BIOFUELS

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Bioscience in the 21st Century
October 15, 2010
I. Microbiology

II. Fossil Fuels

III. Microbes and alternative energy (biofuel) production
I. Microbiology
Microbiology: The study of small (microscopic) organisms

**Bacteria**

![Bacteria Image](http://www.srs.dl.ac.uk/)

**Viruses**

![Viruses Image](http://www.sciencefriday.com/)

**Protists**

![Protists Image](http://www.microscopy-uk.org.uk/)

**Fungi**

![Fungi Image](http://www.independent.co.uk/)

**Archaea**

![Archaea Image](http://web.mit.edu/)

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1. Microbiology: The study of small (microscopic) organisms.
2. **Bacteria**
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6. **Archaea**
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   - [Link to Archaea Image](http://web.mit.edu/)
“Tree of Life”
(evolutionary relatedness of organisms)

Prokaryotes
- Bacteria
- Archaea

Eukaryotes
- Eucarya

[Diagram of a tree showing the evolutionary relationships between different groups of organisms, with branches for Bacteria, Archaea, and Eucarya, and specific taxa such as Thermococcus, Methanosarcina, and Thermoplasma.]
Almost ALL of biology is “Microbiology”!
It’s a microbial world! (No really. It is.)

7,000,000,000   ~7 x 10^9 people
200,000,000,000  ~2 x 10^{11} burgers
10,000,000,000,000 ~1 x 10^{13} dollars
8,000,000,000,000,000 ~8 x 10^{18} grains of sand
10,000,000,000,000,000,000 ~1 x 10^{22} stars
5,000,000,000,000,000,000,000,000,000,000,000,000 ~5 x 10^{30} bacteria
What do microbes do?

Paved the way for the evolution of life on Earth as we know it.

Incredible diversity in where they can live, what they can eat, and the chemicals they can produce.

Many cause disease, but many many more play positive roles in the health of humans and the planet.
Where can microbes be found?

Everywhere, on every surface, all the time

- Water, soil, and air
- Deep in the earth
- High in the atmosphere
- In and on all plants and animals
Microbial colonies

Microbes are almost always invisible but sometimes we can see them!

Petri plate

Acid mine drain (pH 0)

Rainbow Pool
Yellowstone National Park
Bioluminescent bacteria seen from space!

Miller et al., 2005
Bioluminescent bacteria seen from space!

Miller et al., 2005
Microbiology: Take-home messages

Most of biology is microbiology

If we want to understand life at a molecular level, we need to study microbes too

The answers to some of the most important challenges facing humankind may be found in microbiology...

*Bacillus subtilis*
II. Fossil fuels
Deepwater Horizon
Deepwater Horizon

US Coast Guard April 2010

NASA's Terra satellite May 2010

A disaster for the Gulf ecosystem, affecting humans and animals alike.
>85% of energy produced in the US comes from burning fossil fuels: coal, petroleum products, and natural gas.

Fossil fuels:
- Non-renewable
- Affect national and global security
- Damage human health
- Cause environmental harm
  - Water, air pollution
  - Oil-spills, damaged ecosystems
- Increasing atmospheric CO₂ levels → global warming
What are fossil fuels?

~300 million years ago

BIOMASS

HEAT
PRESSURE

Coal
Natural Gas
Oil (Petroleum)
Fossil fuels = Hydrocarbons

• Molecules made up of hydrogen and carbon

• Contain a lot of energy (the higher the H/C ratio, the better)

• Can be chemically modified or crosslinked to make synthetic rubber, nylon, plastics, other useful chemicals.

• Various lengths and structures → different properties and energy content
Butane

\[
\begin{align*}
\text{CH}_3\text{-CH}_2\text{-CH}_2\text{-CH}_3 \\
\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3
\end{align*}
\]
Butane

Isobutane

“isomers”
Octane

3 of 18 possible octane isomers:
What are fossil fuels?

~300 million years ago

Biomass

Heat

Pressure

Coal

Natural Gas

Oil (Petroleum)
Natural Gas

methane
“C₁”

ethane
“C₂”

propane
“C₃”
Petroleum

$C_1 - C_{70+}$
Petroleum distillation

- $C_1-C_4$
- $C_5-C_9$ (solvents, paint thinners)
- $C_7-C_{11}$
- $C_{12}-C_{15}$
- $C_{14}-C_{20}$
- $C_{20}-C_{70}$
- $C_{70+}$

↑ #C  ↑ boiling point
Petroleum distillation

Richmond Refinery
(http://crudeoilprice.com/Crude_Oil_Refining.htm)
Coal
Hydrocarbon combustion

\[
C_xH_y + O_2 \rightarrow CO_2 + H_2O + \text{energy}
\]

“Exothermic reaction”

The H/C ratio determines the amount of energy released

Incomplete combustion results in toxic byproducts:

- CO (carbon monoxide)
- NO/NO₂ (nitrogen oxides) = SMOG
It’s all about CARBON

<table>
<thead>
<tr>
<th>Period</th>
<th>Group IA</th>
<th>Group IIA</th>
<th>Group IIIA</th>
<th>Group IIIB</th>
<th>Group IV</th>
<th>Group VA</th>
<th>Group VIA</th>
<th>Group VIIA</th>
<th>Group VIIIB</th>
<th>Group VIIIB</th>
<th>Group VIIIA</th>
<th>Group VIIIB</th>
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<th>Group VIIIA</th>
<th>Group VIIIB</th>
<th>Group VIIIA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 1A</td>
<td>H (1.01)</td>
<td>Li (6.94)</td>
<td>Be (9.01)</td>
<td>B (10.81)</td>
<td>C (12.01)</td>
<td>N (14.01)</td>
<td>O (16.00)</td>
<td>F (19.00)</td>
<td>Ne (20.18)</td>
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</tr>
<tr>
<td>2 1B</td>
<td>Na (22.99)</td>
<td>Mg (24.31)</td>
<td>Al (26.98)</td>
<td>Si (28.09)</td>
<td>P (30.97)</td>
<td>S (32.07)</td>
<td>Cl (35.45)</td>
<td>Ar (39.95)</td>
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<tr>
<td>3 2B</td>
<td>K (39.10 )</td>
<td>Ca (40.08)</td>
<td>Sc (44.96)</td>
<td>Ti (47.88)</td>
<td>V (50.94)</td>
<td>Cr (52.00)</td>
<td>Mn (54.94)</td>
<td>Fe (55.85)</td>
<td>Co (58.93)</td>
<td>Ni (58.69)</td>
<td>Cu (63.55)</td>
<td>Zn (65.39)</td>
<td>Ga (69.72)</td>
<td>Ge (72.61)</td>
<td>As (74.92)</td>
<td>Se (79.90)</td>
<td>Br (83.80)</td>
<td>Kr (85.47)</td>
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<tr>
<td>4 3B</td>
<td>Rb (85.47)</td>
<td>Sr (88.01)</td>
<td>Y (88.01)</td>
<td>Zr (91.22)</td>
<td>Nb (92.91)</td>
<td>Mo (95.94)</td>
<td>(98) 101.07</td>
<td>102.91</td>
<td>Te (106.42)</td>
<td>Ru (106.42)</td>
<td>Rh (107.87)</td>
<td>Pd (112.41)</td>
<td>Ag (114.82)</td>
<td>Cd (118.71)</td>
<td>In (121.76)</td>
<td>Sn (127.6)</td>
<td>Sb (126.9)</td>
<td>Te (131.29)</td>
<td>I (136.9)</td>
<td>Xe (131.30)</td>
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<tr>
<td>5 4B</td>
<td>Cs (132.9)</td>
<td>Ba (137.3)</td>
<td>La (138.9)</td>
<td>Hf (178.5)</td>
<td>Ta (180.9)</td>
<td>W (183.9)</td>
<td>Re (186.2)</td>
<td>Os (190.2)</td>
<td>Ir (192.2)</td>
<td>Pt (195.1)</td>
<td>Au (197.0)</td>
<td>Hg (200.6)</td>
<td>Tl (204.4)</td>
<td>Pb (207.2)</td>
<td>Bi (209.0)</td>
<td>Po (210.0)</td>
<td>At (210.9)</td>
<td>Rn (222.0)</td>
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</tr>
<tr>
<td>6 5B</td>
<td>Fr (223)</td>
<td>Ra (226)</td>
<td>Ac (227)</td>
<td>Rf (261)</td>
<td>Db (262)</td>
<td>Sg (263)</td>
<td>Bh (264)</td>
<td>Hs (265)</td>
<td>Mt (268)</td>
<td>Ds (271)</td>
<td>Rg (272)</td>
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</tr>
<tr>
<td>7 6B</td>
<td>Ce (140.1)</td>
<td>Pr (140.9)</td>
<td>Nd (144.2)</td>
<td>Sm (150.4)</td>
<td>Eu (152.0)</td>
<td>Gd (157.3)</td>
<td>Tb (158.9)</td>
<td>Dy (162.5)</td>
<td>Ho (164.9)</td>
<td>Er (167.3)</td>
<td>Tm (168.9)</td>
<td>Yb (172.0)</td>
<td>Lu (175.0)</td>
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<td></td>
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<tr>
<td>8 7B</td>
<td>Th (232.0)</td>
<td>Pa (233.0)</td>
<td>U (238.0)</td>
<td>Np (237.0)</td>
<td>Pu (244.0)</td>
<td>Am (247.0)</td>
<td>Cm (247.0)</td>
<td>Bk (247.0)</td>
<td>Cf (247.0)</td>
<td>Es (247.0)</td>
<td>Fm (257.0)</td>
<td>Md (258.0)</td>
<td>No (259.0)</td>
<td>Lr (260.0)</td>
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</tbody>
</table>
## Global reservoirs of carbon

<table>
<thead>
<tr>
<th>Reservoir</th>
<th>Amount ((10^{12} \text{ kg}))</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Atmosphere</strong></td>
<td></td>
</tr>
<tr>
<td>(\text{CO}_2)</td>
<td>700</td>
</tr>
<tr>
<td><strong>Ocean</strong></td>
<td></td>
</tr>
<tr>
<td>(\text{CO}_2, \text{H}_2\text{CO}_3, \text{HCO}_3^-, \text{CO}_3^{2-})</td>
<td>38,000</td>
</tr>
<tr>
<td>Biomass/organic matter</td>
<td>2,100</td>
</tr>
<tr>
<td><strong>Land</strong></td>
<td></td>
</tr>
<tr>
<td>Crust (carbonate rock)</td>
<td>120,000,000</td>
</tr>
<tr>
<td>Biomass/organic matter</td>
<td>1,700</td>
</tr>
<tr>
<td>Fossil fuel (hydrocarbons)</td>
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Global reservoirs of carbon

<table>
<thead>
<tr>
<th>Reservoir</th>
<th>Amount ((10^{12} \text{ kg}))</th>
<th>Rate of cycling</th>
</tr>
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<tr>
<td>(\text{CO}_2)</td>
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<td>Biomass/organic matter</td>
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<td>Slow</td>
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<td></td>
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The carbon cycle

Photosynthesis

Atmosphere (CO₂)

Respiration, combustion

Biomass (organic carbon compounds)

Combustion

Fossil Fuels (hydrocarbons)

Dissolved

Released

Ocean (CO₂, H₂CO₃, HCO⁻³, CO₂⁻³)

✓

✗
What are fossil fuels?

- BIOMASS
  - HEAT
  - PRESSURE
    - Coal
    - Natural Gas
    - Oil (Petroleum)

~300 million years ago
The carbon cycle

- **Atmosphere (CO₂)**
  - Photosynthesis
  - Respiration, combustion
  - Combustion
  - Dissolved
  - Released

- **Biomass** (organic carbon compounds)
- **Fossil Fuels** (hydrocarbons)
- **Ocean** (CO₂, H₂CO₃, HCO⁻³, CO₂⁻³)

~300 million years ago!!!
The carbon cycle

**Atmosphere**

- Photosynthesis
- Respiration, combustion
- Released

**Biomass**
(organic carbon compounds)

**Fossil Fuels**
(hydrocarbons)

**Ocean**
(CO$_2$, H$_2$CO$_3$, HCO$_{-3}$, CO$_{2-3}$)

- Dissolved
- Combustion

~300 million years ago!!!
Atmospheric CO$_2$ levels

From nasa.gov
The carbon cycle

Time history of atmospheric CO₂

http://www.youtube.com/user/CarbonTracker
III. Microbes and alternative energy (biofuel) production
Alternatives to fossil fuels

Nuclear energy

Geothermal energy

Hydrogen

Wind energy

Tidal energy

Solar energy
Biofuels
**Biofuel:** A fuel derived from biomass

“carbon neutral”

\[
\begin{align*}
\text{CO}_2 & \xrightarrow{\text{production}} \text{Biofuel} \xrightarrow{\text{combustion}} \text{CO}_2 \\
\text{Energy in} & \quad & \text{Energy out}
\end{align*}
\]

“\(\text{CO}_2\) in = \(\text{CO}_2\) out”

**What is the biofuel?**

**What is the source of carbon/energy?**
CO₂ → PHOTOSYNTHESIS → sugar → ATP

“energy in”

RESPIRATION/FERMENTATION

Small carbon molecules (acids, alcohols) → ATP

“energy out”

BIOMASS

cellulose (sugar storage) → carbohydrates

lipids

proteins

nucleic acids
Carbon-based compounds generated by living or recently-living organisms

Contain **ENERGY** in the form of chemical bonds

Originally from the sun!
CO₂ → PHOTOSYNTHESIS

sugar → ATP → “energy out”

RESPIRATION/FERMENTATION

Small carbon molecules (acids, alcohols)

BIOMASS

cellulose (sugar storage)

biosynthesis

carbohydrates

lipids

proteins

nucleic acids
Wood (cellulose) is a biofuel
Cellulose

Firewood: 18-22 GJ/t
Crude oil: 42-45 GJ/t

http://bioenergy.ornl.gov/papers/misc/energy_conv.html
CO$_2$ → PHOTOSYNTHESIS

sugar → “energy in”

BIOMASS

Small carbon molecules (acids, alcohols) → ATP → RESPIRATION/FERMENTATION

“energy out”

cellulose (sugar storage) → BIOSYNTHESIS

carbohydrates

lipids → biodiesel

proteins

nucleic acids

ethanol
“Generations” of biofuel

- Ethanol = 1\textsuperscript{st} and 2\textsuperscript{nd} generation

- Lipids $\rightarrow$ Biodiesel = 3\textsuperscript{rd}+ generations

Microbes play a critical role in producing the biofuel
- remarkable metabolic capabilities
- can grow quickly and in large amounts
- can be manipulated and optimized in the laboratory
Ethanol: 1\textsuperscript{st} and 2\textsuperscript{nd} generation biofuel

\[
\begin{array}{c}
\text{H} \\
\text{H} \\
\text{H} \\
\text{C} \quad \text{C} \\
\text{O} \\
\text{H} \\
\text{H}
\end{array}
\]

Ethanol: 26.7 GJ/t
Crude oil: 42-45 GJ/t

http://bioenergy.ornl.gov/papers/misc/energy_conv.html
Generation 1: Ethanol from corn

**Generation 1 biofuels:** Corn *(shown at left)* and yeast can be mixed in a bioreactor for fermentation, which produces ethanol for use as fuel, along with water and carbon dioxide by-products *(above).*

Generation 1 biofuel

**CO₂ → PHOTOSYNTHEIS → “energy in” → BIOMASS → sugar → “energy out” → ATP → Small carbon molecules (acids, alcohols) → ethanol → cellulose (sugar storage) → carbohydrates → lipids → proteins → nucleic acids**
Saccharomyces cerevisiae

- Unicellular yeast (eukaryote)
- Can ferment sugar → ethanol
- Also a model organism for many cell biological studies
Problems with corn-based ethanol biofuels

Waste
   Corn husks/stalks not used
   To make 1 gallon of ethanol need:
      21 pounds of corn (fresh water + ½ gallon of fossil fuel!)

Food-shortages
   Corn grown for ethanol production vs. food
   Corn prices driven up by demand

Inefficiency of ethanol as a biofuel
   Can’t produce enough ethanol to meet energy demands
“Generation 2” biofuel: Ethanol from cellulose

**Generation 2 biofuels:** Cellulose from plant sources such as sawgrass (shown below) is mixed in a bioreactor with either yeast or bacteria for fermentation, which produces ethanol, butanol or other compounds for use as fuel, along with water and carbon dioxide by-products (above).

“Generation 3” biofuel: Biodiesel from CO₂

**Generation 3 biofuels:** When photosynthetic algae or cyanobacteria (shown growing inside cylinders at right) are exposed to sunlight and carbon dioxide, they produce and stockpile fats inside their cells. Exposing the cells to a chemical solvent frees these fat molecules, which can be refined into biodiesel (above).

Summary

Microbiology has far-reaching implications on our understanding of the origins and workings of life on Earth, our health, and our environment.

Renewable and carbon-neutral forms of energy, including biofuels, are desperately needed to replace fossil fuels.

Microbes are poised to play an increasingly pivotal role in the generation of biofuels.
Want to learn more?

**BIOS xxx. Microbiology**
An examination of microbial life, including archaea, bacteria, fungi, and protists. Viruses will also be considered. Emphasis on the molecular genetics of microbes and their relationship to the origin of life, human health and medicine, and the environment.