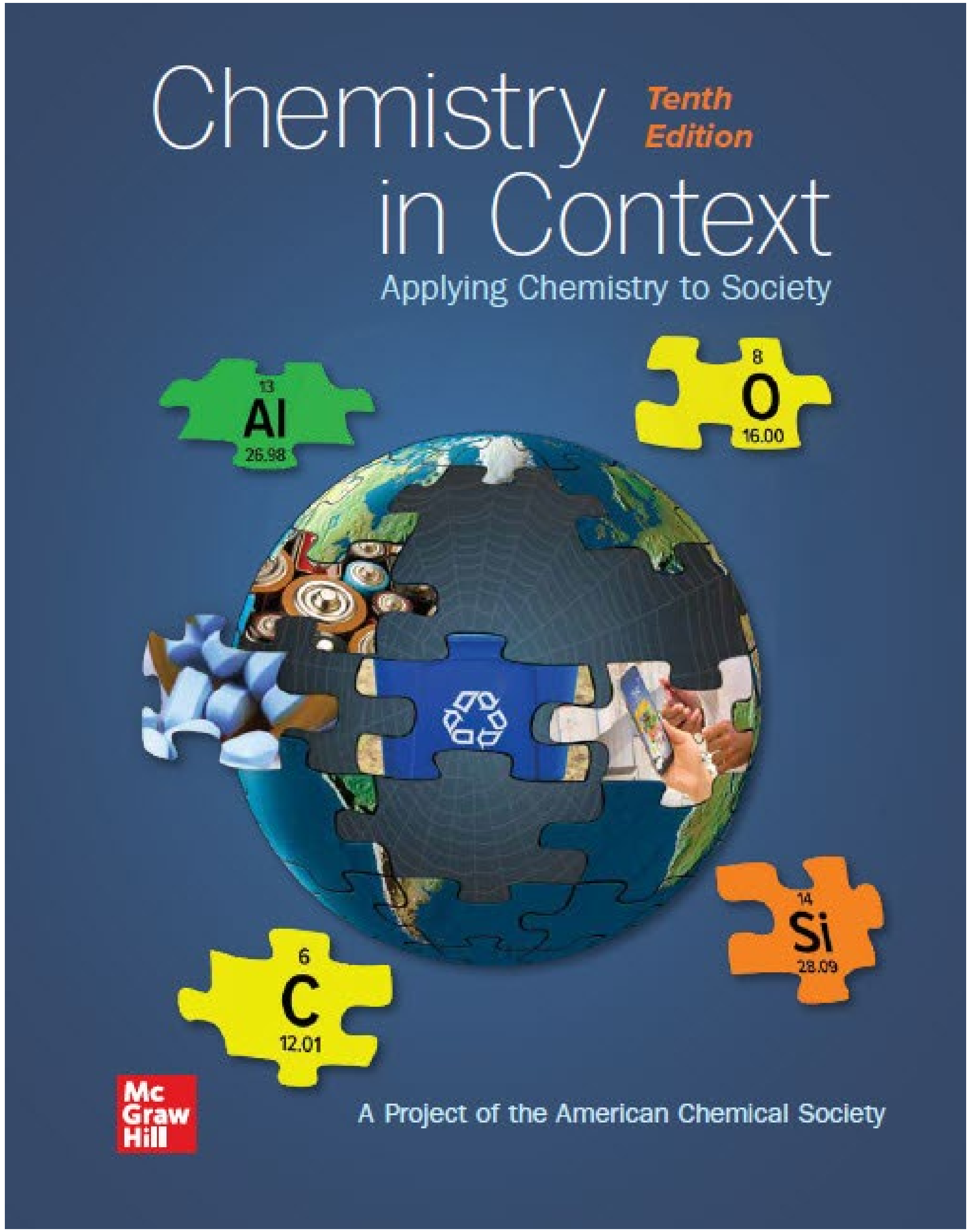
General Chemistry (CH101): Chemistry around Us

Department of Chemistry

KAIST

Energy from Combustion

Chapter 06



Chapter 6
Energy from Combustion

- What are fuels and how much energy is released when they are burned?
- How is electricity generated?
- What are the environmental implications of obtaining and using fossil fuels?
- What are the benefits and overall sustainability of using biofuels?

Reflect

What Does It Take?

Watch the opening chapter video and answer the following questions.

a. Imagine you are going to take a road trip across the United States. from New York City to Los Angeles. The distance of this trip is 4460 km and the vehicle you will use gets 30 miles per gallon of gasoline. Now much gasoline would you need for this trip?

b. Now, imagine that the car you are using has the capability of also using an alternative, renewable fuel such as biodiesel or ethanol. However. using ethanol is less efficient than using gasoline. In other words. when using ethanol, you can achieve only 20 miles per gallon. How many gallons of ethanol would you need to cover your entire trip?

c. Currently, the ethanol used for fuel is predominantly made from corn. Assume it takes 26.1 pounds of corn to make 1 gallon of ethanol, and 1 acre of land to produce 7110 pounds of corn. How much land is needed to produce sufficient fuel for your trip?

Chapter 6 video

What Are Fuels?

- **Fuels** are any solid, liquid, or gas that may be combusted to produce heat or work.
- **Fossil fuels** were formed millions of years ago from decaying plant matter.
- Partial decomposition with heat and pressure produces coal and petroleum.
- Plants gain energy from the sun and store it as **glucose** through photosynthesis:

$$6CO_2 + 6H_2O + 2800\ \text{kJ} \rightarrow C_6H_{12}O_6 + 6O_2$$

- Energy is released through **metabolism**:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 2800\,\text{kJ}$$

- Decay and **combustion** have same overall reaction as metabolism.

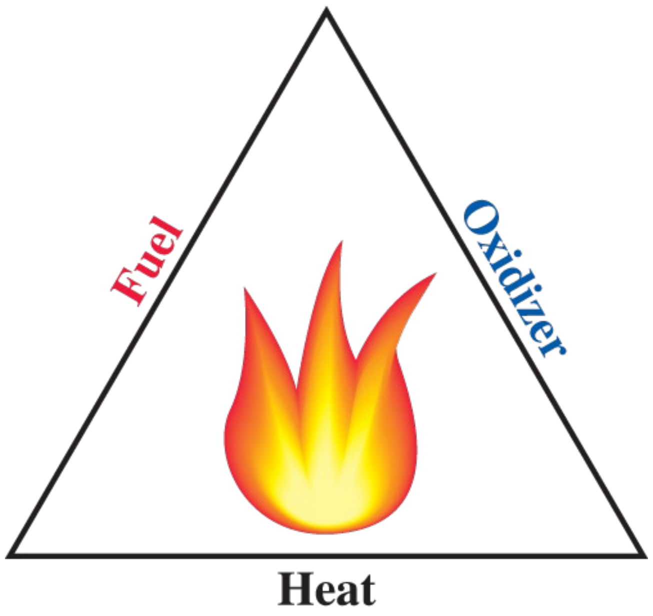
Combustion

There are three requirements to generate a fire: a source of heat, a fuel, and an oxidizer:

$$\text{Fuel} + \text{Oxidizer} \xrightarrow{\text{heat}} \text{Products}$$

The majority of fuels are hydrocarbons.

- Hydrocarbons are compounds made of only hydrogen and carbon atoms.



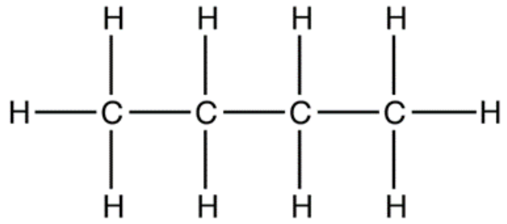
Hydrocarbons

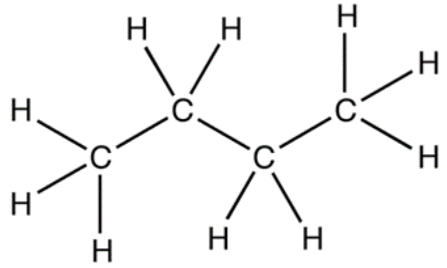
Carbon forms four bonds in hydrocarbon molecules.

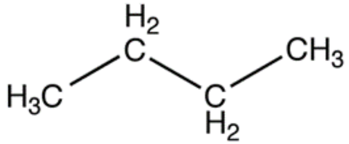
- Total of eight shared electrons.
- Sometimes these involve double or triple bonds.

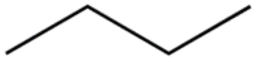
A hydrocarbon can be represented in many different ways:

- Structural formulas are Lewis structures with all bonds drawn.
- Condensed structural formulas don't show all bonds.









$CH_3CH_2CH_2CH_3$

$H_3C\text{-}CH_2\text{-}CH_2\text{-}CH_3$

Hydrocarbon Names [1]

Your Turn 6.5 Mother Eats Peanut Butter

Many generations of chemistry students have used the memory aid “mother eats peanut butter” to remember *meth-, eth-, prop-, but-.* Use this, or another memory aid of your choice, to tell how many carbon atoms are in each of these compounds.

a. Ethanol (a component of adult beverages and a gasoline additive).

b. Methylene chloride (a component of paint strippers and a possible indoor air pollutant).

c. Propane (the major component in liquid petroleum gas, LPG).

Hydrocarbon Names

Table 6.1 Names of Hydrocarbons Based on the Number of Carbon Atoms

Chemical Formula	Number of Carbon Atoms	Compound Name	Chemical Formula	Number of Carbon Atoms	Compound Name
CH_4	1	Methane	C_6H_{14}	6	Hexane
C_2H_6	2	Ethane	C_7H_{16}	7	Heptane
C_3H_8	3	Propane	C_8H_{18}	8	Octane
C_4H_{10}	4	Butane	C_9H_{20}	9	Nonane
C_5H_{12}	5	Pentane	$C_{10}H_{22}$	10	Decane

Hydrocarbon Combustion

Combustion involves fuel and oxygen as reactants, and **carbon dioxide** and **water** as products:

$$2\,C_4H_{10(g)} + 13\,O_{2(g)} \rightarrow 8\,CO_{2(g)} + 10\,H_2O_{(g)}$$

The actual combustion of a fuel is never this simple:

- Fuels contain a variety of different hydrocarbons, as well as other compounds of sulfur.
- At high temperatures, nitrogen from the atmosphere also reacts with oxygen to produce nitrogen oxides.

Your Turn [1]

Your Turn 6.6 Practice with Combustion Reactions

For each of the fuels below, write the balanced combustion reaction.

a. Glucose, sugar ($C_6H_{12}O_6$).

b. Methane, natural gas (CH_4).

c. Butane, fuel in lighters (C_4H_{10}).

Hint: Go back to Section 2.11 for information on balancing equations.

What is Energy?

Energy is the capacity to do work

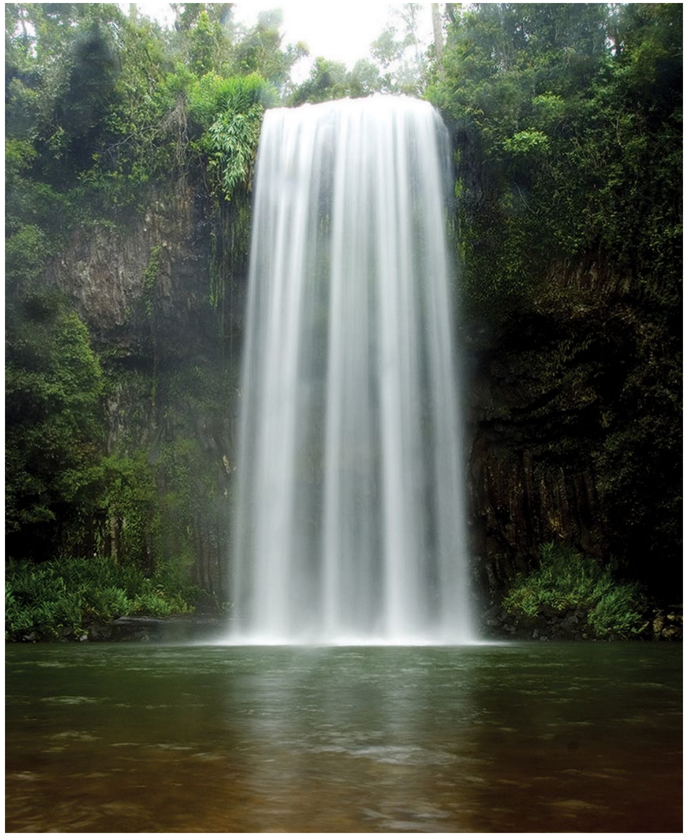
Potential Energy is energy due to position or composition

Kinetic Energy is energy due to movement

Work is movement against a force:

$$\text{work} = \text{force} \times \text{distance}$$

Atomic-interactions



Heat versus Temperature

Heat is energy that flows from a hotter to a colder object.

Temperature is a measure of the average kinetic energy of the atoms and/or molecules.

How Do We Tell Temperature?

Units of Energy

The **joule (J)** is the SI unit of measurement for energy.

- 1 J is the amount of energy required to raise a 100 g object 1 m against the force of gravity.

Another unit of energy often used is the **calorie (cal).**

- 1 calorie is the amount of heat required to raise the temperature of 1 g of water by 1 °C.

Some conversions:

1 calorie = 4.184 J

1 kilocalories (kcal) = 1000 calories (cal) = 1 Cal (dietary calorie)

Food and Drug Administration

Your Turn 2

Your Turn 6.9 Energy Calculations

a. A slice of pizza contains 217 kcal (217 Cal). Express this value in kilojoules.

b. Calculate the number of 1-kg books you could lift to a shelf 2 m off the floor with the amount of energy from metabolizing one slice of pizza.

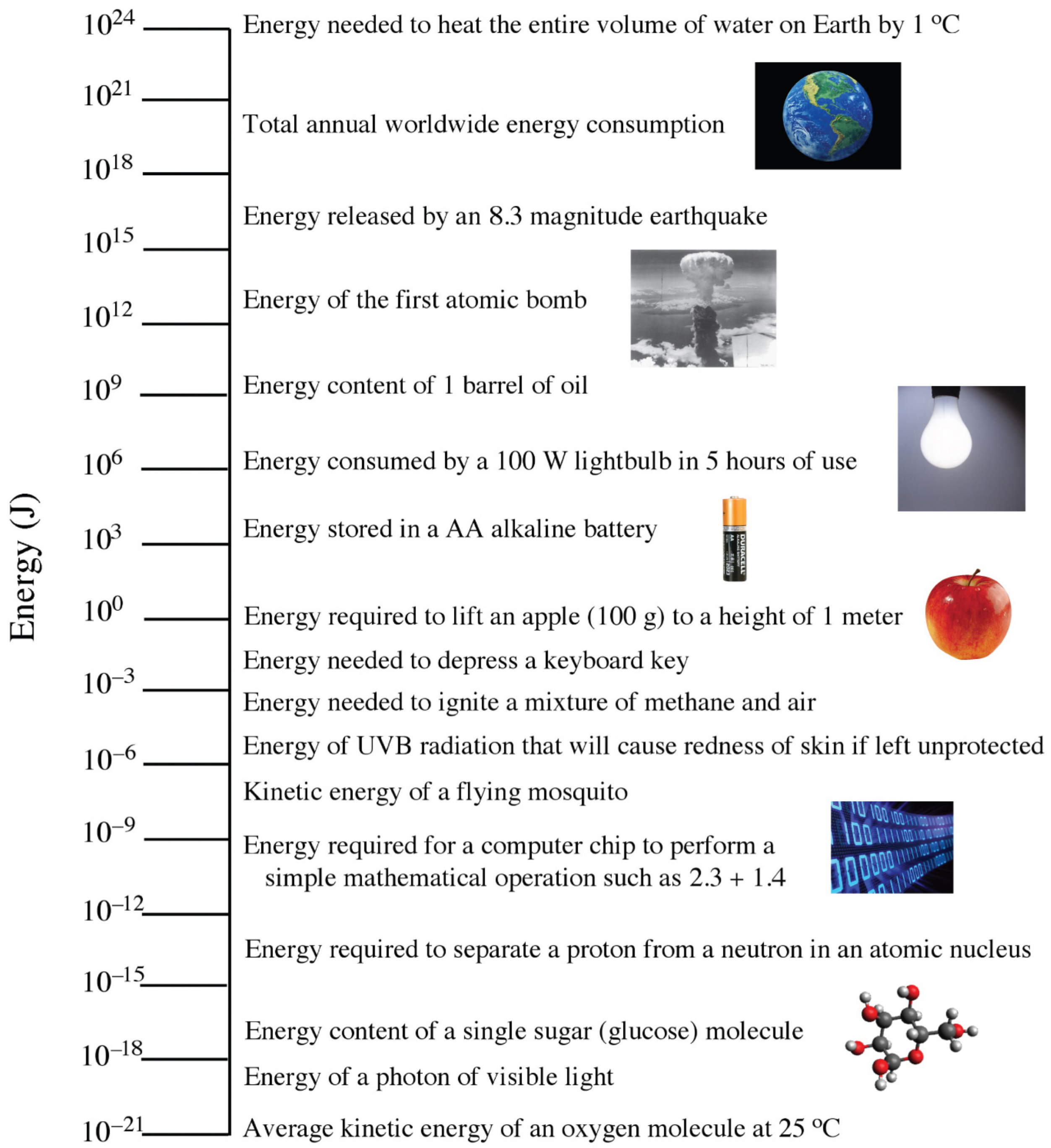
Your Turn 6.10 Checking Assumptions

A simplifying assumption was made in doing the calculations in part **b** of the preceding activity.

a. What was the assumption, and is it reasonable?

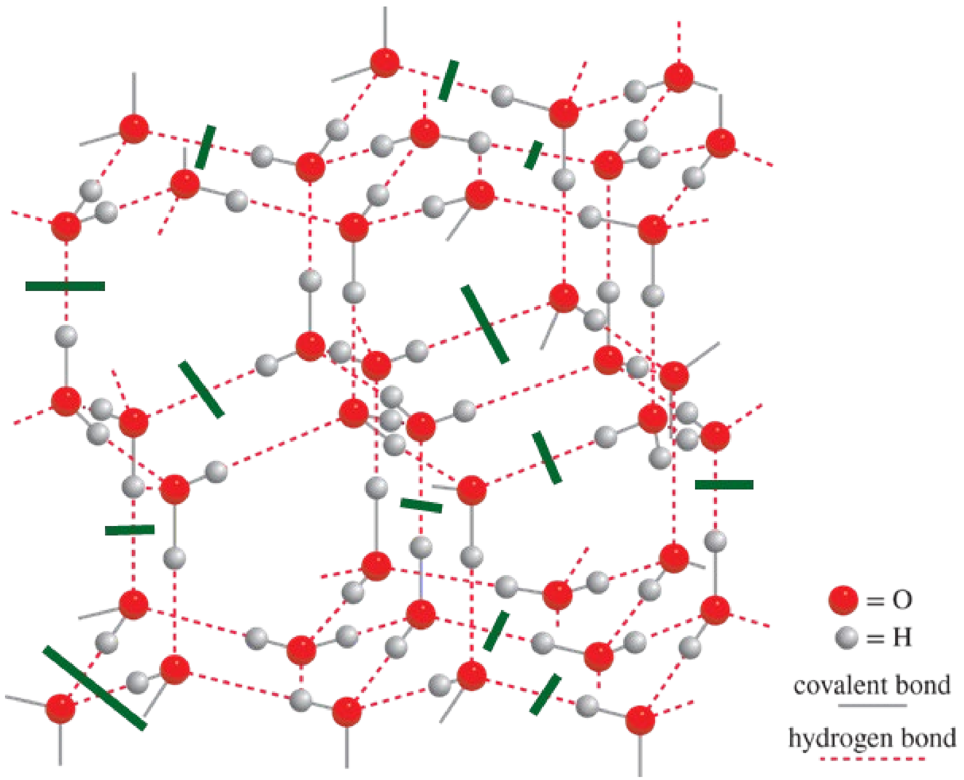
b. Based on this assumption, is your answer too high or too low? Explain your reasoning.

A Contextual Comparison of Energies



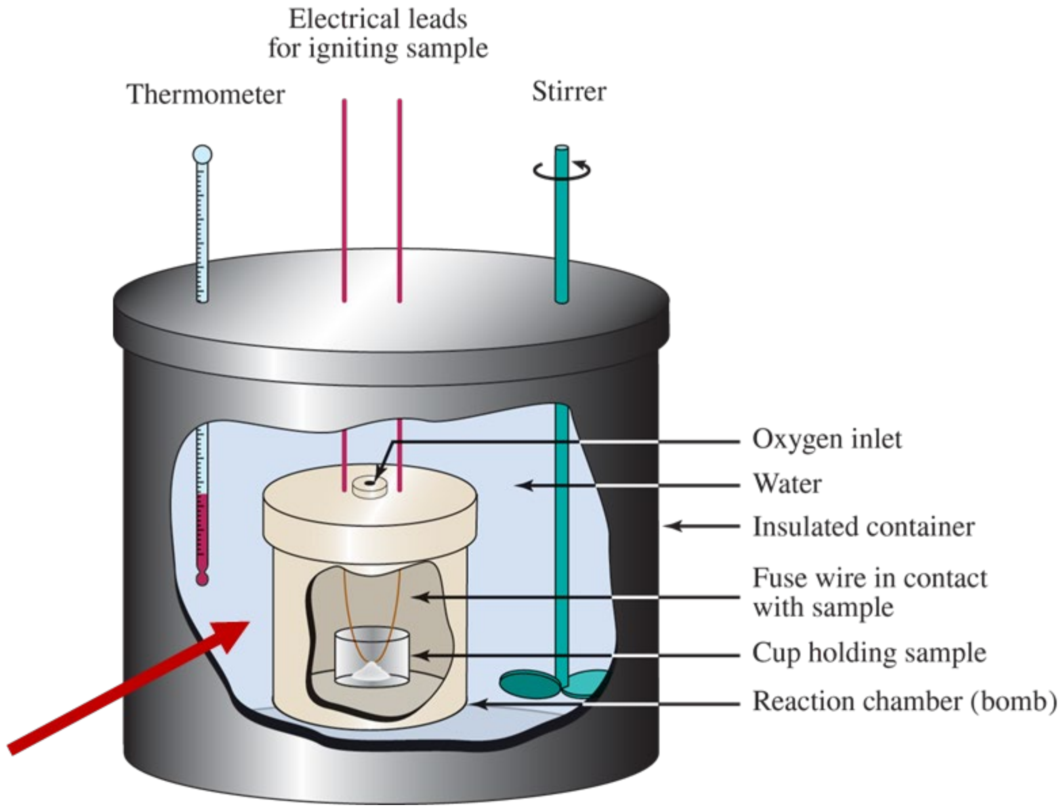
What Else is Special About Water?

- **Specific heat** (1.00 cal/g °C) – a lot of energy required to change the temperature; moist air stores heat energy.
- **Heat of fusion** – released when the liquid freezes to a solid; spray crops to prevent freezing.
- **Heat of vaporization** – released when the gas condenses into a liquid; huge temperature swing during a thunderstorm.
- Energy is required to break the intermolecular hydrogen bonds during a phase change.



Measuring Energy Changes: Calorimetry

- A **calorimeter** is used to measure the quantity of heat energy released in a combustion reaction.
- The heat of combustion is the quantity of heat given off when a specified amount of a substance burns in oxygen.
- Heats of combustion are reported in units of energy per mole or per gram.
- If you test a reaction that releases heat, the temperature of the water will increase.



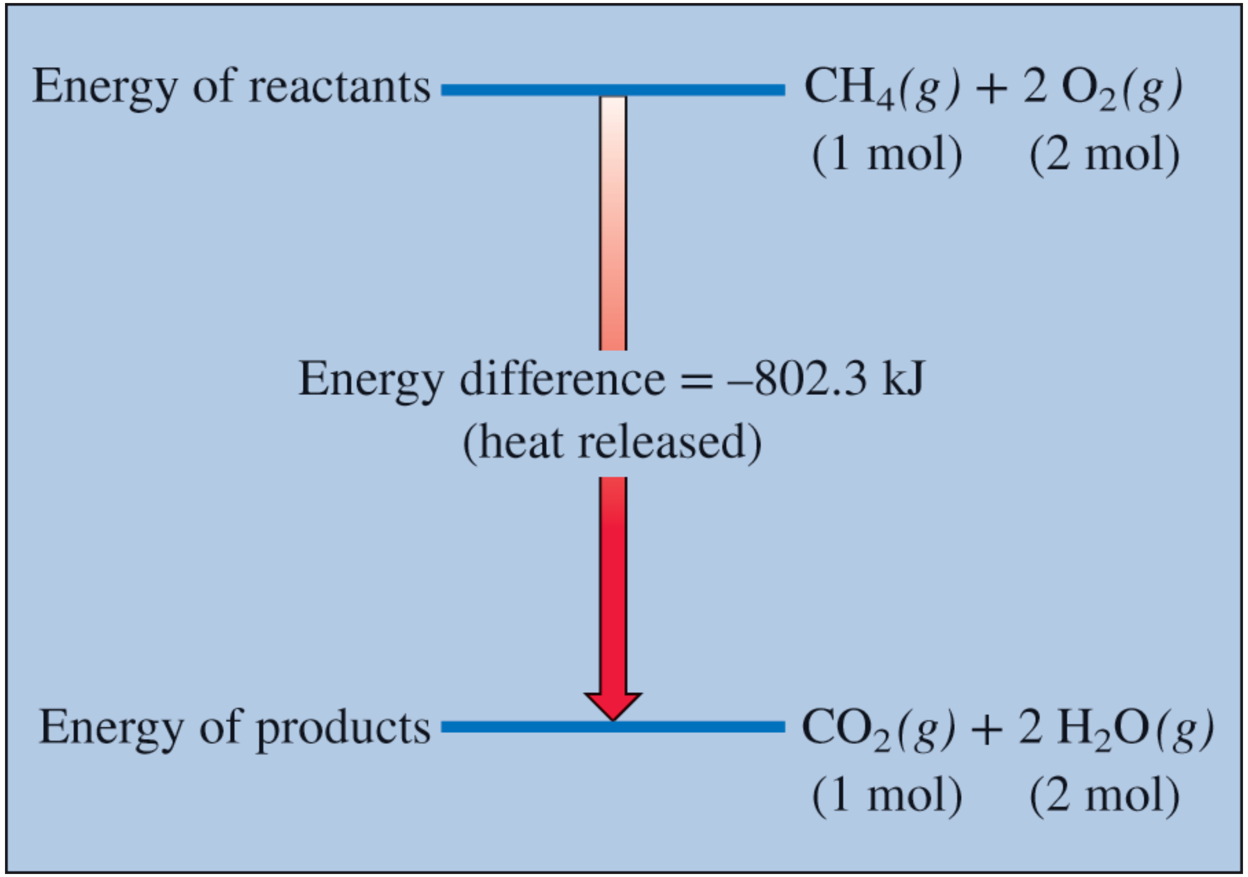
[Calorimetry - American Chemical Society (acs.org)]

Exothermic Reactions

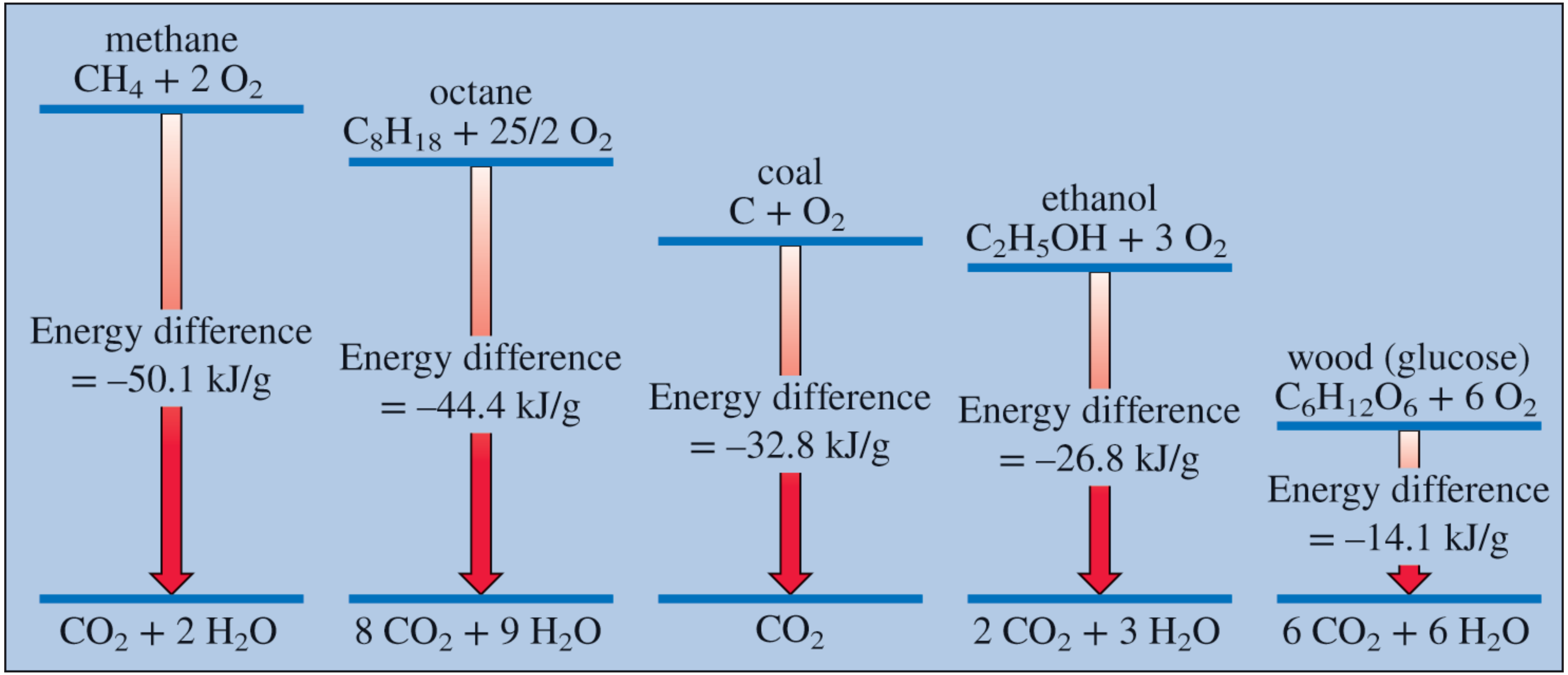
- Burning a fuel can be compared to water flowing from the top of a waterfall. Both undergo a conversion from potential to kinetic energy.
- When energy is released during the course of a reaction, it is said to be an **exothermic reaction**.
- The combustion of methane gas (CH_4) releases 802.3 kJ/mol of energy. This is equivalent to 50.1 kJ/g:

$$\frac{802.3\,\text{kJ}}{1\,\text{mole}\,CH_4} \times \frac{1\,\text{mole}\,CH_4}{16.0\,\text{g}\,CH_4}$$

$$= 50.1\,\text{kJ/g}\,CH_4$$



Not All Fuels Are Equal!



Due to differences in their chemical composition, the combustion of different fuels will release different amounts of heat energy.

The fuels with the highest heats of combustion are hydrocarbons.

- As the ratio of hydrogen-to-carbon decreases, the heat of combustion decreases.
- As the amount of oxygen in the fuel increases, the heat of combustion decreases.

Endothermic versus Exothermic Reactions

Some reactions are **endothermic** which absorb energy.

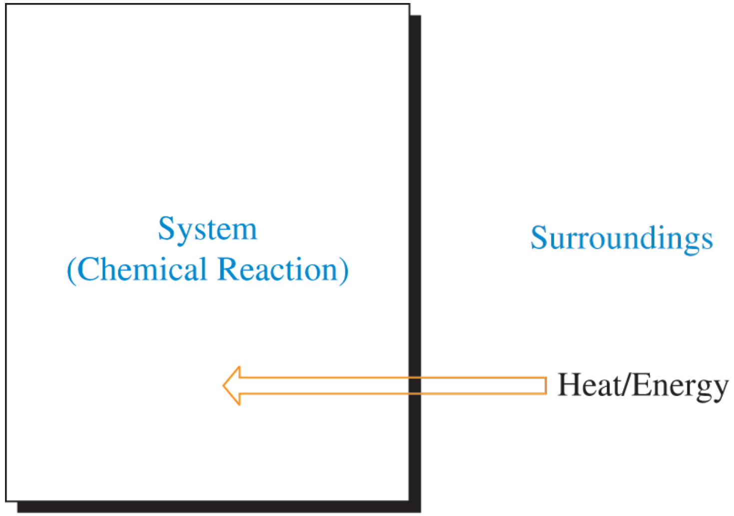
- Photosynthesis is an endothermic reaction.

Endothermic Reaction

$Energy_{products} > Energy_{reactants}$

Net energy change is positive

Energy is absorbed



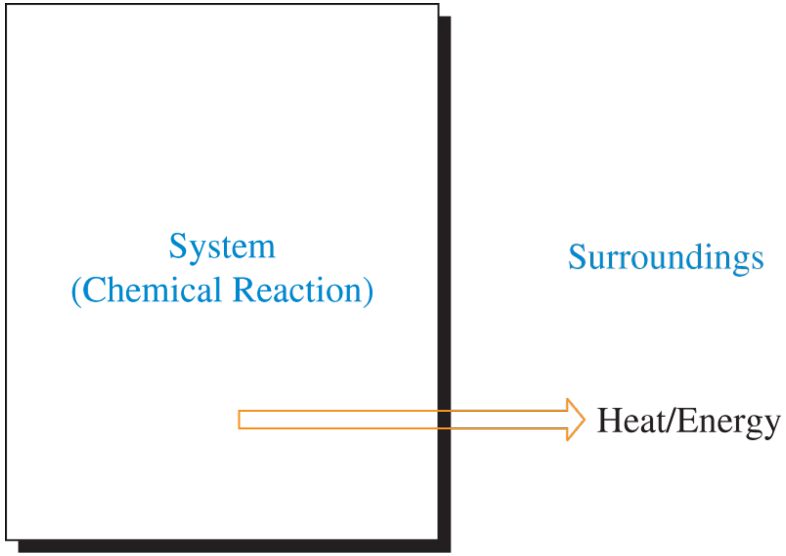
Endothermic
(a)

Exothermic Reaction

$Energy_{products} < Energy_{reactants}$

Net energy change is negative

Energy is released



Exothermic
(b)

Energy Changes at the Molecular Level

Energy changes are due to breaking and forming bonds.

- Breaking bonds requires energy.
- Forming bonds releases energy.

Net change in energy dictates if a reaction is endothermic or exothermic.

Bond energy is the amount of energy that must be absorbed to break a chemical bond.

- Breaking bonds ALWAYS requires energy.

Bond Energies

Table 6.2 Covalent Bond Energies (in kJ/mol)

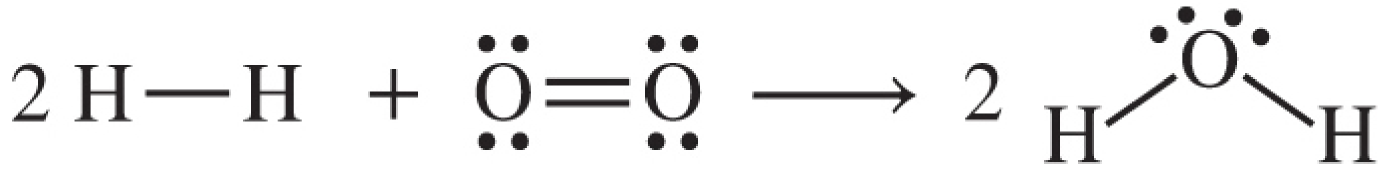
	H	C	N	O	S	F	Cl	Br	I
Single Bonds									
H	436								
C	416	356							
N	391	285	160						
O	467	336	201	146					
S	347	272	—	—	226				
F	566	485	272	190	326	158			
Cl	431	327	193	205	255	255	242		
Br	366	285	—	234	213	—	217	193	
I	299	213	—	201	—	—	209	180	151

Multiple Bonds

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

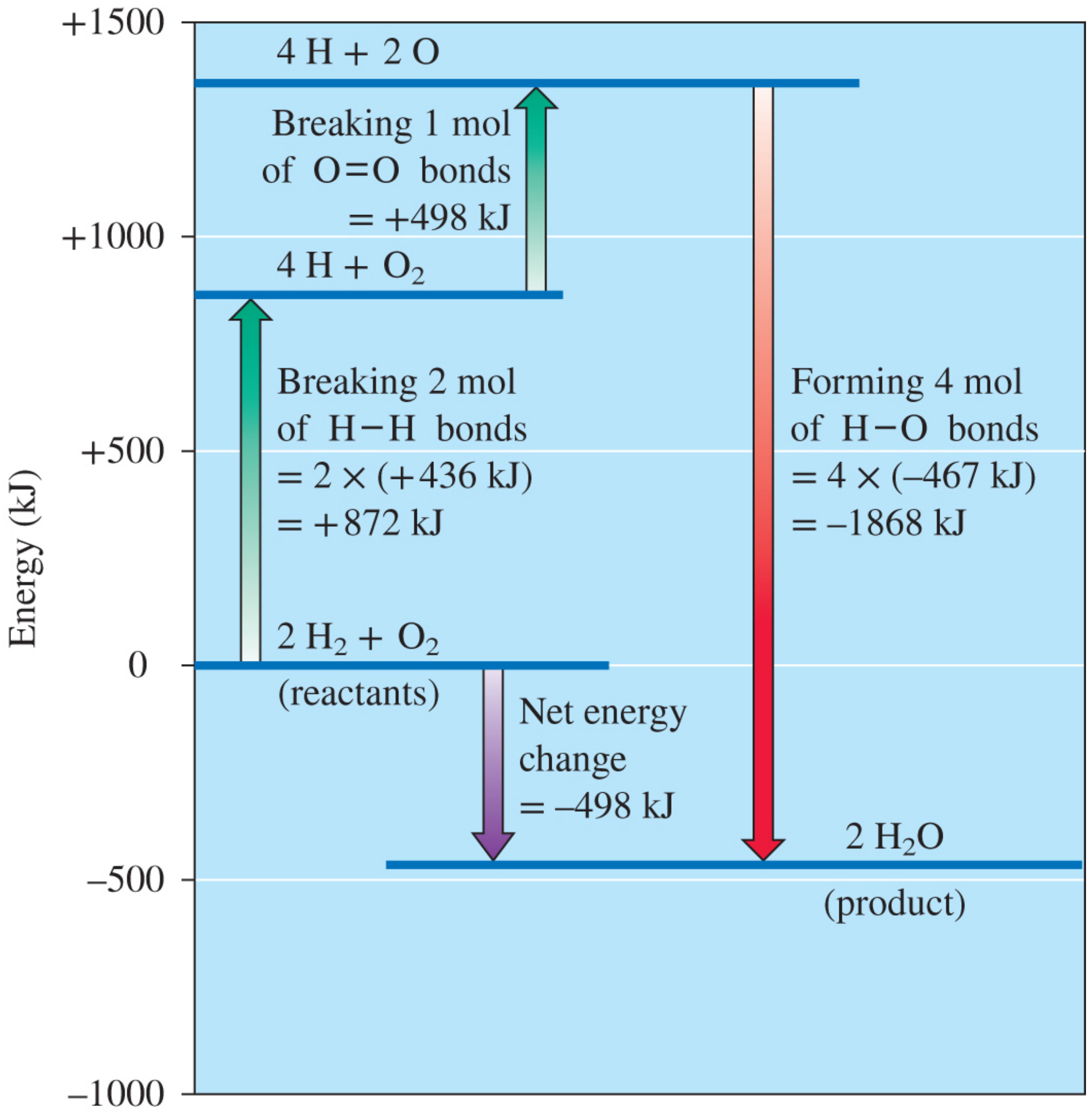
*In CO_2

Combustion of Hydrogen



Molecule	Bonds per Molecule	Moles in Reaction	Moles of Bonds	Bond Process	Energy per Bond	Total Energy
H–H	1	2	$1 \times 2 = 2$	breaking	+436 kJ	$2 \times (+436\ \text{kJ}) = +872\ \text{kJ}$
O=O	1	1	$1 \times 1 = 1$	breaking	+498 kJ	$1 \times (+498\ \text{kJ}) = +498\ \text{kJ}$
H–O–H	2	2	$2 \times 2 = 4$	forming	−467 kJ	$4 \times (-467\ \text{kJ}) = -1868\ \text{kJ}$
					Total:	**−498 kJ**

Combustion of Hydrogen



Combustion of Propane

$$C_3H_{8(g)} + 5O_{2(g)} \rightarrow 3CO_{2(g)} + 4H_2O_{(g)}$$

Bonds broken

$$8\,C-H \Rightarrow 8\times 416 = 3328\ \text{kJ}$$

$$5\,O=O \Rightarrow 5\times 498 = 2490\ \text{kJ}$$

$$2\,C-C \Rightarrow 2\times 356 = 712\ \text{kJ}$$

Total Energy required = **+6530 kJ**

Bonds made

$$6\,C=O \Rightarrow 6\times 803 = 4818\ \text{kJ}$$

$$8\,O-H \Rightarrow 8\times 467 = 3736\ \text{kJ}$$

Total Energy generated = **−8554 kJ**

Overall = −2024 kJ

C−H 416 kJ/mol

O=O 498

C−C 356

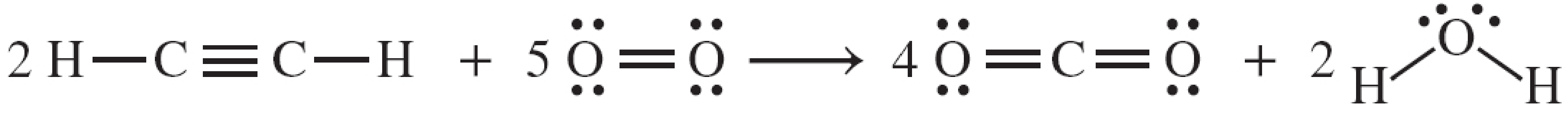
C=O 803

H−O 467

Your Turn 3

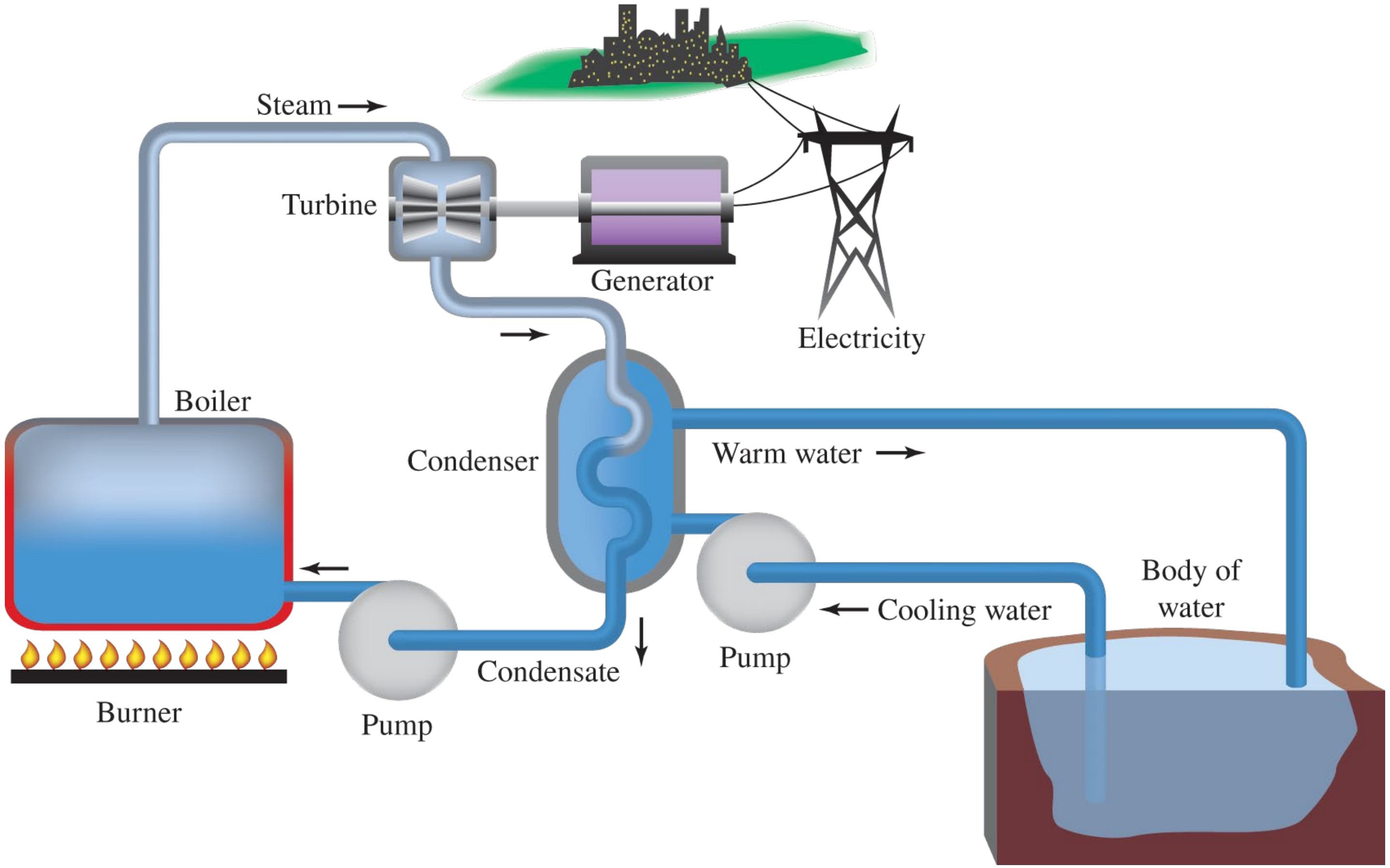
Your Turn 6.14 Heat of Combustion for Ethyne

Use the bond energies in Table 6.2 to calculate the heat of combustion for ethyne, C_2H_2 also commonly referred to as acetylene. Report your answer both in kJ/mol C_2H_2 and kJ/g C_2H_2. Here is the balanced chemical equation:



Hint: The coefficient for acetylene In the chemical equation is 2. Heat of combustion is for 1 mole.

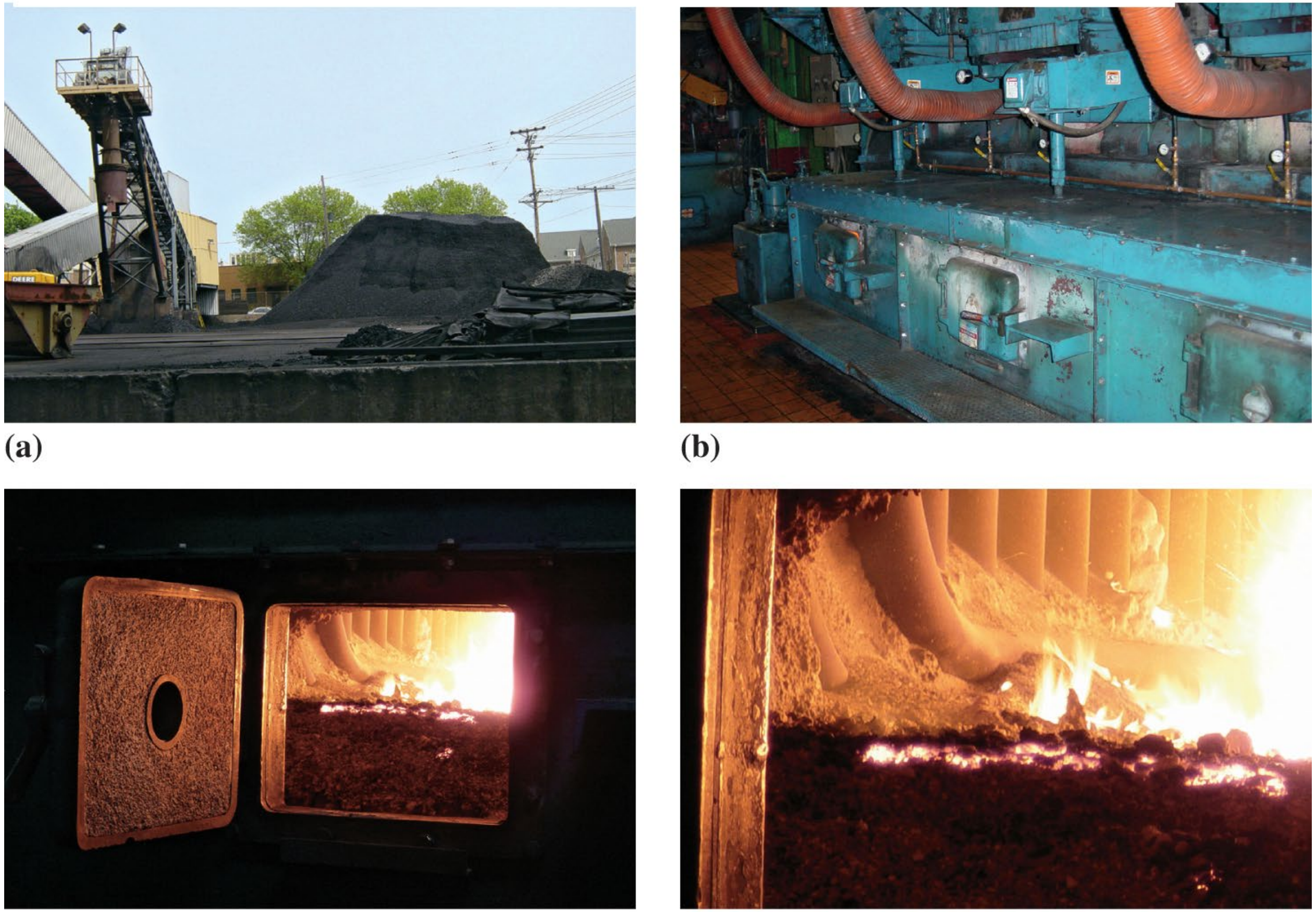
Fossil Fuels and Electricity



Potential energy (fuel molecules) → Burner → Kinetic energy → Turbine → Mechanical energy → Generator → Electrical energy

Fossil Fuels and Electricity

Photos from a small coal-fired electric power plant
(a) Piles of coal
(b) A row of boilers
(c) Behind the blue door
(d) Coal burning on the boiler bed



(a) (b) (c) (d)

Power Plant Efficiency [1]

- No electric power plant can completely convert one type of energy into another:

$$\text{Net efficiency}\left(\%\right)=\frac{\text{electrical energy produced}}{\text{heat from fuel}}\times 100$$

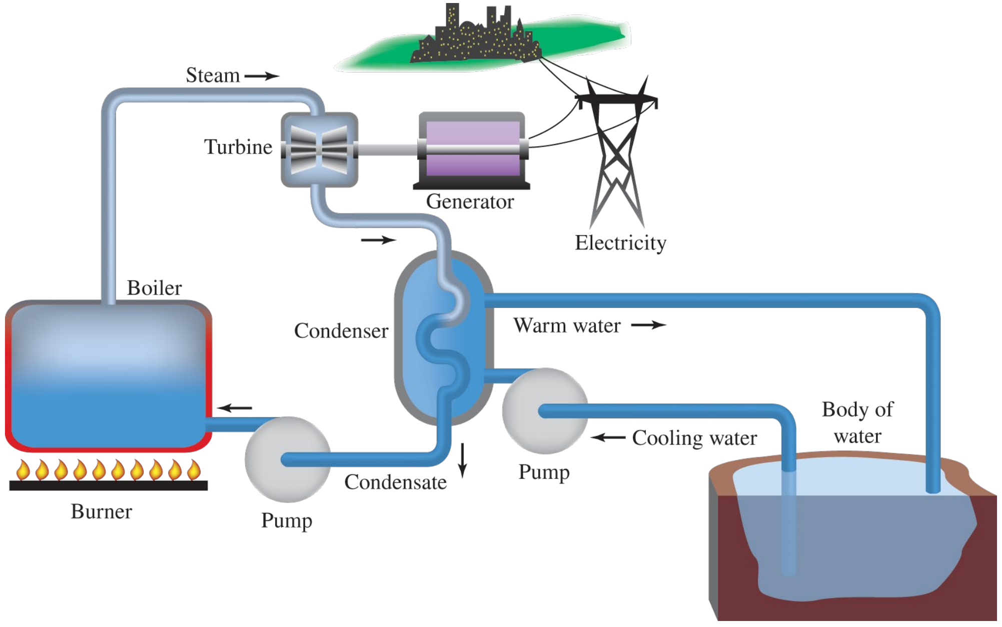
- Some of the energy is transferred into useless heat.
- In general, the higher the temperature of the steam, the more efficient the power plant.

Energy skate park basics

Power Plant Efficiency 2

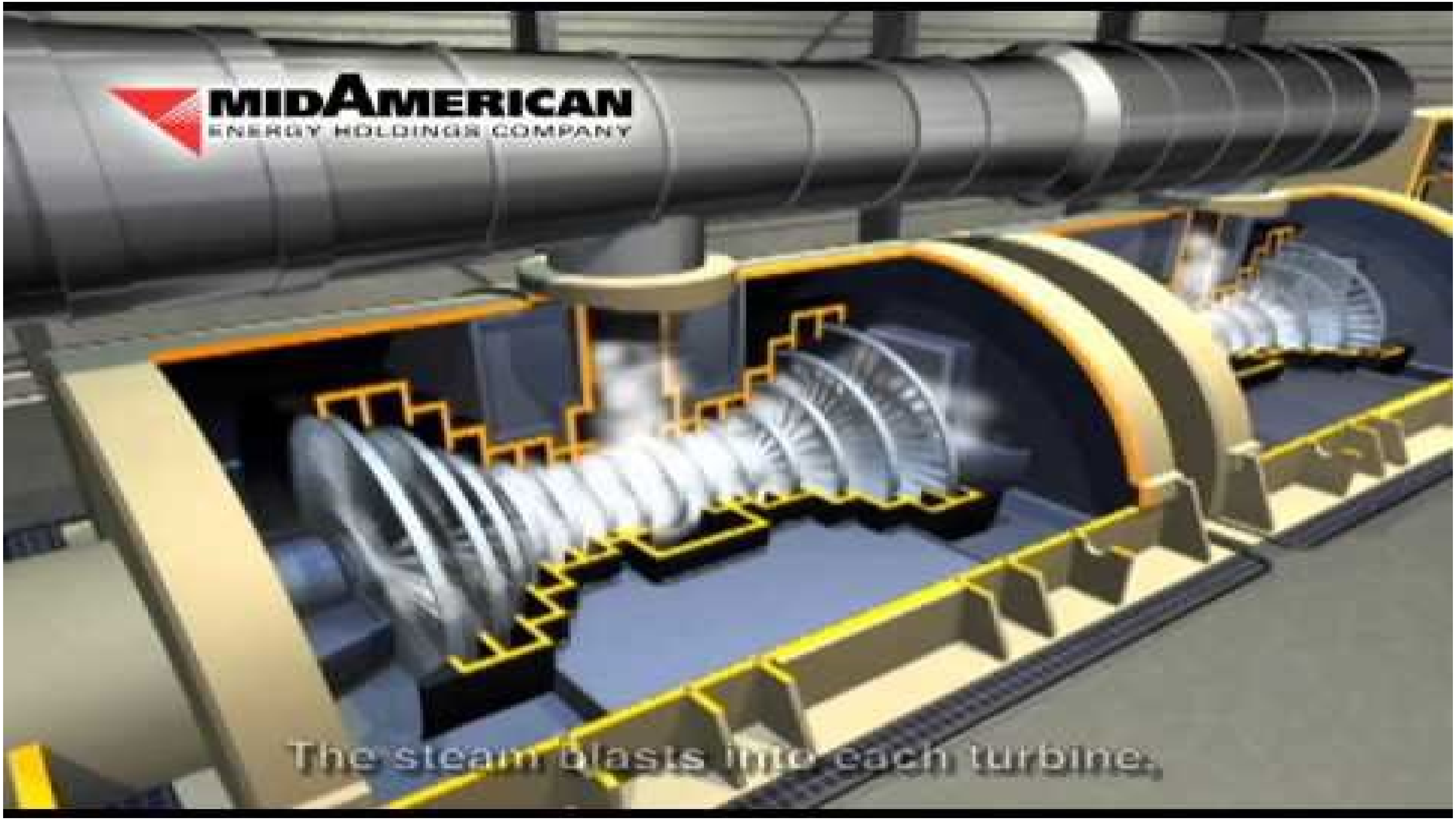
- Maximum theoretical efficiency is a function of the highest and lowest temperatures (need to make steam and then condense it).
- Overall efficiency is the product of the individual efficiency terms.

Theoretical	55 to 65%
Boiler	90%
Turbine	75%
Generator	95%
Transmission	90%
Overall	32 to 37.5%



[MidAmerican Energy Coal-Fueled Power Plant]

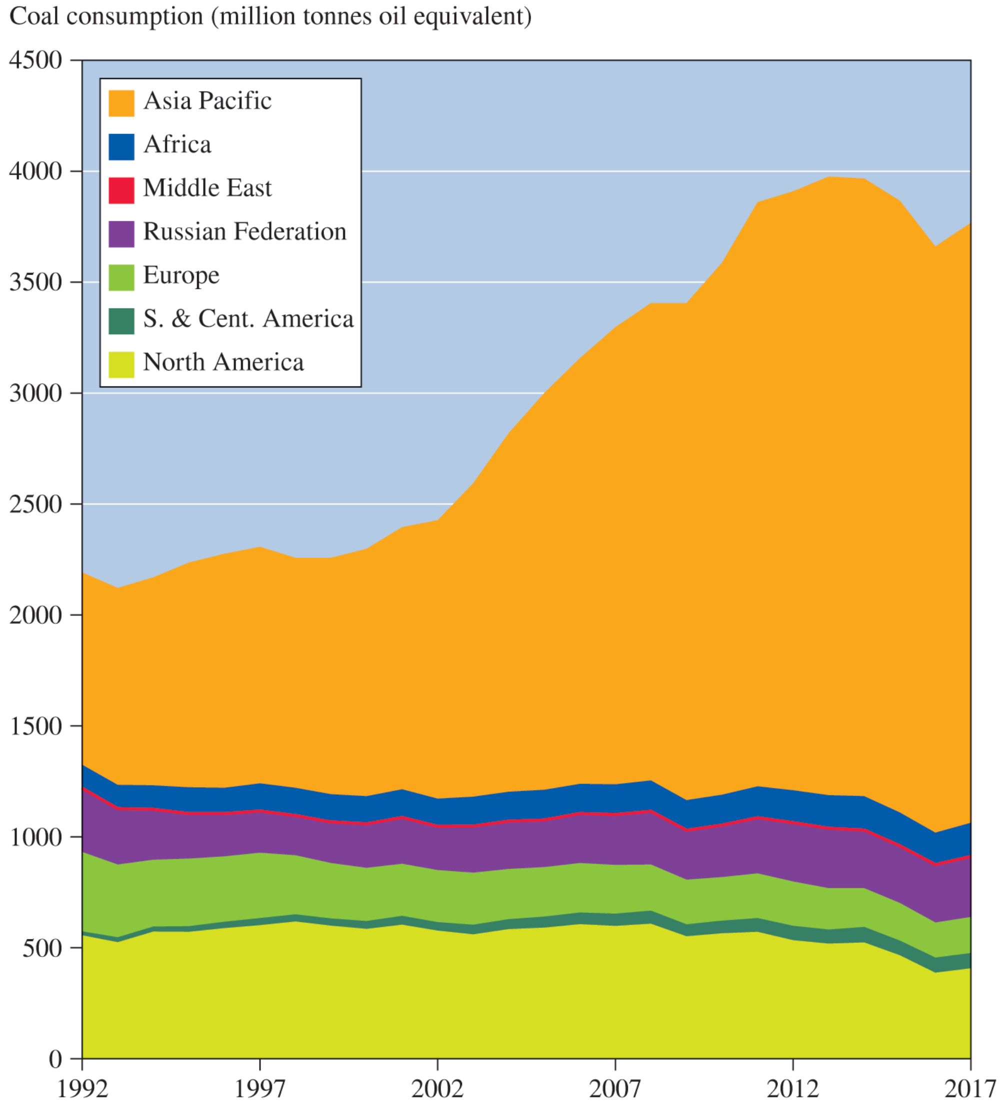
Cars and trucks: 15%


MIDAMERICAN
ENERGY HOLDINGS COMPANY
The steam blasts into each turbine.

Coal: An Ancient Fuel Source

In the US, wood was used as the major source of energy until the 1960's when coal became the largest source

- Today, 92% of all US coal consumption is due to electrical power generation.
- Asia Pacific countries are the largest users of coal worldwide, followed by North America and Europe.
- Drawbacks include: mine safety, environmental harm by mining and combustion.



Source: BP Statistical Review of World Energy, June 2018

Your Turn

Your Turn 6.20 Coal Calculations

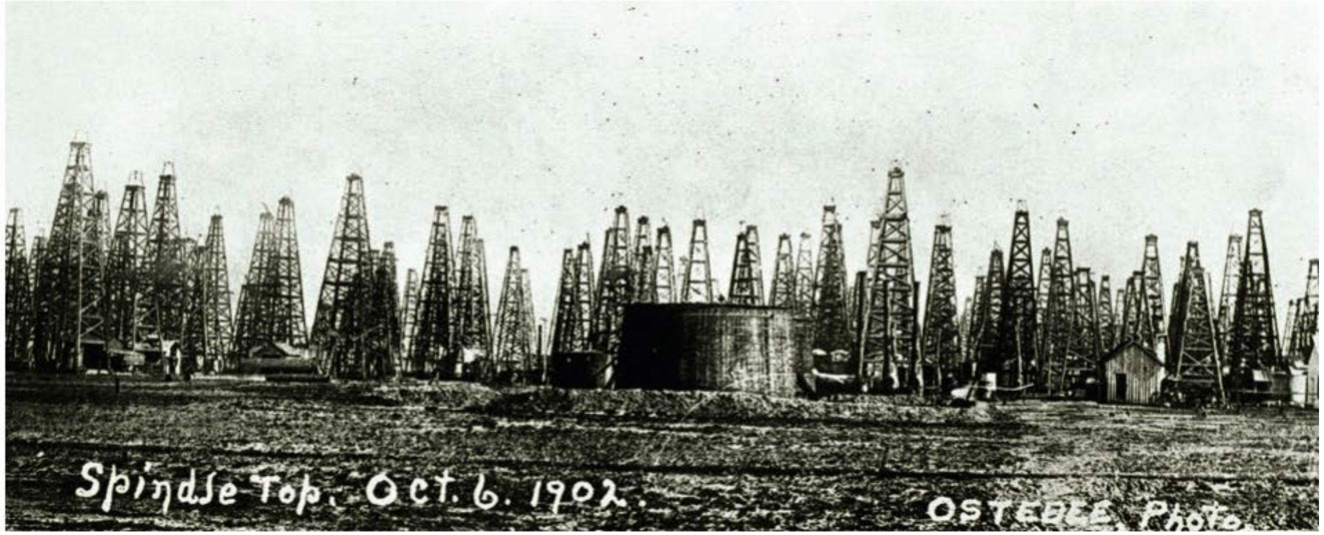
a. Assuming the composition of coal can be approximated by the formula $C_{135}H_{96}O_9NS$, calculate the mass of carbon (in tons) in 1.5 million tons of coal. This quantity of coal might be burned by a typical power plant in 1 year.

b. Compute the amount of energy (in kJ) released by burning this mass of coal. Assume the process releases 30 kJ/g of coal. Useful conversion factors: 1 ton = 2000 lb and 1 pound = 454 g.

c. What mass of CO_2 would be formed by the complete combustion of 1.5 million tons of this coal?

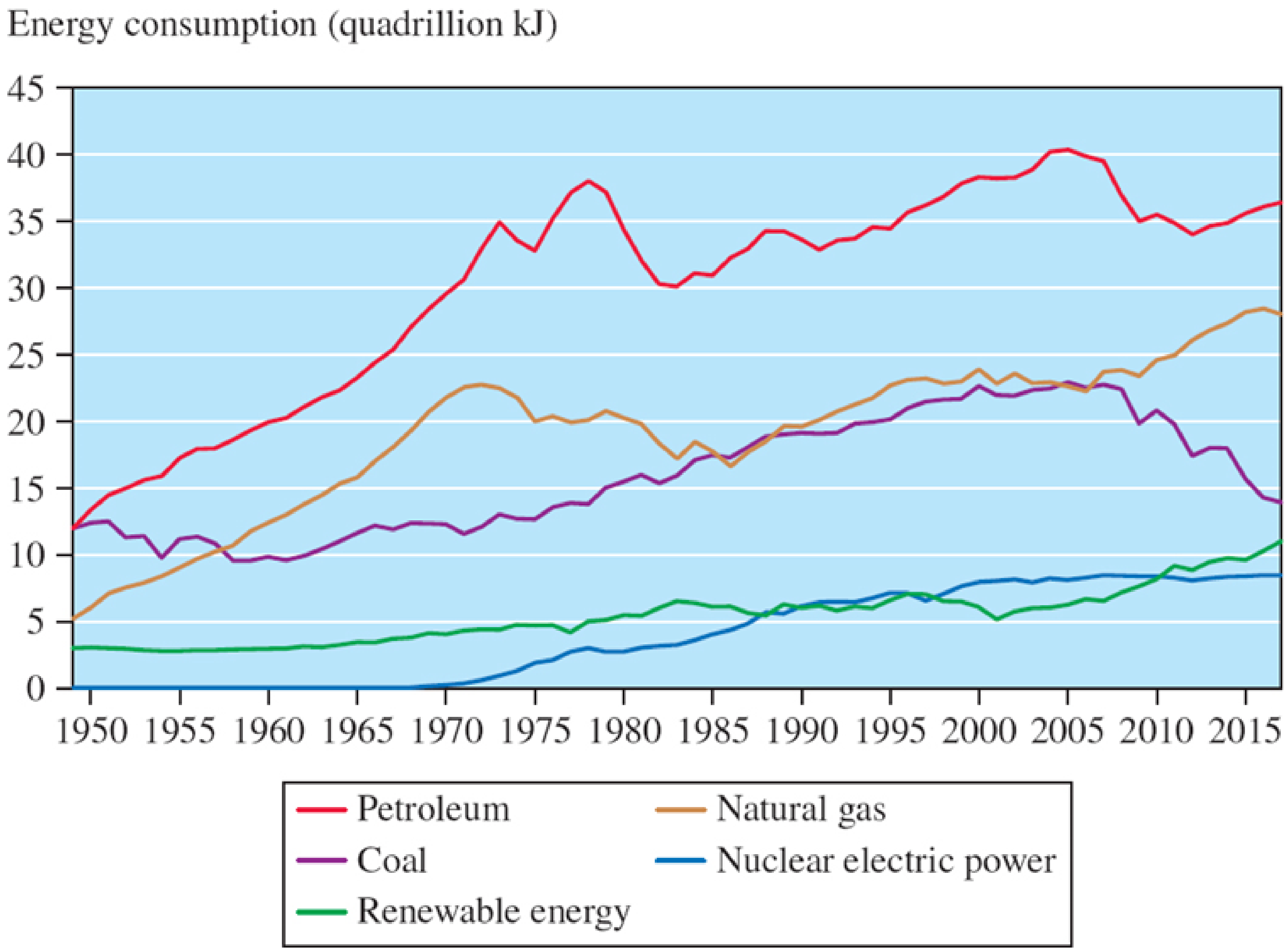
Hint: In the balanced chemical equation, assume a mole ratio of coal:CO_2 of 1:135.

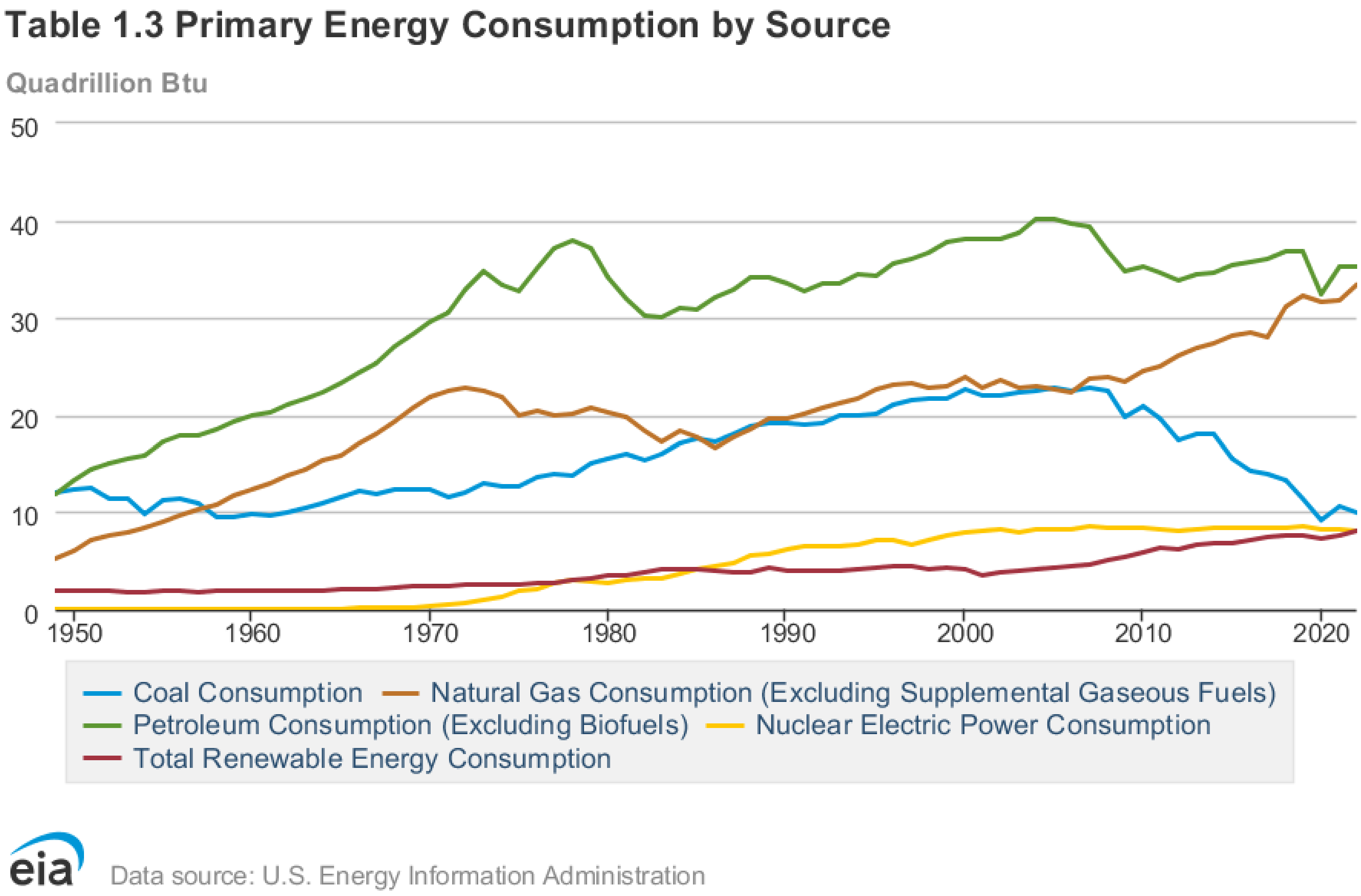
The Shift to Petroleum



- The shift from coal to oil occurred in the mid-1950's, brought on by the Texas oil boom.
- 1950 marked the first year that petroleum surpassed coal as the major energy source in the US.

The Shift to Petroleum

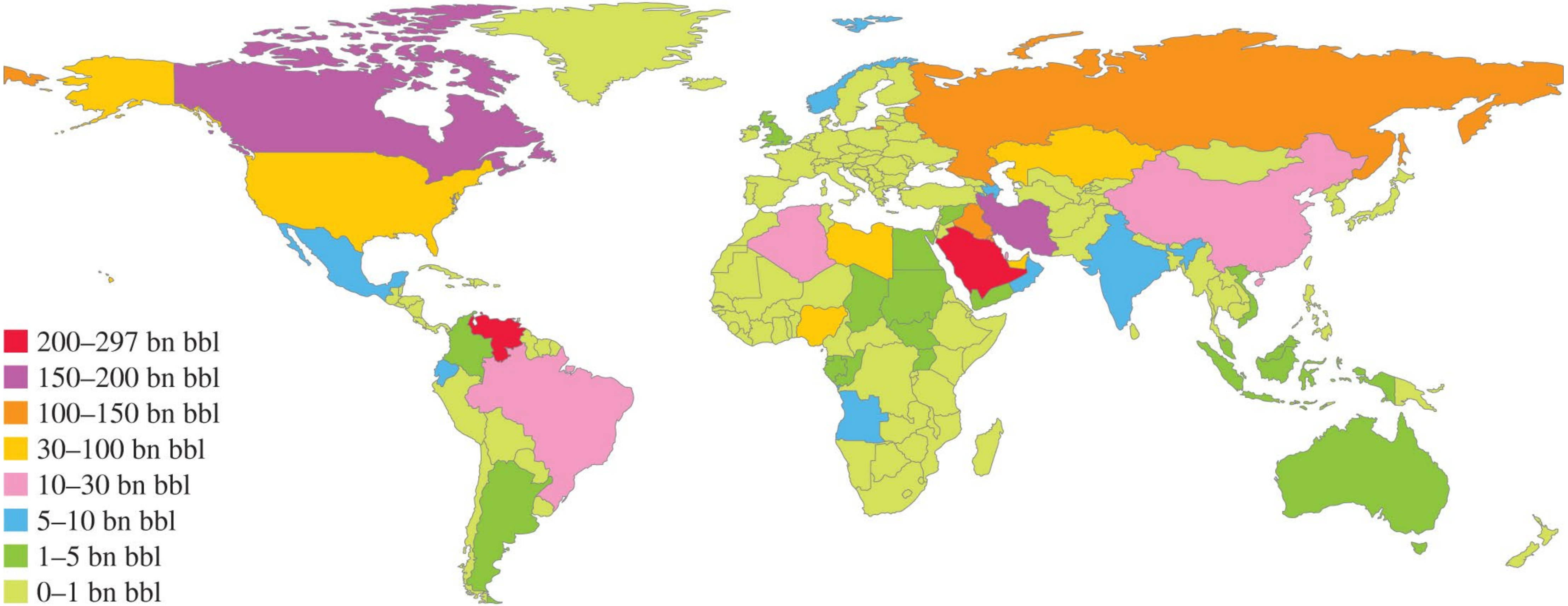




US Energy Information Agency’s interactive data browser page for energy consumption

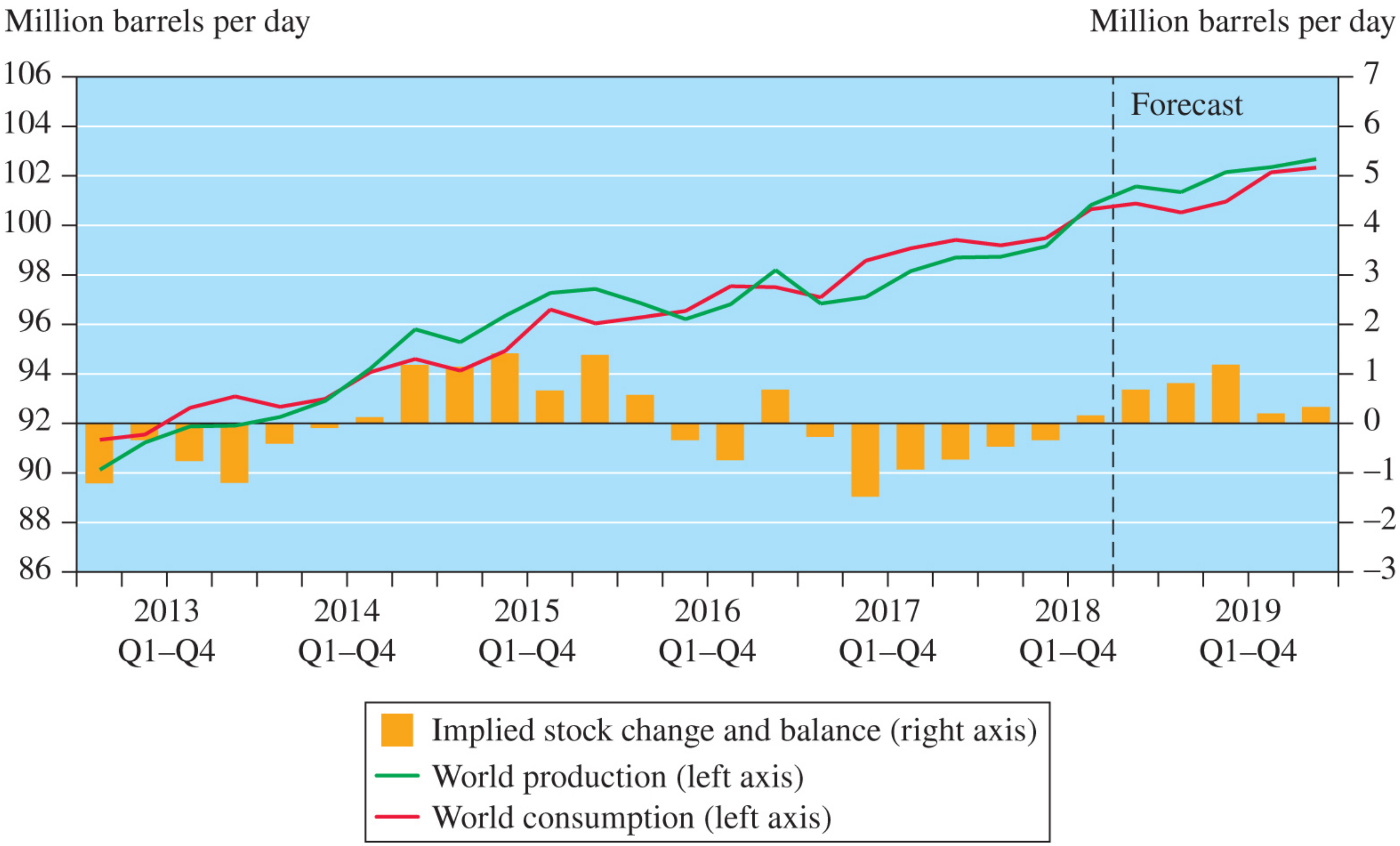
지표서비스 | e-나라지표 (index.go.kr)   keei.re.kr/keei/kidspage_2021/sub01_02_02.html

Oil Production: How long can this continue?



Worldwide proven oil reserves as of 2017

Oil Production: How long can this continue?



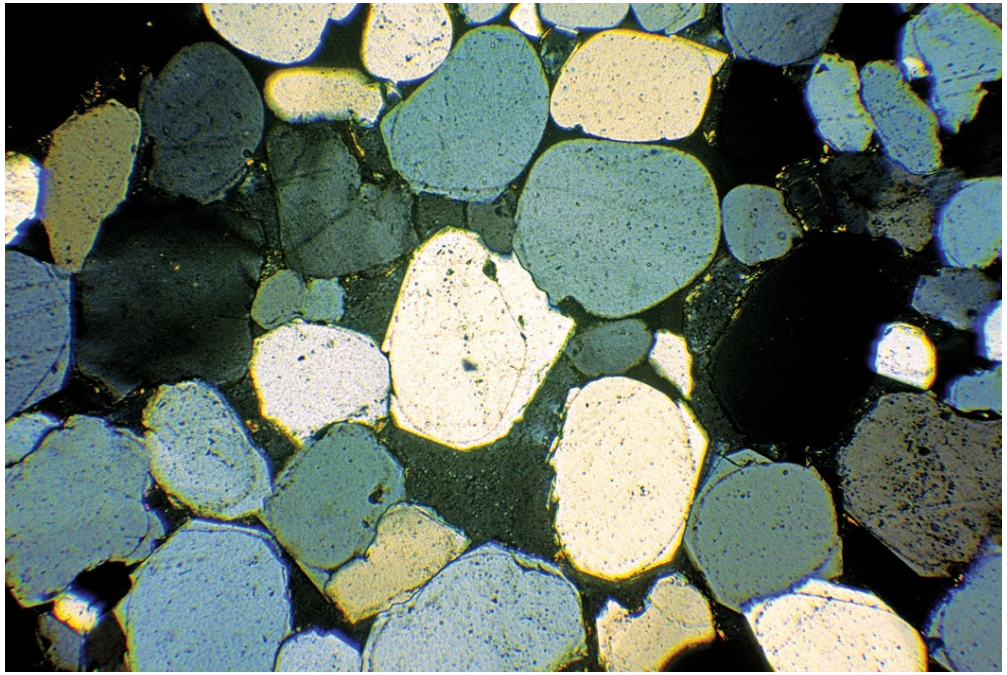
Source: EIA

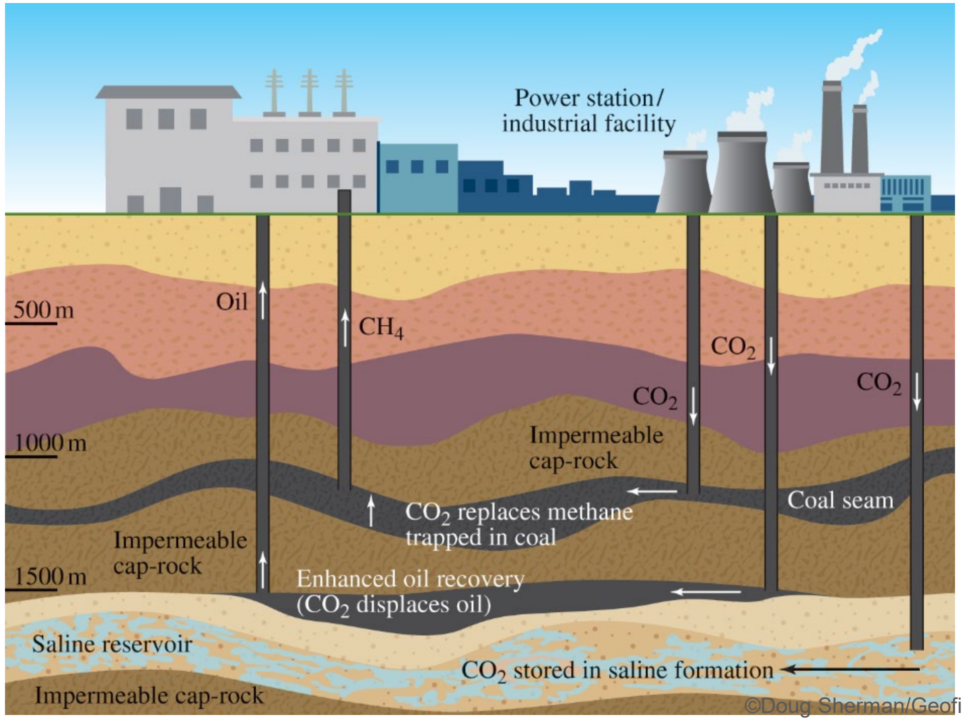
Squeezing Oil from Rock

Oil is not found in underground pools, but within the pores of geologic rock formations such as sandstone.

Once oil is extracted from oil-rich rock formations, such as reservoirs, more expensive and time-consuming methods must be used.

- Examples include using pressurized water or carbon dioxide to push oil to the surface.



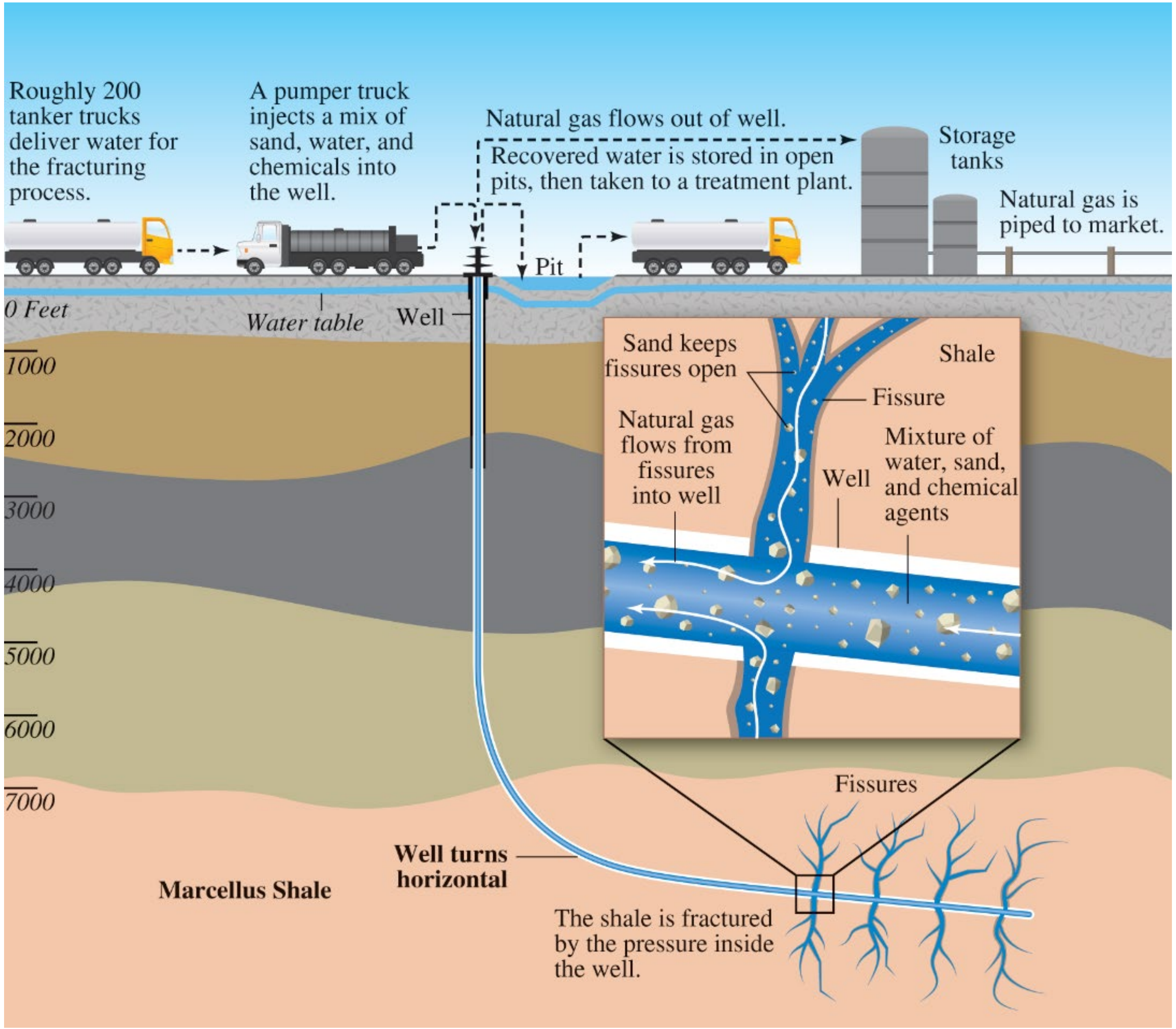


Natural Gas: Fracking

Fracking is used to obtain natural gas or petroleum from hard rock formations such as shale.

- Drill down 1 to 3 miles beneath the Earth's surface.
- Fracking fluid containing a variety of substances is injected under pressure to create cracks into which natural gas and oil can flow.

Highly controversial: questions about water quality; destabilized rock formation leading to increased seismic activity.



How do we obtain useful petroleum products from crude oil?

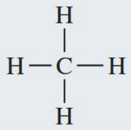
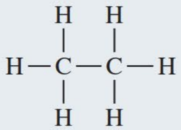
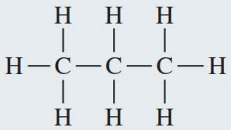
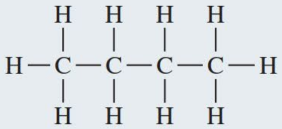
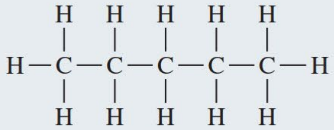
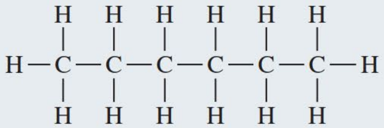
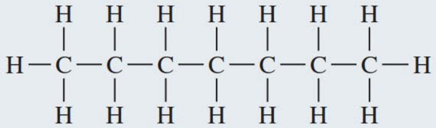
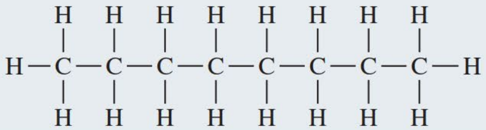
Crude oil is a mixture of several thousand compounds, with the majority being hydrocarbons composed of 5 to 12 carbon atoms per molecule.

- Alkanes are hydrocarbons with single bonds between carbon atoms.
- Alkenes feature at least one double bond.
- Alkynes have at least one triple bond.

Hydrocarbons use prefixes and suffixes to identify the compound.

- Prefixes denote the number of carbon atoms: meth-, eth-, prop-, but-, pent-, hex-, hept-, oct-, non-, dec-
- Suffixes identify the presence or absence of multiple bonds: -ane, -ene, -yne.

Table 6.3 Selected Alkanes (Gases and Liquids)

Name and Chemical Formula	Boiling Point (physical state at 25 °C)	Structural Formula	Condensed Structural Formula
Methane CH_4	−161 °C (gas)		CH_4
Ethane C_2H_6	−89 °C (gas)		CH_3CH_3
Propane C_3H_8	−42 °C (gas)		$CH_3CH_2CH_3$
n-Butane C_4H_{10}	−0.5 °C (gas)		$CH_3CH_2CH_2CH_3$
n-Pentane C_5H_{12}	36 °C (liquid)		$CH_3CH_2CH_2CH_2CH_3$
n-Hexane C_6H_{14}	69 °C (liquid)		$CH_3CH_2CH_2CH_2CH_2CH_3$
n-Heptane C_7H_{16}	98 °C (liquid)		$CH_3CH_2CH_2CH_2CH_2CH_2CH_3$
n-Octane C_8H_{18}	125 °C (liquid)		$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_3$

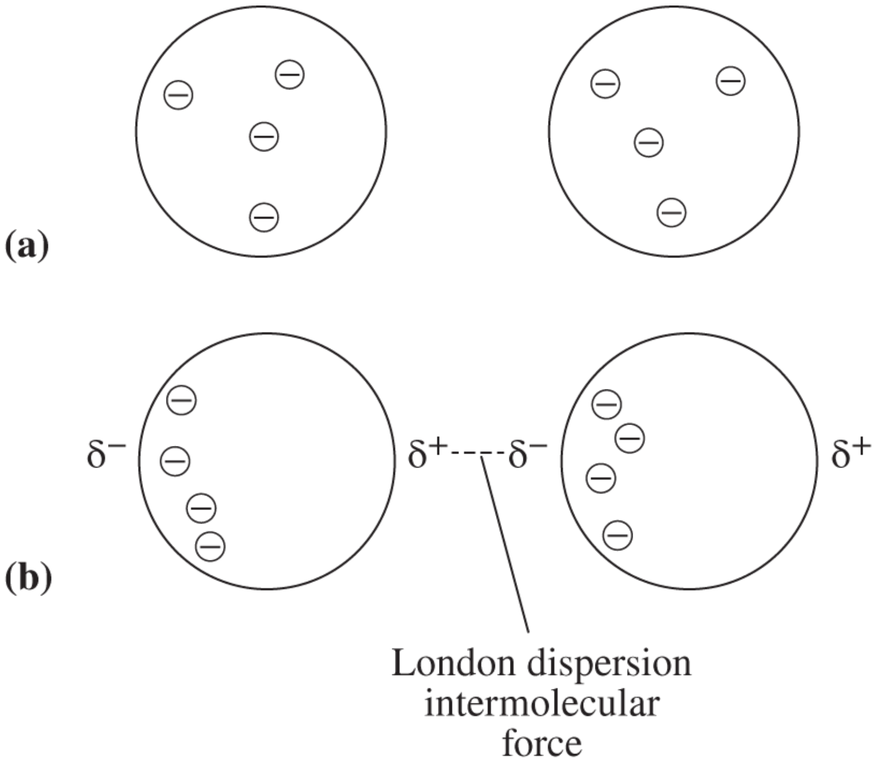
Note: n-butane, *n*-pentane, *n*-hexane, *n*-heptane, and *n*-octane all have other structural forms, known as *isomers* (see Section 6.13). The *n* stands for normal, the straight-chain isomer.

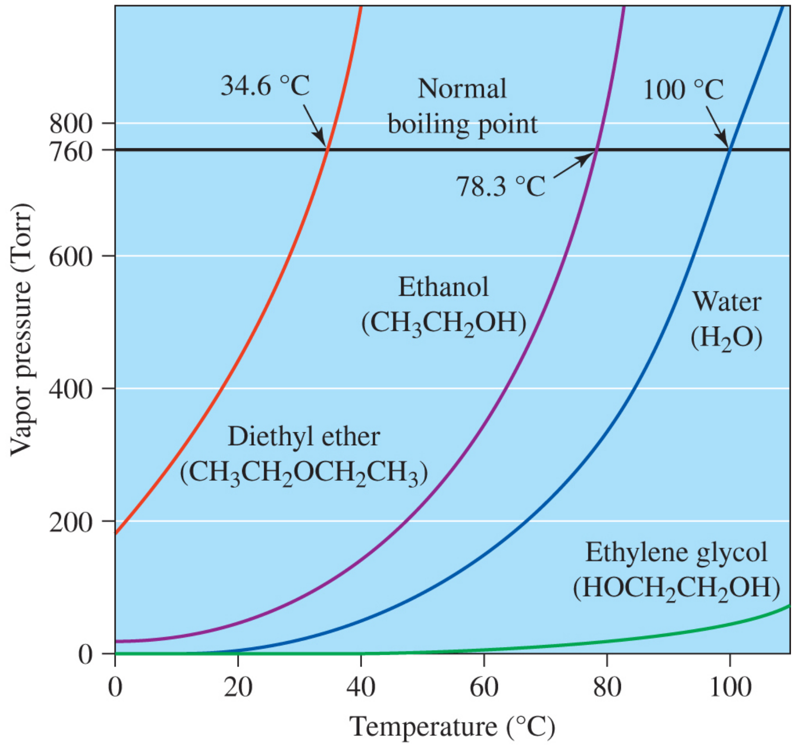
Boiling Points

The **volatility** of a liquid refers to how easily it is transformed into a gas.

Intermolecular forces known as London dispersion forces are broken between liquid molecules during vaporization of hydrocarbons.

- The stronger the forces, the higher the boiling point.





Oil Refineries

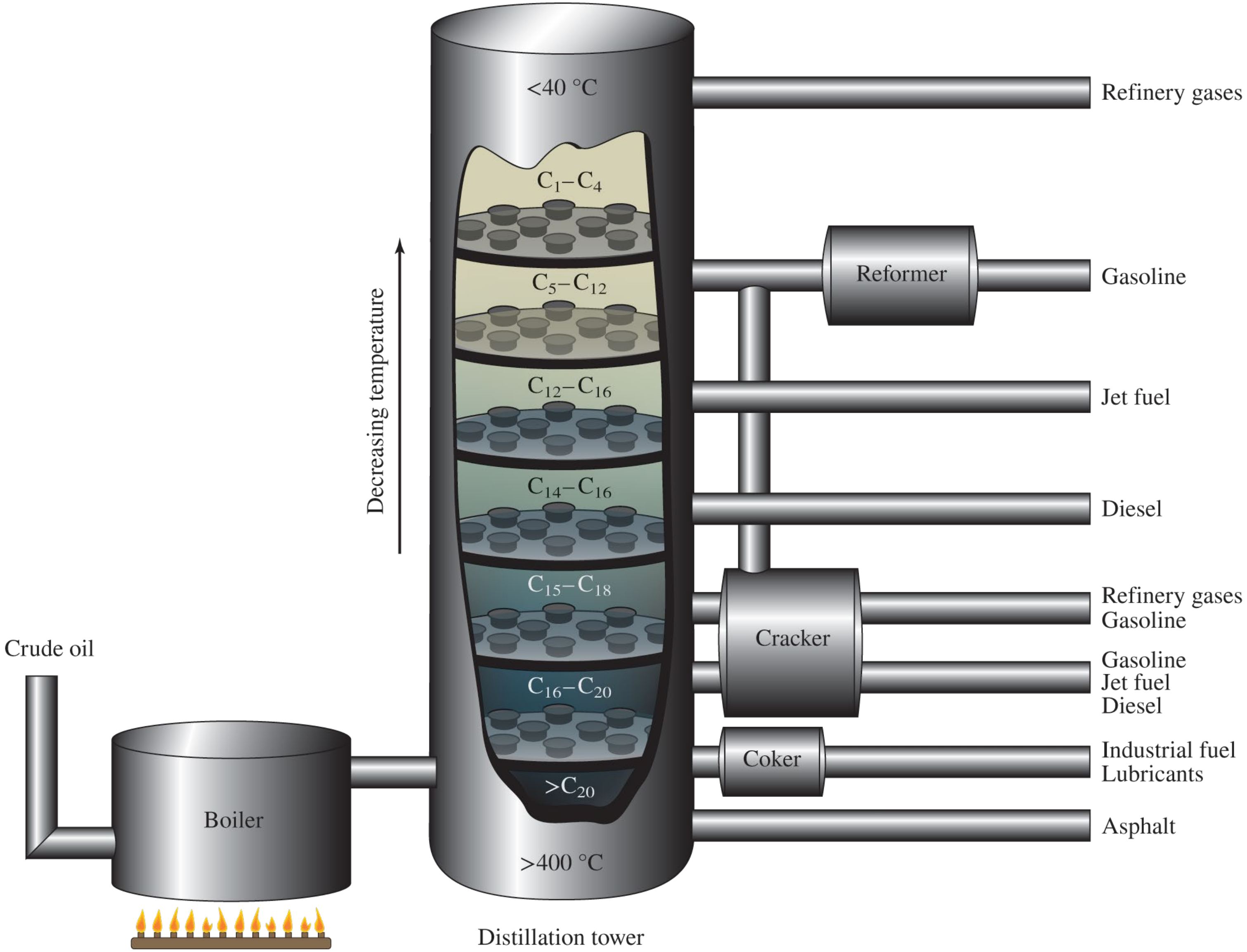
Photo of a crude oil refinery showing the tall distillation towers.

Oil Refineries: Distillation

Hydrocarbons will have different volatilities and boiling points due to differing strengths of their intermolecular forces.

Distillation is used to separate crude oil into its components

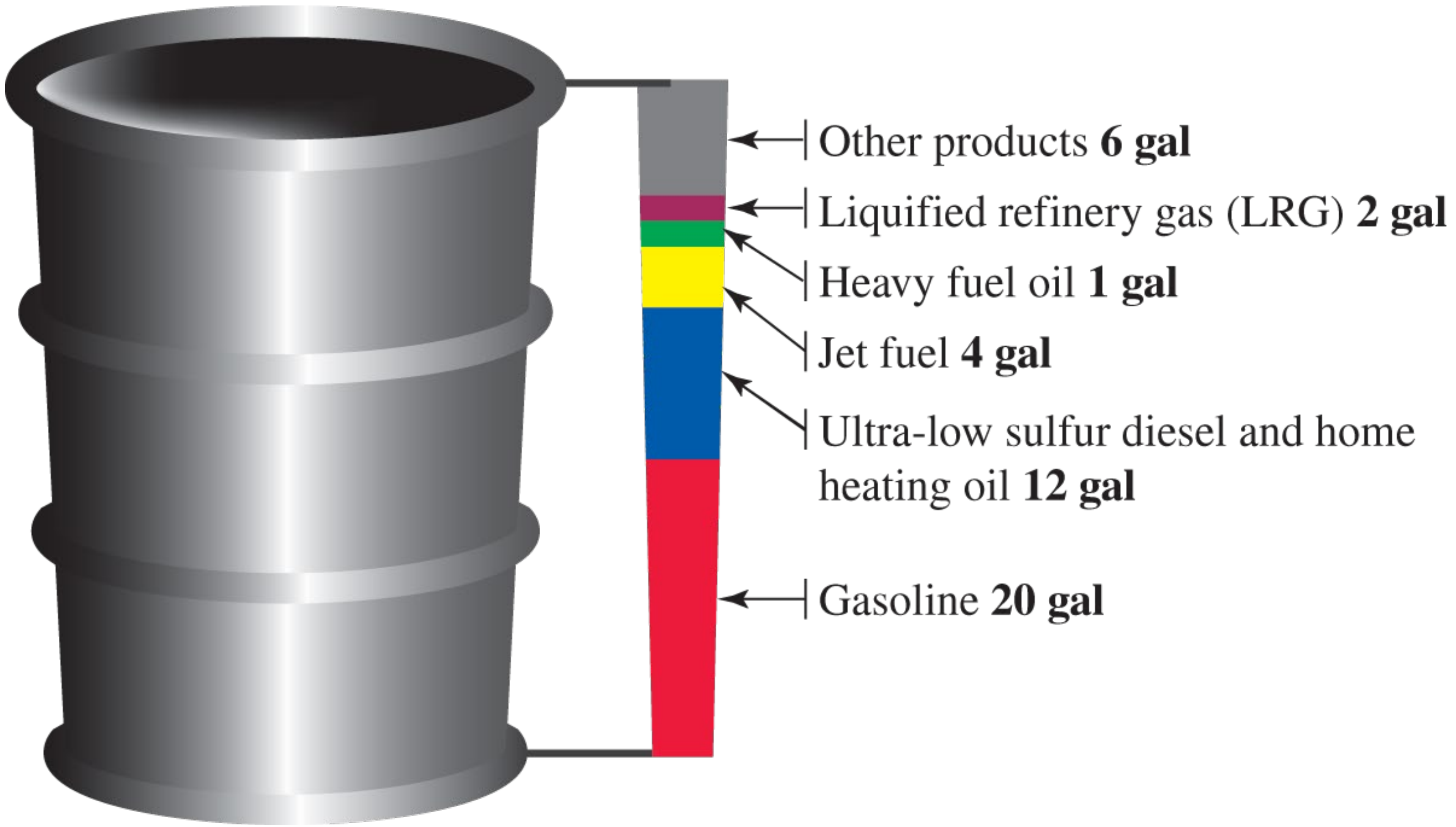
- The boiler heats the oil, vaporizing most of it.
- Vapors condense at different temperatures on the distillation tower and are collected.



Source: McGraw-Hill Education

Oil Use

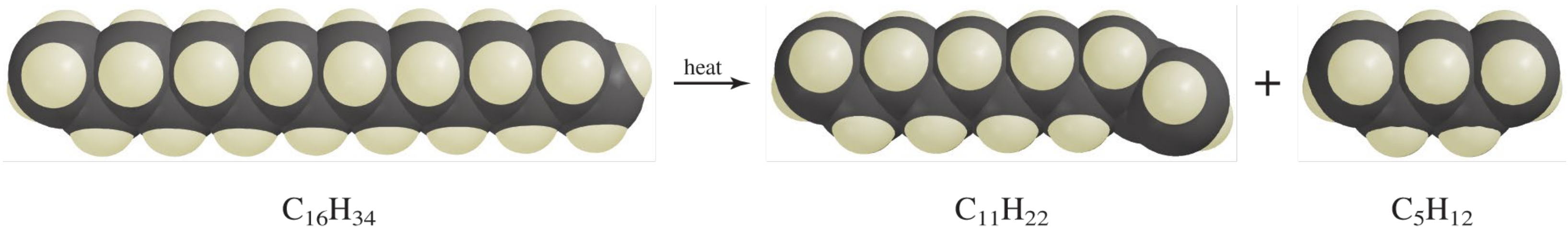
Over 87% of each barrel (42 gallons) is used for transportation and heating.



Source: U.S. Energy Information Administration, 2018.

Cracking

- To meet the large demand for gasoline, the higher-boiling fractions are cracked into smaller molecules by heating them to a high temperature (**thermal cracking**).
- **Catalytic cracking** uses a catalyst to lower the temperature required for cracking.



Reforming

Catalytic reforming involves the rearrangement of atoms within a molecule, usually starting with a linear molecule and producing one with branches.

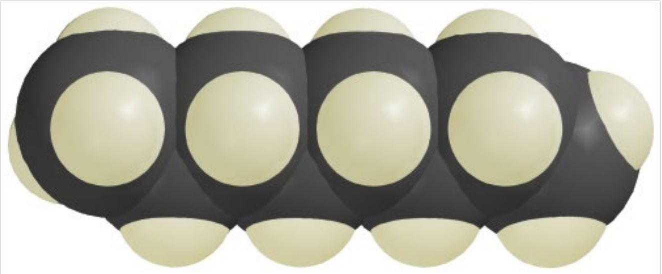
Molecules with the same molecular formula but different structures are known as **isomers.**

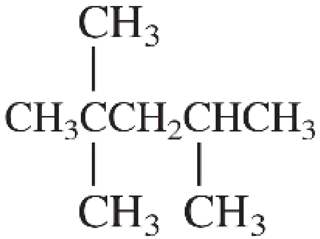
- Molecules with linear structures have stronger London dispersion forces and higher boiling points.
- A branched hydrocarbon known as iso-octane is used as a gasoline additive to prevent engine knocking.

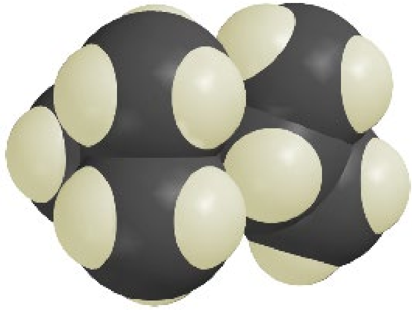
[Rotatable model of n-octane in MolView]

[Rotatable model of iso-octane in MolView]

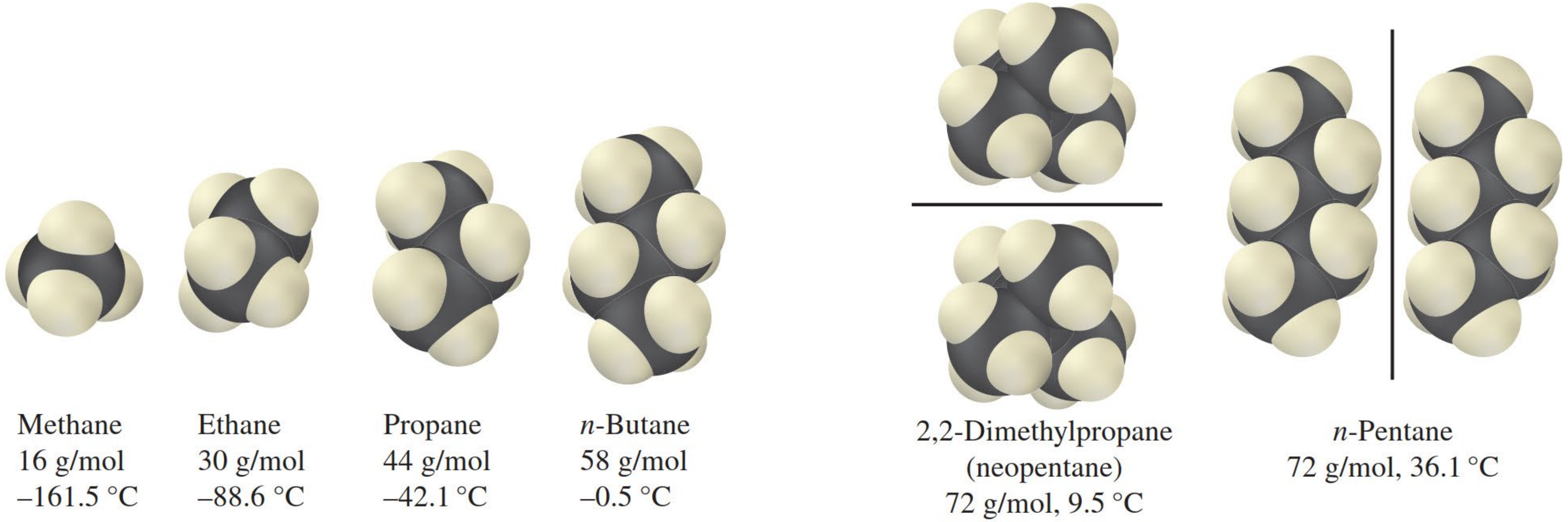
$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_3$







Reforming



(a) Increasing mass and boiling point

(b) Increasing surface area and boiling point

Gasoline Octane Ratings

Engine knocking is caused by the composition of gasoline.

- Lower engine efficiency, higher fuel consumption, and engine damage.

Octane rating was developed to indicate gasoline quality related to knocking.

The Chemistry of Petrol

Table 6.4 Octane Ratings of Several Compounds

Compound	Research Octane Number
n-octane	−20
n-heptane	0
iso-octane	100
methanol (CH_3OH)	109
ethanol (CH_3CH_2OH)	109
methyl tertiary-butyl ether (MTBE, $CH_3OC(CH_3)_3$)	116

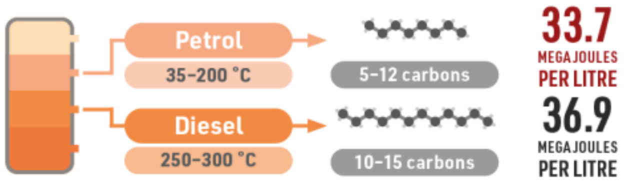
Additives are used to increase octane ratings

- Tetraethyl lead (toxic).
- MTBE.
- Ethanol.

How do petrol and diesel fuel vehicles?

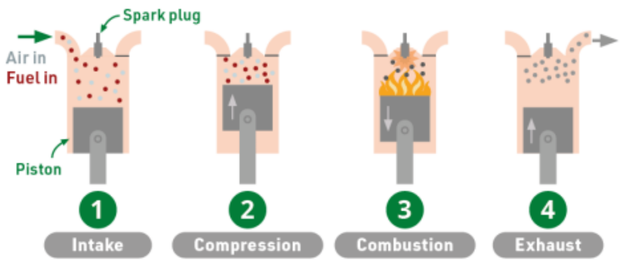
COMPOUND INTEREST

Petrol and diesel: What's the difference?



Petrol and diesel are obtained by fractional distillation of crude oil. Diesel is removed from crude oil at a higher boiling point, and contains a larger amount of energy per litre, meaning more miles can be covered with the same volume of fuel.

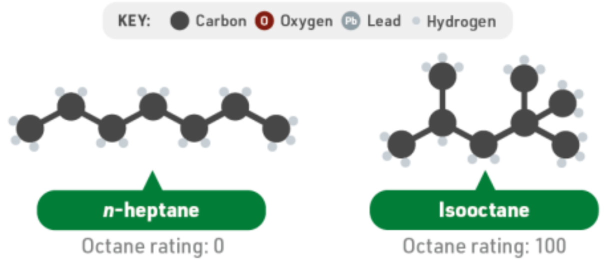
How do engines work?



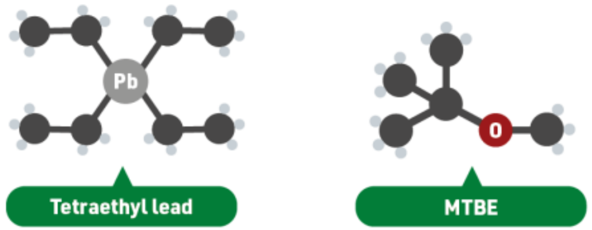
In the engine, a mixture of air and fuel is compressed and burned. Combustion forces the piston down, then the piston pushes back up to expel exhaust gases and the cycle begins again. In diesel engines, the fuel is injected after the air has been compressed, before combustion.

Engine knocking and unleaded petrol

Engine knocking happens when the combustion of the fuel doesn't occur in sync with the engine cycle, causing lower engine efficiency and engine damage. Octane ratings measure how well fuel avoids this problem; higher values indicate less knocking. Isooctane and *n*-heptane are references.



Compounds can be added to petrol to boost its octane rating. Tetraethyl lead was one of these, but is now banned in most countries as it releases toxic lead fumes. Alternative anti-knocking agents used in unleaded petrol include methyl tertiary-butyl ether (MTBE), ethanol, benzene, and toluene.

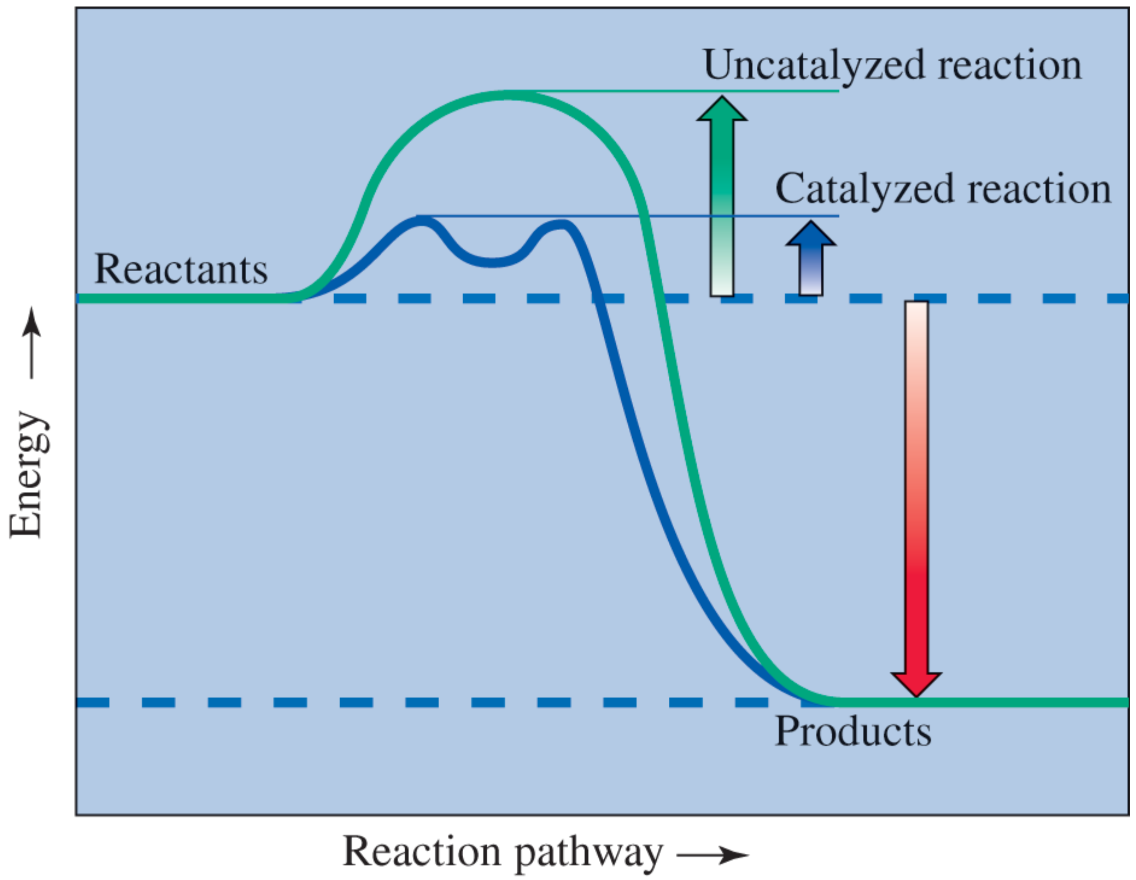


Catalysts

The energy needed to initiate a chemical reaction is known as the **activation energy.**

A catalyst lowers the activation energy for a reaction by providing an alternative pathway.

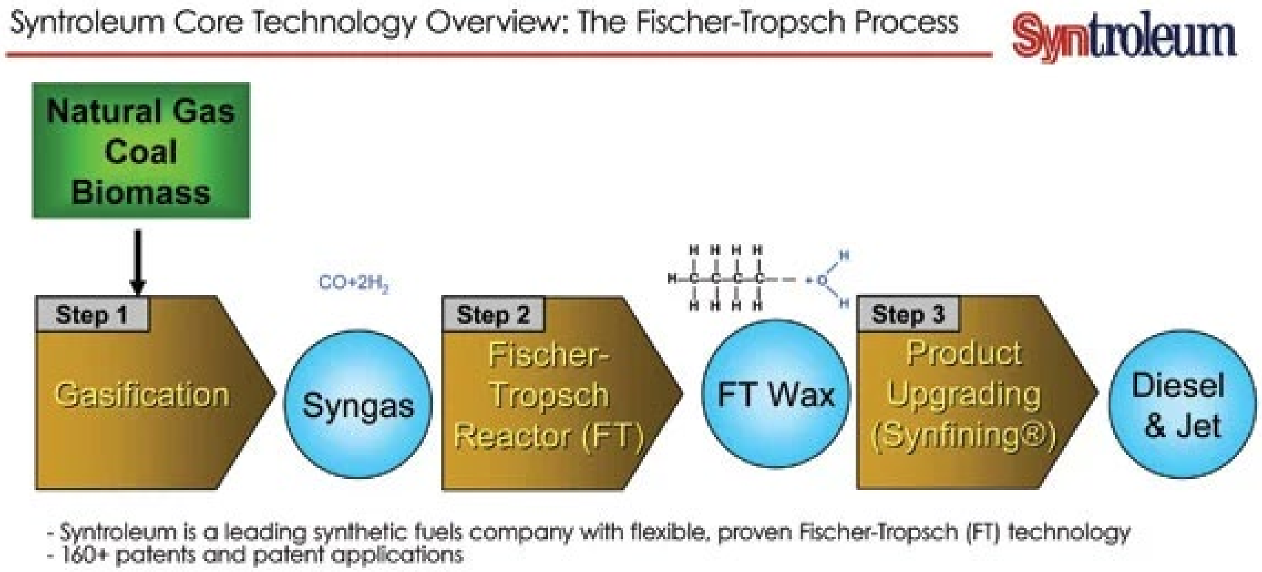
- Causes the reaction to proceed faster than an uncatalyzed process.
- The Fischer-Tropsch catalysis reaction is used to convert coal into gasoline.



Fischer-Tropsch Process

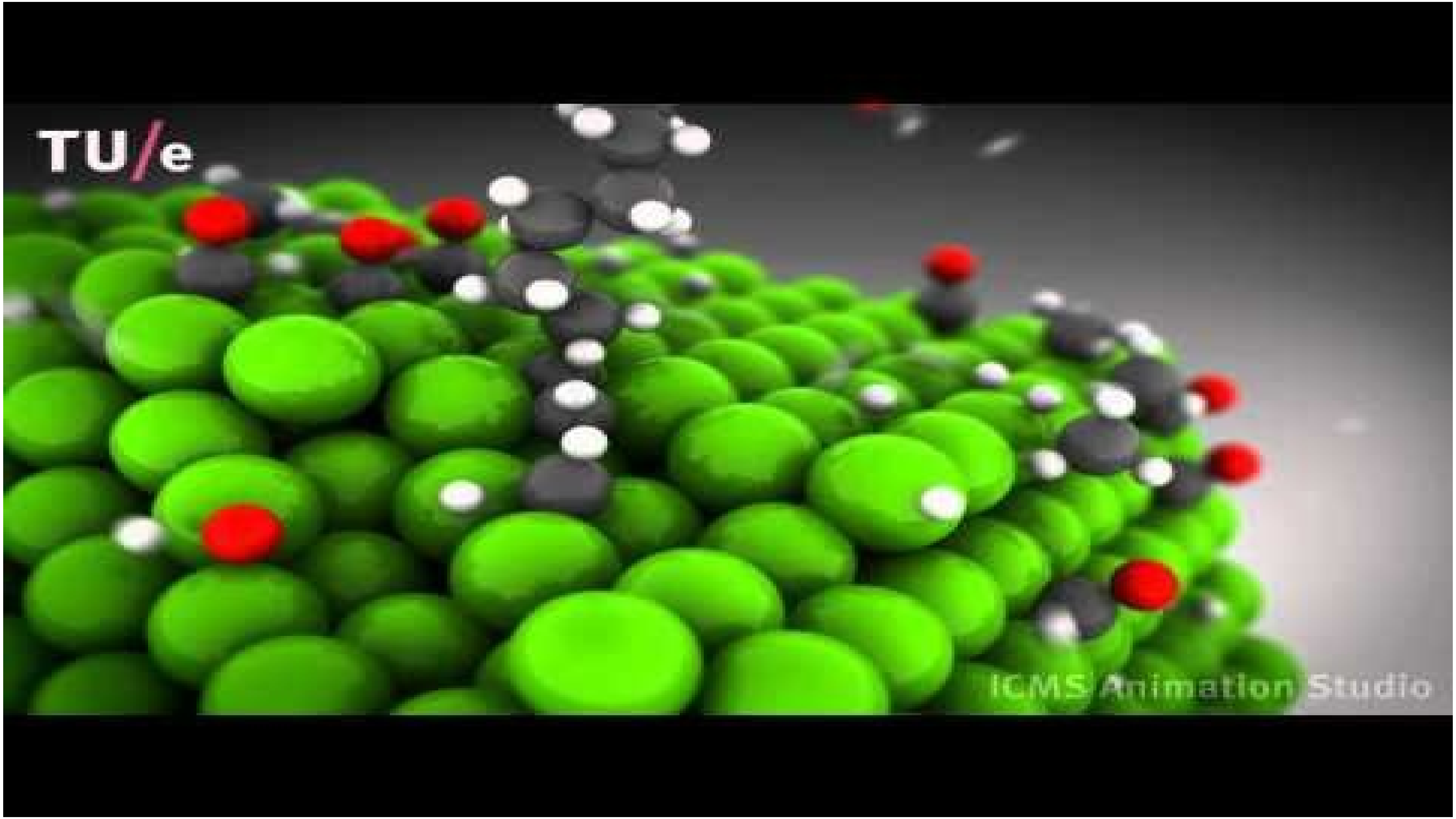
The Fischer-Tropsch (FT) process, originally developed by Franz Fischer and Hans Tropsch in early 1920s, is a series of chemical reactions that involve the conversion of hydrogen and carbon monoxide into liquid hydrocarbons by using a catalyst

$$(2n+1)\ H_2 + n\ CO \rightarrow C_n\ H_{(2n+2)} + n\ H_2O$$



[(4) The Fischer-Tropsch reaction - YouTube]

Fischer-Tropsch Process



Biofuels: From Brewery to Fuel Tank

Biofuels are renewable fuels derived from a biological source such as trees, grasses, or agricultural crops.

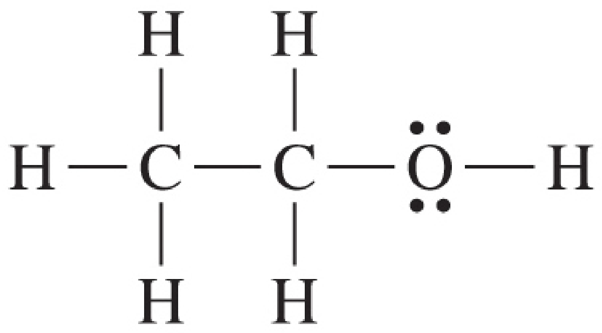
cone

swichgrass

Ethanol

Ethanol is an alcohol, with an –OH functional group.

- To obtain ethanol from corn, a “soup” of corn kernels and water is mixed with enzymes that catalyze the breakdown of starch to make glucose.
- Fermentation converts the glucose into ethanol which is purified by distillation.
- Ethanol can also come from plants containing cellulose such as cornstalks, switchgrass, wood chips, and other materials inedible by humans.



ethanol

Oxygenated Fuels

Oxygenated fuels such as ethanol contain a lower amount of energy per amount burned than the hydrocarbons found in gasoline.

- Ethanol (C_2H_5OH) releases 1,240 kJ/mol of energy.
- Octane (C_8H_{18}) releases 5,060 kJ/mol of energy.

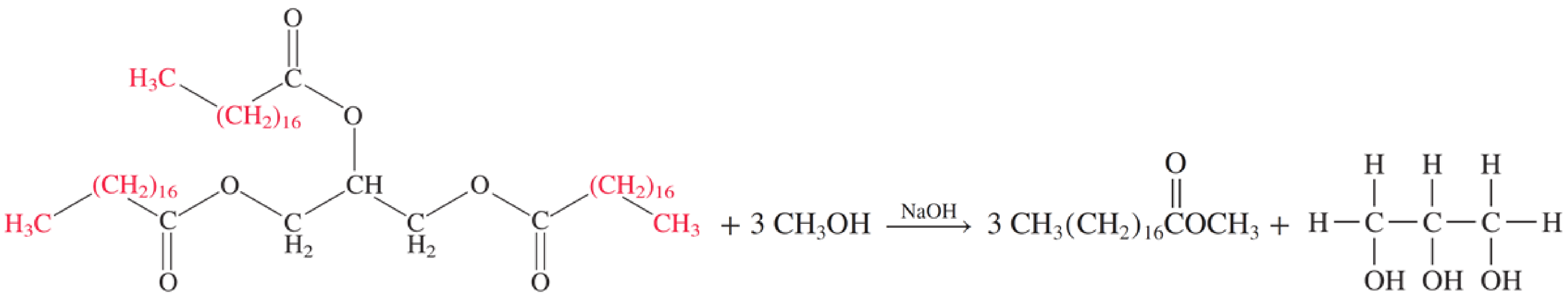
Car engines cannot run on ethanol by itself, so gasoline blends are used, which often contain 10% ethanol.

Biodiesel

Biodiesel is generated from fats and oils (called triglycerides), such as waste cooking oil.

Biodiesel molecules contain a hydrocarbon chain with 16 to 20 carbon atoms.

- The chains usually contain at least one C=C double bond.
- Biodiesel molecules also contain oxygen as an ester functional group.
- Glycerol is a byproduct of biodiesel production, which can be used in its own applications or converted to other alcohols.



[3d Model of Triglyceride - American Chemical Society (acs.org)]

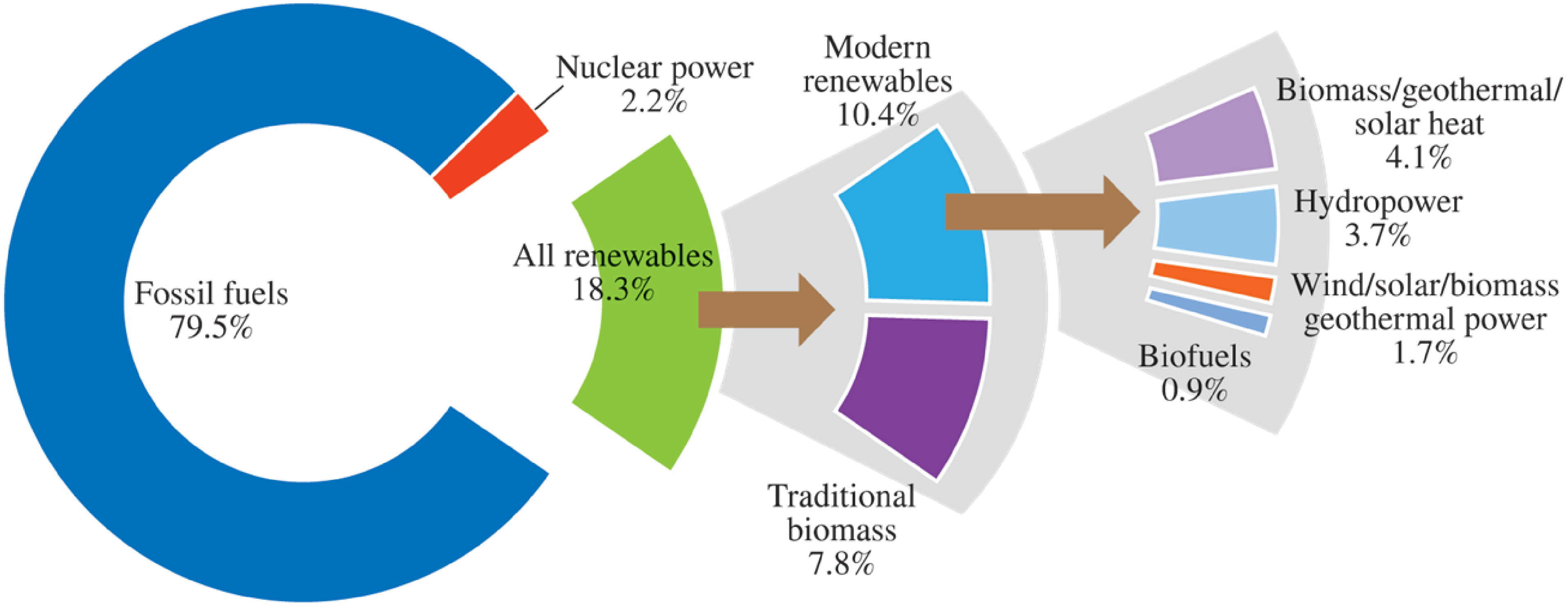
Biodiesel

Collected cooking oil

B20 biodiesel: a mixture of 80% petroleum diesel and 20% biodisel

[Biodiesel - American Chemical Society (acs.org)]

Renewable Energies



Traditional biomass includes wood, garbage, agricultural waste, and animal dung.

Source: Renewable Energy Policy Network for the 21st Century (2018), Renewables 2018: Global Status Report, Paris, REN21 Secretariat.

Table 6.5	Ethical Principles to Apply to Current and Future Use of Biofuels
1.	Biofuels development should not be at the expense of peoples' essential rights (including access to sufficient food and water, health rights, work rights, and land entitlements).
2.	Biofuels should be environmentally sustainable.
3.	Biofuels should contribute to a net reduction of total greenhouse gas emissions and not exacerbate global climate change.
4.	Biofuels should develop in accordance with trade principles that are fair and recognize the rights of people to just reward (including labor rights and intellectual property rights).
5.	Costs and benefits of biofuels should be distributed in an equitable way.
6.	If the first five principles are respected and if biofuels can play a crucial role in mitigating dangerous climate change, then depending on additional key considerations, there is a duty to develop such biofuels. These additional key considerations are absolute cost, alternative energy sources, opportunity costs, the existing degree of uncertainty, irreversibility, degree of participation, and the notion of proportionate governance.

Source: Nuffield Council on Bioethics, Biofuels: Ethical Issues ***2011,*** 84

Are Biofuels Really Sustainable?

Biofuels are potentially more carbon-neutral since they were derived from modern-day crops, grasses and trees.

- Carbon released on combustion is partially offset by the carbon these plants once absorbed via photosynthesis.

Hard to gauge the net reduction in carbon dioxide emissions for biofuels:

- Direct and indirect changes in the use of land.
- Waste products from biofuel production.
- How much energy was required to produce the biodiesel, including that used to plant and harvest the crop, produce fertilizers, and water the crops.

Your Turn 6.36 Palm Oil, Biodiesel, and Ethics

Are there ethical issues with biodiesel that need attention? In 2008, an Oxfam report noted:

The big losers from the rich countries' biofuel boom are poor people at risk from spiraling food prices, and a 'scramble to supply' that places their land rights, labor rights, and human rights under threat.

Use palm oil as a case study. It is produced in many parts of world, including Indonesia and Malaysia

A plantation of young palm trees in Malaysia

A palm oil plant in Malaysia

Palm oil isn't as bad as you think (youtube.com)

Your Turn The Problem with Biofuels

What are the key challenges associated with the production and utilization of biofuels, as explained in the YouTube video?

https://www.youtube.com/watch?v=OpEB6hCpIGM

https://www.youtube.com/watch?v=I9arI2e5bkw

Example topics that you can delve into further...

1. Explore the environmental issues associated with coal-fired power plants.
2. Identify alternative uses of coal beyond its role as a fuel.
3. Examine advancements in technology for extracting oil from rock
4. Define shale gas and analyze its economic and environmental impacts.
5. Define oil sands and discuss their global reserves. Explain how oil sands can be utilized.
6. Discuss the challenges and future outlook of bio-derived ethanol as a fuel source.
7. Explain the process of producing biodiesel and assess its viability as an alternative fuel source.