Fuels: Today and Tomorrow

See also "Chemistry in Context" textbook, Chapters 4 & 8

- Background
- Current Energy Sources
- Fuels for the Future: Examples
  - Clean Coal
  - Solar Cells
  - Fuel Cells

Background

Heat of Combustion

- Energy released when a compound reacts with O_2

$$\text{fuel} + O_2 \longrightarrow CO_2 + H_2O + \text{heat (energy)}$$

We crudely demonstrated this concept with the burning peanut demonstration.

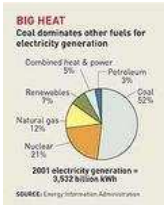
Energy Content of Fuels

From heats of combustion, the following results have been obtained.

Molecule	Formula	%C	%O	%H	kcal/gram
hydrogen	H_2	0%	0%	100%	60
propane	C_3H_8	82%	0%	18%	12
octane	C_8H_{18}	84%	0%	16%	11
ethanol	C_2H_6O	52%	35%	13%	7
coal	?	84%	8%	5%	5.7-7.3
methanol	CH_4O	37%	50%	13%	5.4
wood	?	50%	41%	6%	2.5-3.4

Current Fuel Sources

For all energy, see Text Figure 4.4 (p. 155)



http://pubs.acs.org/cen/coverstory/8208/8208coal.html

Chemical Reactions & Energy

- Breaking bonds always requires energy (put energy in)
- Forming bonds always releases energy (energy out)

For a fuel to be useful, the energy released by forming bonds MUST be greater than the energy required to break bonds.

Combustion of Hydrogen

$$2\,H_2 + O_2 \longrightarrow 2\,H_2O$$

Structures

H_2 : H–H

H_2O : H–O–H

O_2 : O=O

Combustion of Hydrogen (2)

$2\ H_2 + O_2 \longrightarrow 2\ H_2O$

Bond Breaking			Bond Forming		
2 H-H	2 x 436 =	872			
1 O=O	1 x 498 =	498	4 H-O	4 x 467 =	1868
Energy Required		1370	**Energy Released**		1868

Since more energy was released than required, H_2 is a good fuel.

Amount energy released is 1868 - 1370 = 498 $\frac{kJ}{mol}$

(See Table 4.1 on p. 159 for bond energies)

Combustion of Methane

$CH_4 + 2\ O_2 \longrightarrow CO_2 + 2\ H_2O$

Structures

CH_4 : 

CO_2 : O=C=O

O_2 : O=O

H_2O : H-O-H

Combustion of Methane (2)

$CH_4 + 2\ O_2 \longrightarrow CO_2 + 2\ H_2O$

Bond Breaking			Bond Forming		
4 C-H	4 x 416 =	1664	2 C=O	2 x 803 =	1606
2 O=O	2 x 498 =	996	4 H-O	4 x 467 =	1868
Energy Required		2660	**Energy Released**		3474

Since more energy was released than required, CH_4 is also a good fuel.

Amount energy released is 3474 - 2660 = 814 $\frac{kJ}{mol}$

Moles and Grams

In our calculations of bond energies, the following results were obtained:

H_2	CH_4
498 $\frac{kJ}{mol}$	814 $\frac{kJ}{mol}$

While H_2 gives off less energy *per molecule*, it gives off much more energy *per gram*. The weights of the elements provide the necessary conversion factors

Energy per gram

H = 1.0 $\frac{gram}{mol}$ C = 12.0 $\frac{gram}{mol}$

H_2	CH_4
Energy = 498 $\frac{kJ}{mol}$	Energy = 814 $\frac{kJ}{mol}$
Mass = 2.0 $\frac{g}{mol}$	Mass = 16.0 $\frac{g}{mol}$
$\frac{Energy}{mass}$ = 249 $\frac{kJ}{gram}$	$\frac{Energy}{mass}$ = 51 $\frac{kJ}{gram}$

Problems

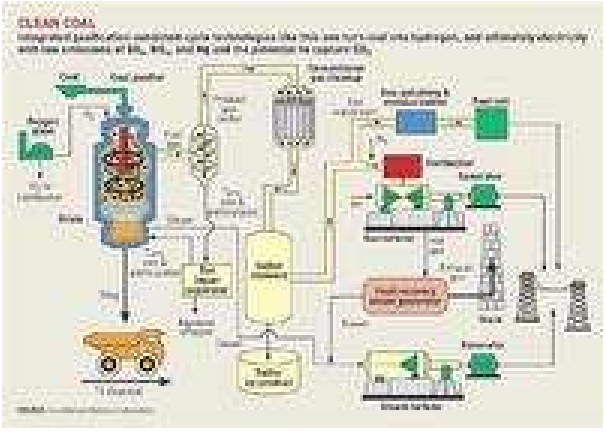
- ed● Energy consumption is increasing (See Figure 4.3, p. 154).
- ed● Finite amounts of current fuels (See Figure 4.12, p. 168).
- ed● Some problems with current fuels
  - Combustion increases NO_x
  - Coal increases SO_x
  - Radioactive waste from nuclear reactors
  - Oil, coal, ... increase CO_2

Fuel for the Future

The following slides mention possible fuels for the 'future'. Some of these applications are 'close', while others are somewhat more speculative. This is not meant to be an exhaustive list. For example, I do not mention:

- Wind Power
- Wave (Tidal) Power
- Hydroelectric
- Nuclear Fusion

Clean Coal

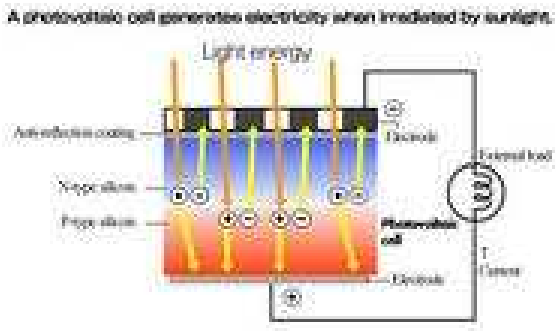


Solar Energy

See Section 8.6 (pp. 348-356) for more details

- Energy in Sunlight converted to electricity
- Practical on small scale. (Calculators, small lights, ...)
- Cells still too expensive and inefficient on larger scale

Electricity from Solar Energy



http://www.apec-vc.or.jp/solar/outline/outlne03.htm

Fuel Cells

Direct conversion of "fuel" into electricity.

- Advantages
  - Less polluting
  - More efficient (maybe)
  - Dream is to use H_2 from water as fuel
- Disadvantages
  - Still requires fuel
  - Still releases CO_2
  - Technology not there yet

H_2/O_2 Fuel Cells

- Cathode

$$O_2 + 4\,H^+ + 4\,e^- \longrightarrow 2\,H_2O$$

- Anode

$$2\,H_2 \longrightarrow 4\,H^+ + 4\,e^-$$

- Net Reaction

$$2\,H_2 + O_2 \longrightarrow 2\,H_2O$$

Methanol Fuel Cells

- Cathode

$$3\,O_2 + 12\,H^+ + 12\,e^- \longrightarrow 6\,H_2O$$

- Anode

$$2\,CH_3OH + 2\,H_2O \longrightarrow 2\,CO_2 + 12\,H^+ + 12\,e^-$$

- Net Reaction

$$2\,CH_3OH + 3\,O_2 \longrightarrow 4\,H_2O + 2\,CO_2$$

Aluminum-Air Fuel Cells

Still being developed.
Uses oxidation of aluminum as fuel.

- Lycos Environmental News - Aug 23, 2000
- Aluminum-Power, Inc.

Miniature Fuel Cells

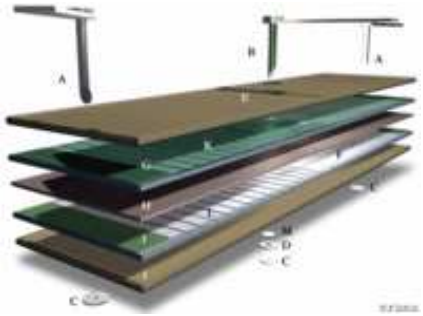
Being developed as a replacement for batteries

- Advantages
  - Could last much longer
  - Replace fuel instead of recharge
  - Fuel might come from renewable sources
- Disadvantages
  - Will require liquid (or gaseous) fuel
  - Might still release CO_2
  - Technology not there yet

Miniature Fuel Cells References

- MIT Technology Review
- ABC News (Sep. 9, 1999)
- ABC News (1999)
- Scientific American (July 2001)
- Energy Related Devices - Hockaday's company
- Manhattan Scientifics' site - Developing Hockaday's fuel cell
- Motorola's prototype

Schematic



Hockaday's fuel cell

Prototype

Prototype methanol fuel cell in a phone

Prototype

Prototype methanol fuel cell in a calculator

Prototype

Motorola’s fuel cell powering a Palm