Chapter 9
Energy for Today

Molecules in Motion
- A burn is the transfer of energy (too much of it for comfort) from a hot object to the human body.
- The atoms and molecules are in constant motion.
- The hotter an object is, the faster its molecules move.

Fundamental Concepts
- Heat is the flow of energy due to a temperature difference.
- Energy, and our use of it, is ultimately tied to molecular motion.
- We use energy to move atoms and molecules in a nonrandom or orderly motion.
- This use of energy is called WORK.
Reliance on Energy

• Without it, our most common tasks become impossible.

<table>
<thead>
<tr>
<th>Sector</th>
<th>% of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industrial</td>
<td>25.9%</td>
</tr>
<tr>
<td>Commercial</td>
<td>14.4%</td>
</tr>
<tr>
<td>Residential</td>
<td>19.8%</td>
</tr>
<tr>
<td>Transportation</td>
<td>17.9%</td>
</tr>
</tbody>
</table>

(4)

The average U.S. citizen enjoys the energy output of 120 people at the flip of a switch or the push of a pedal.

(5)

Energy Vocabulary

• Thermodynamics – the study of energy and its transformation from one form to another
• Energy – the capacity to do work
• Work – a force acting over a distance
• Total energy of an object – the sum of its kinetic energy (motion) and its potential energy (position)
Vocabulary (continued)

- Thermal energy – the energy associated with the temperature of an object
- System – the subject we are thermodynamically studying
- Surroundings – the environment in which the system is exchanging energy

The First Law of Thermodynamics

- Energy can neither be created nor destroyed, only transferred between the system and the surroundings.

- An exception occurs in nuclear processes where mass and energy are interchangeable as $E = mc^2$.

Implications of the First Law

- We cannot create energy that was not there to begin with; a device that continuously produces energy, without the need for energy input, cannot exist.

- You can't get something for nothing.
The Second Law of Thermodynamics

- Energy is dispersed (becomes arranged in a more disorderly way) in any spontaneous process.
- For any spontaneous process, the entropy of the universe (the entirety of any system and its surroundings) must increase.

Implications of the Second Law: No spontaneous process can be 100% efficient with respect to energy.

- Nature takes a heat tax, an unavoidable cut of every energy transaction; additional energy is lost to the surroundings as well due to inefficiencies.
- No perpetual motion machines
- Lesson: Minimize the number of energy conversions required to achieve a particular goal. 
  - *You can’t break even.*
Units of Energy

• Joule (J)
  – James Joule demonstrated that energy could be converted from one form to another, as long as total energy was conserved.

• Calorie (cal)
  – The amount of energy required to heat 1 g of water by 1°C

<table>
<thead>
<tr>
<th>Energy Unit</th>
<th>Conversion Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 calorie (cal)</td>
<td>= 4.184 joules (J)</td>
</tr>
<tr>
<td>1 kilocalorie (kcal)</td>
<td>= 1000 calories (cal)</td>
</tr>
<tr>
<td>1 British thermal unit (Btu)</td>
<td>= 1055 joules (J)</td>
</tr>
<tr>
<td>1 watt (W)</td>
<td>= 1 joule per second (J/s)</td>
</tr>
</tbody>
</table>

Power

• Power is energy per unit time, the rate of energy input or output.

• Basic unit for the expression of power is the watt (W), equivalent to 1 J/s.

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Required Power (W)</th>
<th>annual Required Energy (KWh)</th>
<th>Annual Input (kWh)</th>
<th>Annual Output (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>coal</td>
<td>1.6 x 10^6</td>
<td>2.2 x 10^10</td>
<td>2.3 x 10^10</td>
<td>2.2 x 10^10</td>
</tr>
<tr>
<td>natural gas</td>
<td>0.5 x 10^6</td>
<td>7.4 x 10^9</td>
<td>7.4 x 10^9</td>
<td>7.4 x 10^9</td>
</tr>
<tr>
<td>wind</td>
<td>0.3 x 10^6</td>
<td>4.2 x 10^8</td>
<td>4.2 x 10^8</td>
<td>4.2 x 10^8</td>
</tr>
<tr>
<td>solar</td>
<td>0.1 x 10^6</td>
<td>1.4 x 10^7</td>
<td>1.4 x 10^7</td>
<td>1.4 x 10^7</td>
</tr>
<tr>
<td>nuclear</td>
<td>0.1 x 10^6</td>
<td>1.4 x 10^6</td>
<td>1.4 x 10^6</td>
<td>1.4 x 10^6</td>
</tr>
</tbody>
</table>

EXAMPLE 3.1

Conversion of Energy Units

1000 kilowatt hours (kWh) = 3.6 x 10^10 joules (J)

SOLUTION

250 cal = 250 x 10^-3 kJ

500 W = 500 x 10^-3 kW

1 kcal = 4.184 x 10^3 J

20 Btu = 20 x 10^-3 kcal
Temperature

- A measure of the kinetic energy associated with the motion of its composite atoms and molecules.
  - Fahrenheit
  - Celsius
  - Kelvin

\[ K = ^\circ C + 273 \]
\[ ^\circ C = \frac{5}{9}[^\circ F - 32] \]
\[ ^\circ F = \frac{9}{5[^\circ C]} + 32 \]
Heat Capacity
• The quantity of heat energy required to change the temperature of a given amount of a substance by 1°C
  – Substances with higher heat capacities resist changes in temperature more than other substances.
  • Water’s heat capacity is integral to global temperature regulation.

Chemistry and Energy
• Exothermic reactions
  – Chemical reactions that give off energy to the surroundings
• Endothermic reactions
  – Chemical reactions that absorb energy from the surroundings
• Enthalpy of reaction ($\Delta H_{\text{rxn}}$)
  – The amount of heat absorbed or emitted by a chemical reaction
  – Refers to the enthalpy change from the point of view of the system
  – By convention, negative enthalpy values describe exothermic reactions (and positive values endothermic ones).

Enthalpy of Combustion
• Fuels have significant and exothermic enthalpies of combustion ($\Delta H_{\text{comb}}$).

<table>
<thead>
<tr>
<th>Fuel</th>
<th>$\Delta H_{\text{comb}}$ (kJ/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Firewood</td>
<td>-51</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>-41</td>
</tr>
<tr>
<td>Alcohol</td>
<td>-73</td>
</tr>
<tr>
<td>Methane</td>
<td>-71</td>
</tr>
<tr>
<td>Liquefied Petroleum</td>
<td>-120</td>
</tr>
<tr>
<td>Wood</td>
<td>-167</td>
</tr>
<tr>
<td>Wood (as measured by gasometer)</td>
<td>-196</td>
</tr>
<tr>
<td>Natural gas</td>
<td>-364</td>
</tr>
<tr>
<td>Alcohol</td>
<td>-41</td>
</tr>
</tbody>
</table>
Energy for Our Society

• Pre-1970s – energy taken for granted
• 1970s – North American energy crisis
• 1981 – gas prices at historical high
• 1990s – benign increases in energy costs
• Post-1990s – Prudence gained from the last energy crisis is largely forgotten.
Fossil Fuels

• Natural gas – mixture of methane and ethane
• Petroleum – hydrocarbon range from 5 to about 18 or even more
• Coal – hydrocarbon range upwards of 200 in chains and rings
• The molecules that compose fossil fuels contain a large amount of energy since they were formed by endothermic reactions.

Fuels and Sunlight

• Ancient plants used the sun’s energy to synthesize energetic molecules.
  \[ \text{sunlight} + 6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow 6\text{O}_2 + C_6\text{H}_{12}\text{O}_6 \]
• Photosynthesis yields glucose, which was ultimately converted to fossil fuels, by processes taking millions of years.
• Combustion, the opposite of photosynthesis, releases the energy.
Electricity from Fossil Fuels

- About 70% of U.S. electricity is generated by burning fossil fuels.

Smog

- Hydrocarbon combustion should only produce carbon dioxide and water, but impurities in fuels and combustion inefficiencies produce other products.
  - Carbon monoxide – binds with hemoglobin in blood limiting oxygen transport
  - Nitrogen oxides – NO emitted in exhaust undergoes chemistry to form NO₂, the brown gas that gives smog its characteristic color.
  - Ozone and PAN – partially burned hydrocarbons combine with NO₂ and sunlight to form ozone (O₃) and PAN (CH₃CO₂NO₂) which sting eyes, damage rubber and crops, make breathing difficult.
Catalytic Converters
- Employs catalysts to promote the decomposition of exhaust into less environmentally harmful substances.
- They address partially burned hydrocarbons, carbon monoxide, and nitrogen monoxide.

Acid Rain
- Sulfur dioxide emission
  - Fossil fuels contain sulfur impurities.
- Nitrogen monoxide and nitrogen dioxide emission
  - Air used in fossil fuel combustion is mostly nitrogen.
- These nonmetallic oxides form acids that fall as acid rain, damaging lakes and streams, building materials, forests, and limiting visibility.
The most significant greenhouse gas is carbon dioxide.

Kyoto Protocol

- Despite complexity of climate models, it is generally agreed that global warming has begun.
- Responses vary
- The 1997 Climate Change Convention formalized a plan to begin the reduction of greenhouse gas emissions.
- The only industrialized nations to not ratify the resulting treaty were the U. S. and Australia.