Chapter 4:
Energy, Chemistry and Society

Breaking news...

Britain aims for CO_2-limit target dates

18 minutes ago

LONDON - Britain proposed setting legally binding targets for cutting carbon dioxide emissions, saying Tuesday it wanted to lead by example in the global campaign against climate change.

Environment Secretary David Miliband said the bill, which includes targets for reducing emissions that must be achieved by 2020 and 2050, was "the first of its kind in any country."

"The debate on climate change has shifted from whether we need to act to how much we need to do by when, and the economic implications of doing so," he said.

The draft also outlines plans for five-year "carbon budgets" capping CO2 levels, and a new independent body that would report to Parliament on Britain's progress in the fight against climate change.

The bill must be approved by both houses of Parliament to become law.

In the U.S., fossil fuel combustion provides

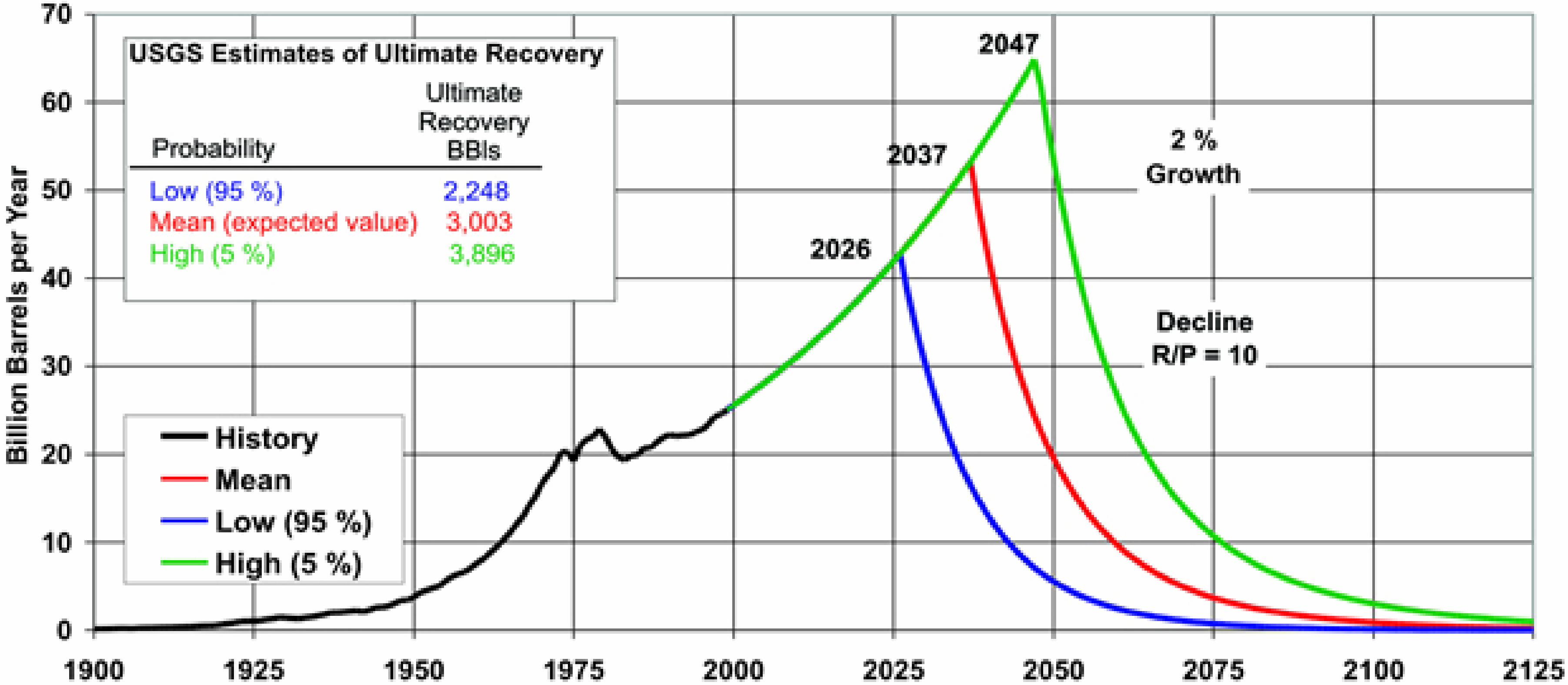
- 70% of electricity
- 85% of total energy

Fossil fuels produce large amounts of CO_2

The supply of fossil fuels is finite, and may be running out (estimates vary)

- 150 years left for coal
- 50 years left for oil

Figure 2. Annual Production Scenarios with 2 Percent Growth Rates and Different Resource Levels (Decline R/P=10)



Source: Energy Information Administration
Note: U.S. volumes were added to the USGS foreign volumes to obtain world totals.

Energy, work, and heat – some definitions

- Energy – the capacity to do work
- Work is done when movement occurs against a restraining force.
  - The force multiplied by the distance
- Heat is energy that flows from a hotter to a colder object.
  - Temperature is a measure of the heat content of an object.

Energy, work, and heat

- Both work and heat are forms of molecular motion
  - Work is **organized** motion (all the molecules moving in the same direction)
  - Heat is **random** motion (all the molecules moving in different directions)
- Energy is the sum of all these molecular motions

Energy, work, and heat

Units of Energy

Joule

- The amount of energy required to raise a 1-kg book 10 cm against the force of gravity
- The amount of energy required for each beat of the human heart

Calorie

- Defined as the amount of heat necessary to raise the temperature of exactly one gram of water by one degree Celsius
- 1 cal = 4.184 J
- 1 “food calorie” = 1 kcal = 1000 cal

Energy Transformations

First Law of Thermodynamics:

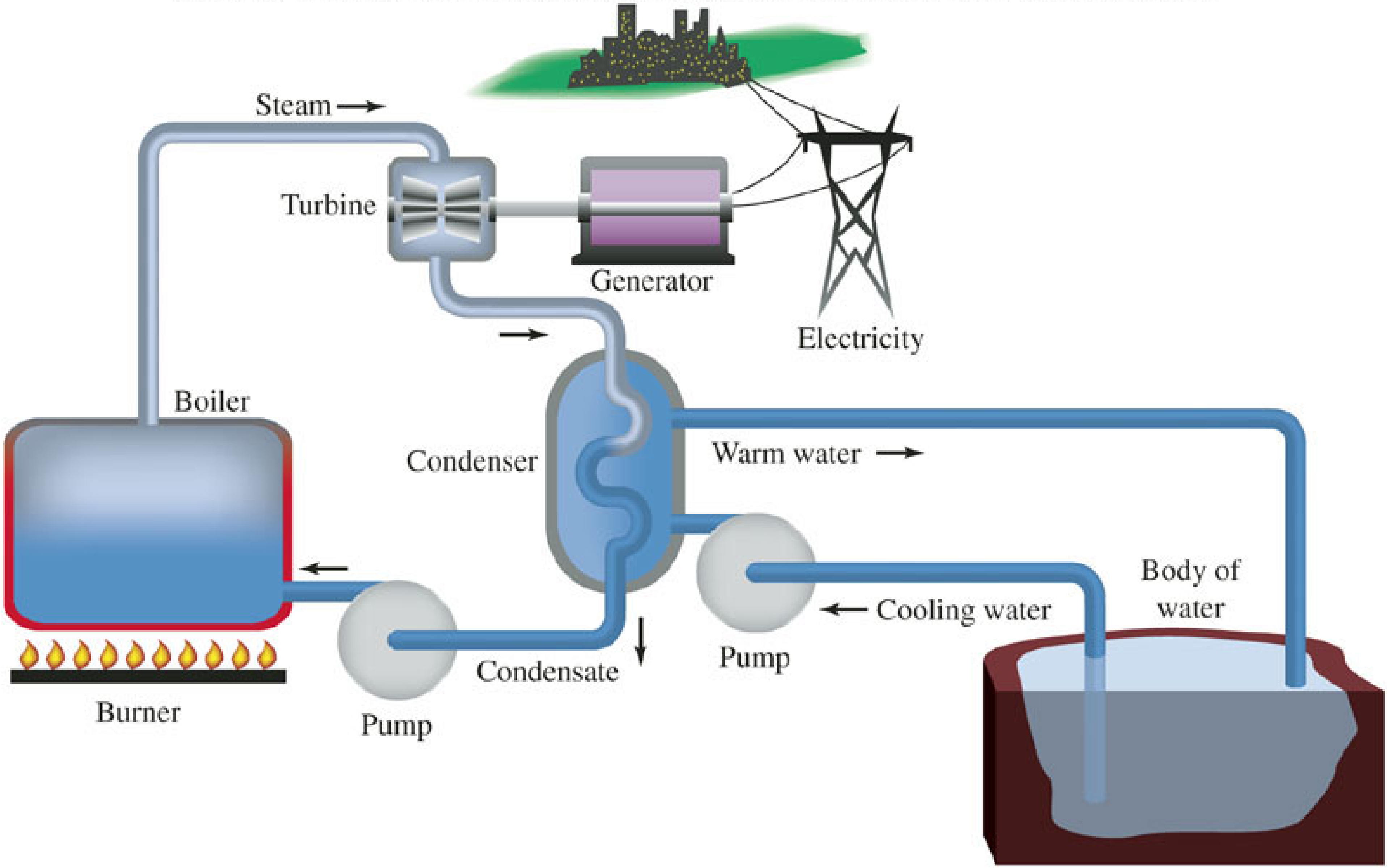
Energy is neither created nor destroyed

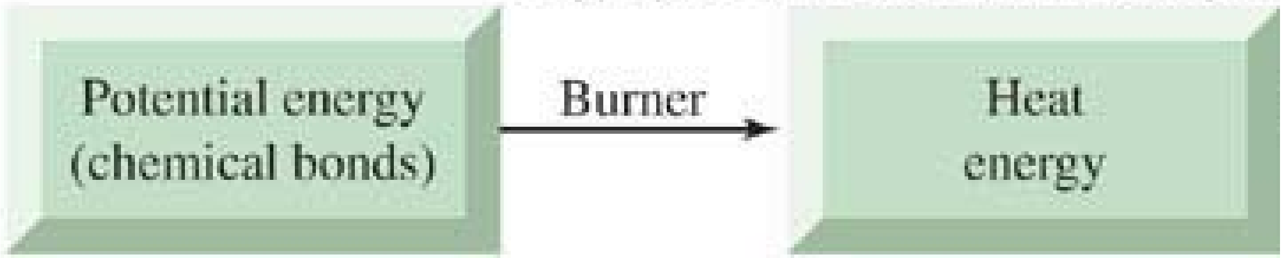
- Conservation of Energy
- Conservation of Mass

Energy **can** be converted from one form into another

Energy Transformations

- Energy from fossil fuels
- Combustion
- Transform chemical energy to heat energy
- Engines transform heat energy into work energy


Steam
Turbine
Generator
Electricity
Boiler
Condenser
Warm water
Body of
water
Cooling water
Pump
Condensate
Burner
Pump


Potential energy
(chemical bonds)
Burner
Heat
energy


Heat
energy
Gas turbine
Mechanical
energy


Mechanical
energy
Generator
Electrical
energy

Energy Transformation

- Can we get complete energy conversion?
  - Does all the potential energy get transformed into electricity (or even heat energy)
- ***Efficiency*** measures the ability of an engine to transform chemical energy to mechanical energy
- Efficiencies are multiplicative
  - Overall efficiency = efficiency of (power plant) x (boiler) x (turbine) x (electrical generator) x (power transmission) x (home electric heater)

Energy Transformation

- Efficiencies are multiplicative
  - Overall efficiency = efficiency of (power plant) x (boiler) x (turbine) x (electrical generator) x (power transmission) x (home electric heater)
- How much energy does it take to heat your house for a month – say, January?
- How much methane does the power plant need to burn in order to give your house that much electrical power?

Table 4.1 Some Typical Efficiencies in Power Production

Maximum theoretical efficiency	55–65%
Efficiency of boiler	90%
Mechanical efficiency of turbine	75%
Efficiency of electrical generator	95%
Efficiency of power transmission	90%

Overall efficiency = efficiency of (power plant) x (boiler) x (turbine) x (electrical generator) x (power transmission) x (home electric heater)

Overall efficiency = .60 x .90 x .75 x .95 x .98

Overall efficiency = 0.34

34 % energy generated is used

The rest is wasted

Energy Transformation

It takes about 3.5×10^7 kJ of energy to heat a house in January

Methane releases 50.1 kJ energy per gram

Efficiency of electric heat using natural gas: 34%

Heat needed = heat used x efficiency

Heat used = (heat needed) / efficiency

$= 3.5 \times 10^7$ kJ / .34 = 1.0×10^8 kJ

Methane used = 1.0×10^8 kJ / 50.1 kJ = 2.0×10^6 g

Energy Transformation

It takes about 3.5×10^7 kJ of energy to heat a house in January

Methane releases 50.1 kJ energy per gram

What if you didn't use the power plant's electricity, but just burned the methane yourself at home?

Efficiency of home heater using natural gas: 85%

Heat needed = heat used x efficiency

Heat used = (heat needed) / efficiency

$= 3.5 \times 10^7$ kJ / .85 = 4.1×10^7 kJ

Methane used =4.1×10^7 kJ / 50.1 kJ = 8.2×10^5 g

Energy Transformation

- Potential Energy – energy stored in bonds, or intrinsic to position
- Kinetic Energy – the energy of motion
- Thermal Energy – random motion of molecules
- Entropy – randomness in position or energy level
  - Chaos
  - Disorder

Energy Transformation

Second Law of Thermodynamics

- **The entropy of the universe always increases during a spontaneous process**
- It is impossible to completely convert heat into work without making some other changes in the universe
- Organized energy is always being transformed into chaotic motion or heat energy

Randomness is decreased only through a **non-**spontaneous process (work must be performed)

Entropy

- The more disordered a sample, the higher the entropy
  - Boiled egg vs. scrambled egg
  - People sitting in a classroom vs. people walking in the halls
  - Gas vs. liquid vs. solid
  - Photosynthesis vs. combustion
  - Your desks vs. my desk

Entropy

- Another way of thinking about it… what is the **probability** of a particular state?
- Your text uses the example of a drawer full of socks
  - A drawer full of socks is **more likely** to be disordered than ordered
  - It is **not impossible** for a drawer full of socks to become organized…
  - … but it **does** require work for that to happen if you aren't willing to wait

From Fuel Sources to Chemical Bonds

- Combustion – combination of the fuel with oxygen to form products

  $CH_4(g) + 2\ O_2(g) \rightarrow CO_2(g) + 2\ H_2O(g) + \text{energy}$
- Exothermic reaction – any chemical or physical change accompanied by the **release** of heat
- Heat of combustion – the quantity of heat energy given off when a specified amount the a substance burns in oxygen
  - Typically reported in kilojoules per mole (kJ/mol), but sometimes in kJ/g
  - Most* combustion reactions are exothermic

From Fuel Sources to Chemical Bonds

- $CH_4(g) + 2\ O_2(g) \rightarrow CO_2(g) + 2\ H_2O(g)$ + energy
- Heat of combustion of methane is -50.1 kJ/g
  - For every gram of methane burned we get 50.1 kJ energy

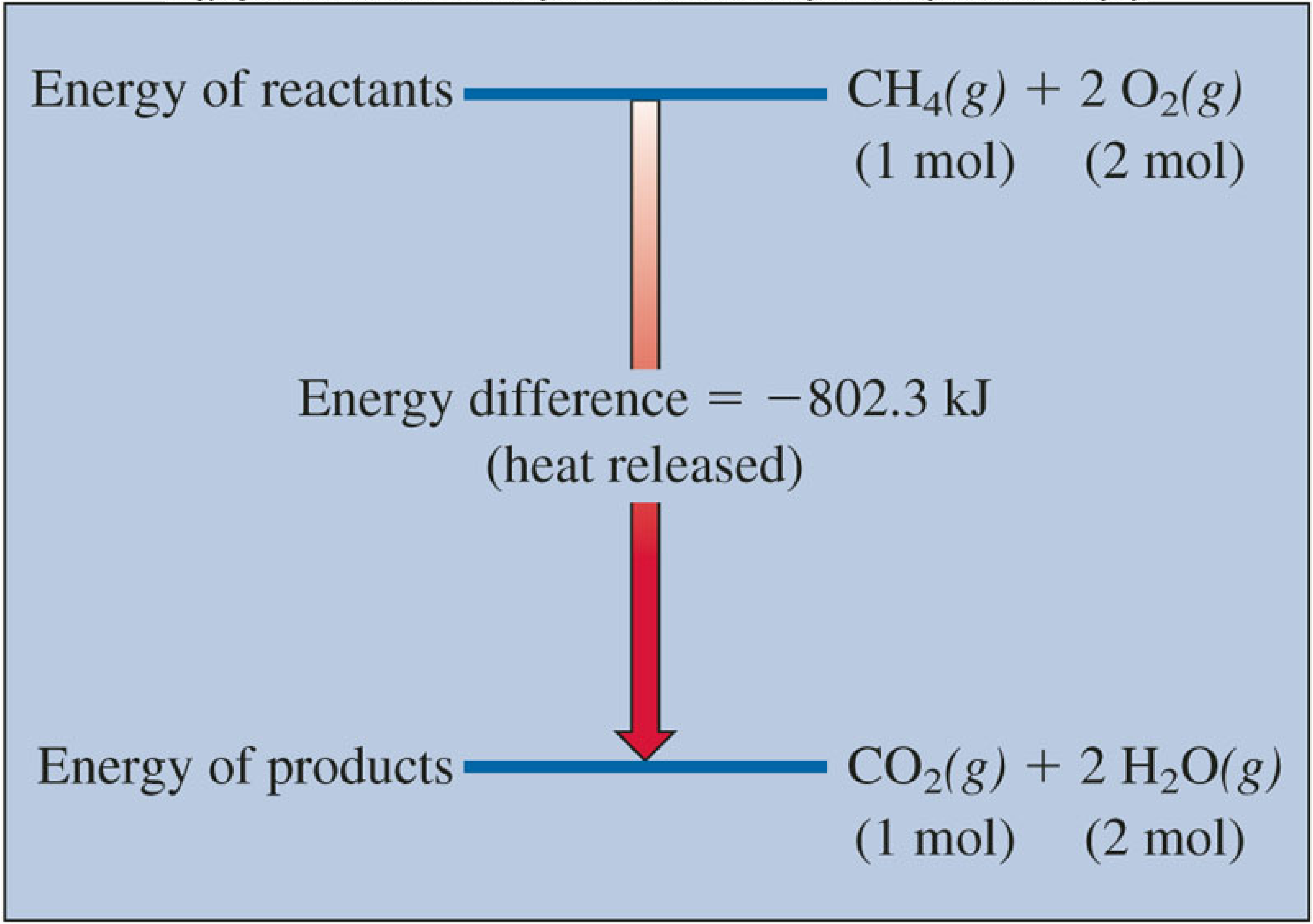
$$1\,mol\,CH_4 \times \frac{16.0\,g\,CH_4}{1\,mol\,CH_4} \times \frac{50.1\,kJ}{1\,g\,CH_4} = 802.3\,kJ$$

  - For every mole of methane burned we get 802.3 kJ energy
- The combustion of one mole of methane will always produce one mole of carbon dioxide, two moles of water, and 802.3 kilojoules of heat energy

Your Turn 4.8

- The heat of combustion of methane is 802.3 kJ/mol. Methane is usually sold by the standard cubic foot (SCF). One SCF contains 1.25 mol of methane. What is the energy that is released by burning one SCF of methane.

$$1\,SCF\ CH_4 \times \frac{1.25\,mol CH_4}{1\,SCF\ CH_4} \times \frac{802.3\,kJ}{1\,mol CH_4} = 1003\,kJ$$


Energy of reactants
$CH_4(g) + 2\ O_2(g)$
(1 mol) (2 mol)
Energy difference = −802.3 kJ
(heat released)
Energy of products
$CO_2(g) + 2\ H_2O(g)$
(1 mol) (2 mol)

From Fuel Sources to Chemical Bonds

- Chemical reactions involve the rearrangement of atoms and bonds
  - Breaking the bonds of reactants
  - Moving atoms around
  - Creating the bonds of products
- It takes energy to break bonds
  - Endothermic (process that absorbs energy)
- It releases energy to form bonds
  - Exothermic (processes that release energy)
- The **difference** between the energy required to break the bonds of the reactants and to make the bonds of the products is the heat of reaction

From Fuel Sources to Chemical Bonds

$$CH_4(g) + 2\ O_2(g) \rightarrow CO_2(g) + 2\ H_2O(g)$$

Reactants

- Methane (4 C-H bonds)
- Oxygen (2 molecules, each with an O=O double bond)

Products

- Carbon dioxide (2 C=O double bonds)
- Water (2 molecules, each with 2 H-O bonds)

Energy is released because there is energy left over

- Energy of reactants > Energy of products

From Fuel Sources to Chemical Bonds

Endothermic Reaction	**Exothermic Reaction**
$\text{Energy}_{\text{products}} > \text{Energy}_{\text{reactants}}$	$\text{Energy}_{\text{products}} < \text{Energy}_{\text{reactants}}$
Energy change is positive.	Energy change is negative.
Energy is absorbed.	Energy is released.

Energy change (ΔE) = $\text{Energy}_{\text{products}} - \text{Energy}_{\text{reactants}}$

The SIGN of the change is important!

Energy Changes at the Molecular Level

- Bond energy – the amount of energy that must be absorbed to break a specific chemical bond.
- Can be used to estimate heats of reactions

Table 4.2 Bond Energies (in kJ/mol)

	H	C	N	O	S	F	Cl	Br	I
Single bonds									
H	436								
C	416	356							
N	391	285	160						
O	467	336	201	146					
S	347	272	—	—	226				
F	566	485	272	190	326	158			
Cl	431	327	193	205	255	255	242		
Br	366	285	—	234	213	—	217	193	
I	299	213	—	201	—	—	209	180	151

Multiple bonds

C=C	598	C=N	616	C=O	803 in CO_2
C≡C	813	C≡N	866	C≡O	1073
N=N	418	O=O	498		
N≡N	946				

Source: Data from Darrell D. Ebbing, *General Chemistry,* Fourth Edition, 1993 Houghton Mifflin Co. Data originally from *Inorganic Chemistry: Principles of Structure and Reactivity,* Third Edition by James E. Huheey, 1983, Addison Wesley Longman.

Formation of Water

$$2\ H_2(g) + O_2(g) \rightarrow 2\ H_2O(g) + \text{energy}$$

Reactants

- Hydrogen (2 molecules, each with 1 H-H bond)
- Oxygen (one O=O double bond)

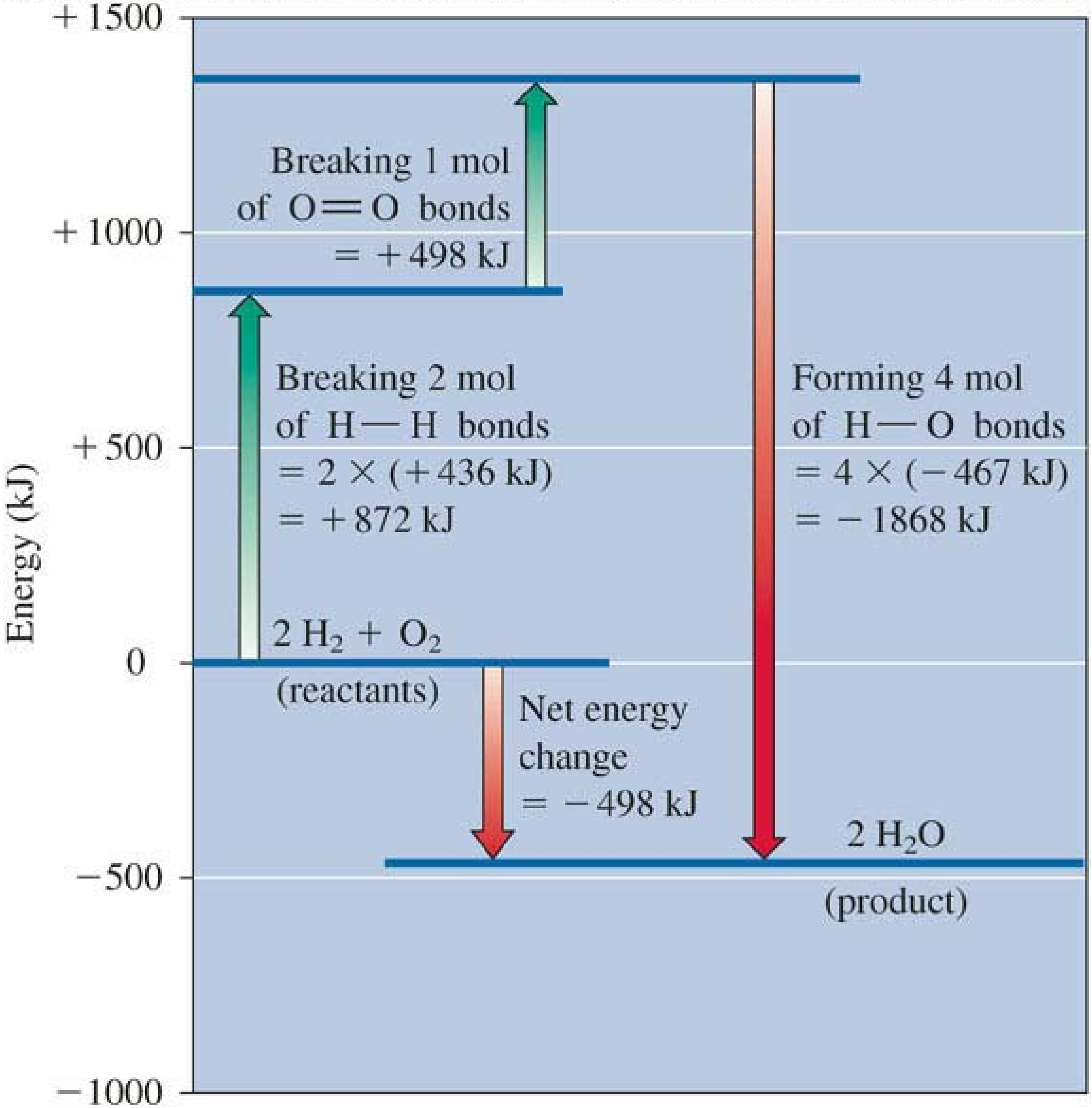
Products

- Water (2 molecules, each with 2 H-O bonds)

Molecule	Bonds per molecule	Moles	Total Number of Bonds	Bond Process	Energy per bond	Total Energy
H—H	1	2	$1 \times 2 = 2$	breaking	+436 kJ	$2 \times (+436) = +872$ kJ
O═O	1	1	$1 \times 1 = 1$	breaking	+498 kJ	$1 \times (+498) = +498$ kJ
H—O—H	2	2	$2 \times 2 = 4$	making	−467 kJ	$4 \times (-467) = -1868$ kJ

Energy is **released** because there is energy left over

- 872 kJ + 498 kJ – 1868 kJ = – 498 kJ (exothermic)


+1500
+1000
+500
0
−500
−1000
Energy (kJ)
Breaking 1 mol of O═O bonds = +498 kJ
Breaking 2 mol of H—H bonds = 2 × (+436 kJ) = +872 kJ
Forming 4 mol of H—O bonds = 4 × (−467 kJ) = −1868 kJ
2 H₂ + O₂ (reactants)
Net energy change = −498 kJ
2 H₂O (product)