt

The biofuel boondoggle:

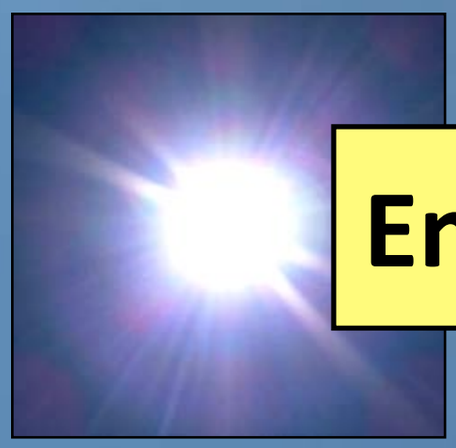
Cultivation

Fertilization

Transport

Processing

Inputs



Energy

Outputs

Sources: 11, 47, 48, 49, 50, 51

Corn ethanol

Nearly all the ethanol in the U.S. is brewed from yellow feed corn. Proliferating ethanol distilleries are already competing for corn with meat producers, driving up prices. Most ethanol is sold as a gasoline additive or, in the Midwest, as E85 (85 percent ethanol, 15 percent gasoline).

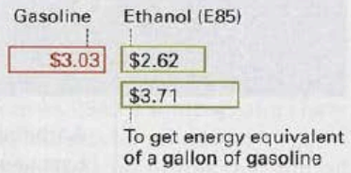
- **U.S. PRODUCTION**

4.86 billion gallons (2006)

U.S. PRODUCTION COST

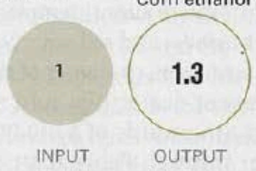
$1.09 per gallon

- **U.S. RETAIL PRICE** (per gallon, July 2007)

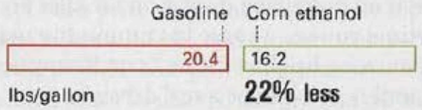


- **ENERGY BALANCE**

Fossil-fuel energy used to make the fuel (input) compared with the energy in the fuel (output)



- **GREENHOUSE GAS EMISSIONS** (production and use)



SOURCES: U.S. DEPARTMENT OF ENERGY; U.S. ENVIRONMENTAL PROTECTION AGENCY; RENEWABLE FUELS ASSOCIATION; ENERGY FUTURE COALITION; WORLDWATCH INSTITUTE

Cane ethanol

Brazil rivals the U.S. in ethanol production because sugarcane yields 600 to 800 gallons an acre, twice as much as corn. The stalk is 20 percent sugar—fermented to make the alcohol—and the waste cane can be burned to power the distillery, lowering fossil-fuel use.

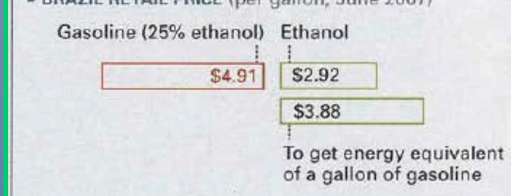
- **BRAZIL PRODUCTION**

3.96 billion gallons (2005)

BRAZIL PRODUCTION COST

$0.87 per gallon

- **BRAZIL RETAIL PRICE** (per gallon, June 2007)



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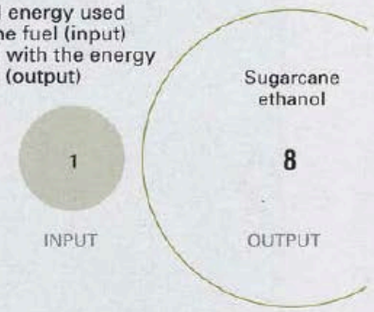
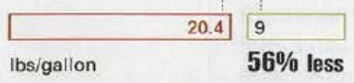


- **GREENHOUSE GAS EMISSIONS** (production and use)



SOURCES: U.S. DOE; U.S. EPA; WORLDWATCH INSTITUTE; IOWA STATE UNIVERSITY

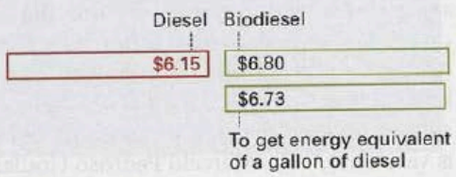
Biodiesel

Chemically altering plant oils to make biodiesel takes less energy than distilling corn into ethanol; the fuel's main drawbacks are low yield and high cost. Germany is the world's leading producer, relying on canola oil; U.S. biodiesel comes from soybeans (right).

- **PRODUCTION IN GERMANY** (from canola)

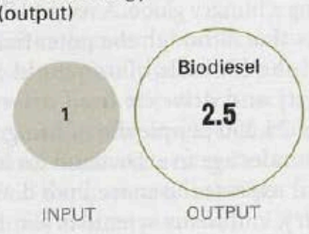
0.5 billion gallons (2005)

- **GERMANY RETAIL PRICE** (per gallon, June 2007)

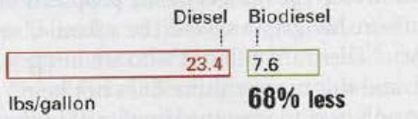


- **ENERGY BALANCE**

Fossil-fuel energy used to make the fuel (input) compared with the energy in the fuel (output)



- **GREENHOUSE GAS EMISSIONS** (production and use)



SOURCES: U.S. DOE; U.S. EPA; WORLDWATCH INSTITUTE

Cellulosic ethanol

Perennial prairie grasses like switchgrass (left), grown on land unfit for other crops, could replace up to 13 percent of the world's oil consumption—if an efficient way to turn cellulosic plant matter into ethanol can be developed.

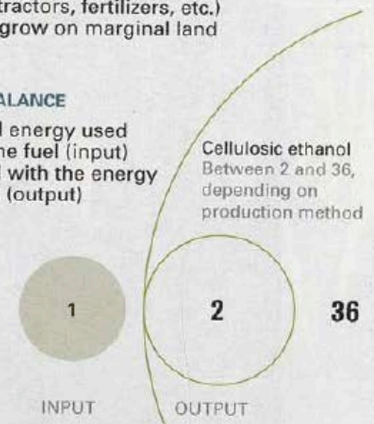
- **U.S. PRODUCTION**

Still in development; no current production

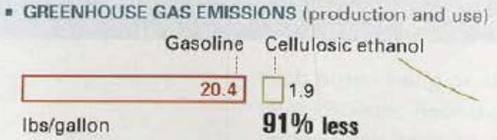
- **SOURCES OF CELLULOSIC ETHANOL**
  - Agricultural residues (leftover material from crops, such as the stalks, leaves, and husks of corn plants)
  - Forestry wastes like wood chips and sawdust from lumber mills, tree bark
  - Municipal solid waste (household garbage and paper products)
  - Paper pulp
  - Fast-growing prairie grasses, such as switchgrass, which require less energy (tractors, fertilizers, etc.) and can grow on marginal land

- **ENERGY BALANCE**

Fossil-fuel energy used to make the fuel (input) compared with the energy in the fuel (output)



- **GREENHOUSE GAS EMISSIONS** (production and use)

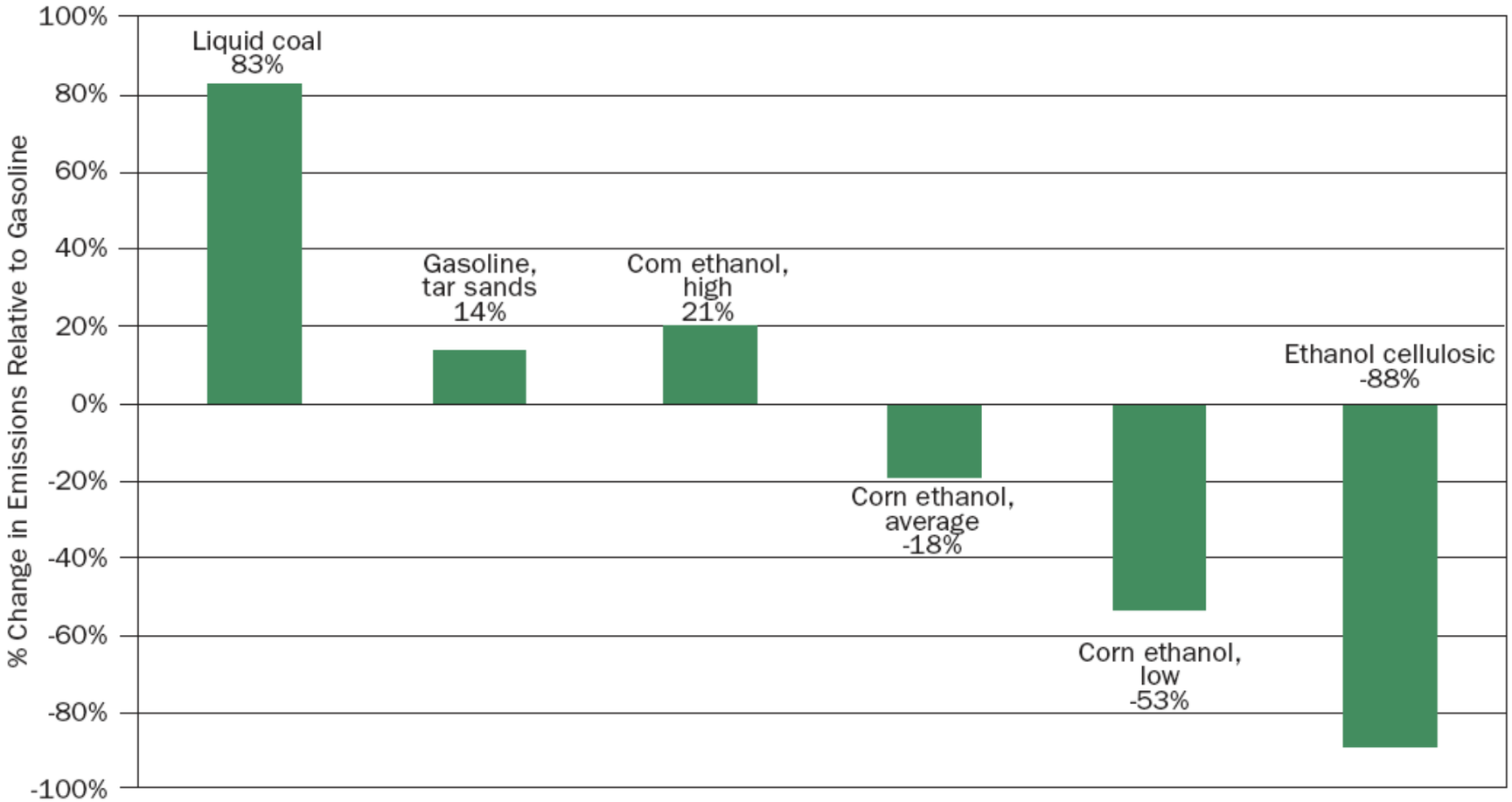


SOURCES: U.S. DOE; U.S. EPA; WORLDWATCH INSTITUTE

Sources: 52

Quantity matters...

FIGURE ES-1 **Life Cycle Global Warming Pollution Relative to Gasoline**



NOTE: These values do not include all potential sources of global warming pollution, particularly the effect of direct or indirect land use changes. Actual global warming emissions may be higher than these estimates.

SOURCES: Gasoline estimate is from Wang (2006). Liquid coal estimate is from Williams (2005). Gasoline from tar sands estimate is from Moorhouse (2006). High corn ethanol estimate is based on ethanol used in California but produced in a Midwest coal-fired dry mill (Unnasch et al. 2007). Current industry average for corn ethanol is from Farrell et al. (2006a). Low corn ethanol estimate is based on ethanol produced in a biomass-fired wet mill (Turner et al. 2007). Cellulosic ethanol estimate is based on switchgrass (Farrell et al. 2006a).

Sources: 53

Christopher X Jon Jensen
Pratt

What about cultural evolution?

Sources: 42, 54

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Pratt

What about cultural evolution?

Products we consume

Sources: 42, 54

What about cultural evolution?

Products we consume

Culture of consumption

Sources: 42, 54

Conclusions:

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- Although much is known about how ecosystems function, we lack sufficient knowledge to make decisions based on reliable predictions.
- Humans have come to dominate current ecosystems by breaking the fundamental rules that govern ecological systems.
- As we strive for sustainability, we need to carefully consider the balance between conservation and innovation.

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2. **RNA formation image from:** Ricardo, Alonso and Jack W. Szostak. 2009. **Origin of Life on Earth**. *Scientific American* 301(3):54-61.
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12. **Food web image from:** http://upload.wikimedia.org/wikipedia/commons/b/b3/FoodWeb.jpg
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30. **Coal mine image from:** http://en.wikipedia.org/wiki/File:Coal_mine_Wyoming.jpg
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46. **Soybean biofuel bus image from:** http://en.wikipedia.org/wiki/File:Soybeanbus.jpg

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Questions or Comments?

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