Name: _____ Date: _____ Period: _____

Energy Content of Fuels - Guided Notes

Slide 3: Energy Sources

- Law of _____ of Energy: energy cannot be created or destroyed, but only converted from one form to another.
- The **quality** of energy is degraded, so when energy is lost to the _____, it is no longer available to do work
- e.g. burning fossil fuels creates high-quality energy, but heat that is lost to the _____ can no longer be used
- Energy sources should be cheap, plentiful, readily accessible, provide high-quality energy at a suitable rate, and have minimal impact on _____
- **Energy Sources that meet this _____:**
- fossil fuels
- nuclear fission
- _____ cells
- solar energy
- biomass
- alternative energy (e.g. wind, _____, etc.)

Slide 4: Fuels

- _____ that can release energy by changing its chemical or nuclear structure.

Table 1. Features of fossil fuels.

Type of fossil fuel	State at room temperature	Composition
Coal	Solid	Mainly carbon, traces of hydrogen, oxygen, nitrogen, sulfur and metals.
Crude oil	Liquid	Mixture of medium to long chain hydrocarbons, traces of sulfur, nitrogen and oxygen and metals.
Natural gas	Gas	Mostly methane, traces of other small hydrocarbons, water and carbon dioxide.

Slide 5: Combustion of fossil fuels

- **Coal:**
- $C(s) + O_2(g) \rightarrow CO_2(g)$ $\Delta H = -393.5$ kJ
- **Crude Oil:**
- $C_8H_{18}(l) + 12.5O_2(g) \rightarrow 8CO_2(g) + 9H_2O(l)$ $\Delta H = -5470$ kJ
- **Natural Gas:**
- $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$ $\Delta H = -890.3$ kJ
- _____ = useful output energy x 100
- total input energy

Slide 6: Combustion of fossil fuels

- **Why do you think coal is utilized so frequently if it produces the least amount of energy per unit mass and is the least efficient of the fossil fuels?**

Table 3. Energy per unit mass from fuel sources.

Type of fuel	Energy per unit mass (MJ kg^{-1})
Coal	29.3
Crude oil	42.3
Natural gas	50.0

Slide 7: Combustion of fossil fuels

Type of fuel	Reaction equation	Mol CO_2 per MJ of energy
Coal	$C(s) + O_2(g) \rightarrow CO_2(g)$	$\frac{1\ \text{mol}\ CO_2}{-393.5\ \text{kJ}} \times 1000 = 2.54\ \text{mol}\ CO_2\ \text{MJ}^{-1}$
Crude oil	$C_8H_{18}(l) + 12.5O_2(g) \rightarrow 8CO_2(g) + 9H_2O(l)$	$\frac{8\ \text{mol}\ CO_2}{-5074\ \text{kJ}} \times 1000 = 1.58\ \text{mol}\ CO_2\ \text{MJ}^{-1}$
Natural gas	$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$	$\frac{1\ \text{mol}\ CO_2}{-890.3\ \text{kJ}} \times 1000 = 1.12\ \text{mol}\ CO_2\ \text{MJ}^{-1}$

Slide 8: Combustion of fossil fuels

Table 3. Molar volume of CO_2 produced from fuel sources.

Type of fuel	Amount CO_2 produced	Mass of fuel	Volume per mass of fuel
Coal	$1\,\text{mol} \times 22.7\,\text{dm}^3\,\text{mol}^{-1} = 22.7\,\text{dm}^3$	$1\,\text{mol of C} = 12.01\,\text{g}$	$\frac{22.7}{12.01} = 1.89\,\text{dm}^3\,\text{g}^{-1}$
Crude oil	$8\,\text{mol} \times 22.7\,\text{dm}^3\,\text{mol}^{-1} = 181.6\,\text{dm}^3$	$1\,\text{mol}\,C_8H_{18} = 114.26\,\text{g mol}^{-1}$	$\frac{181.6}{114.26} = 1.59\,\text{dm}^3\,\text{g}^{-1}$
Natural gas	$1\,\text{mol} \times 22.7\,\text{dm}^3\,\text{mol}^{-1} = 22.7\,\text{dm}^3$	$1\,\text{mol}\,CH_4 = 16.05\,\text{g}$	$\frac{22.7}{16.05} = 1.41\,\text{dm}^3\,\text{g}^{-1}$

Slide 9: Incomplete Combustion

- Coal has a tendency to undergo incomplete combustion due to presence of impurities
- Longer hydrocarbon chains require more oxygen during combustion, so more likely to undergo incomplete combustion
- Consequences of incomplete combustion:
- less energy released per mole of fuel
- release of harmful by-products, including CO and carbon particulates
- unreacted fuel is a fire hazard
- **Which fossil fuel do you think is the least likely to undergo incomplete combustion? Why?**

Slide 10: Incomplete Combustion

- **_____ of Carbon:**
- **_____ of Propane:**
- **_____ of Ethanol:**
- Complete:
- Incomplete:
- Limited O_2:
- _____ Limited O_2:
- Limited O_2:
- _____ Limited O_2:

$$C(s) + O_2(g) \rightarrow CO_2(g) \quad \Delta H_{comb} \text{ is negative}$$

$$2C_3H_8(g) + 3\tfrac{1}{2}O_2(g) \rightarrow 3CO(g) + 4H_2O(g)$$

$$2C(s) + O_2(g) \rightarrow 2CO(g) \quad \Delta H_{comb} \text{ is negative}$$

$$C_3H_8(g) + 2O_2(g) \rightarrow 3C(s) + 4H_2O(g)$$

$$2CH_3CH_2OH(l) + 4O_2(g) \rightarrow 4CO(g) + 6H_2O(g)$$

$$2CH_3CH_2OH(l) + 2O_2(g) \rightarrow 4C(s) + 6H_2O(g)$$

Slide 11: You Try!

- The incomplete combustion of propanol takes place under very low amounts of oxygen. List the products for this type of incomplete combustion reaction.

Slide 12: Advantages and Disadvantages of Fossil Fuels

	Coal	Crude oil	Natural gas
Advantages	• Cheap and plentiful throughout the world. • Can be converted into synthetic liquid fuels and gases. • Safer than nuclear power. • Ash produced can be used in making roads.	• Easily transported in pipelines or by tankers. • Convenient fuel for use in cars as volatile and burns easily. • Sulfur impurities can be easily removed.	• Produces fewer pollutants per unit energy. • Easily transported in pipelines and pressurized containers. • Does not contribute to acid rain. • Higher specific energy.
Disadvantages	• Produces many pollutants. • Produces CO_2, SO_2, particulates (electrostatic preceptors can remove most of these). • Difficult to transport. • Waste can lead to visual and chemical pollution. • Mining is dangerous.	• Limited lifespan and uneven world distribution. • Contributes to acid rain and global warming. • Transport can lead to pollution. • Carbon monoxide is a local pollutant produced by incomplete combustion of gasoline in internal combustion engines. • Photochemical smog produced as secondary pollutant due to reactions of the primary pollutants (nitrogen oxides and hydrocarbons) released from internal combustion engines.	• Limited supplies. • Contributes to global warming. • Risk of explosion due to leaks.

Slide 13: Greenhouse Gases

- **Overview of _____ Gases**
- CO_2 is the most abundant _____ gas, but has a lower greenhouse factor as compared to methane (CH_4).

Slide 14: Hydrocarbons

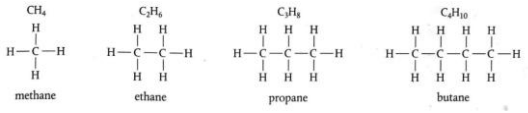
- The **simplest** class of organic _____.
- _____ are compounds formed from carbon and hydrogen.
- Can be classified as **saturated** or _____.
- **_____ only single carbon-carbon bonds**
- **_____ either double or triple carbon-carbon bonds**
- Remember, fuels such as crude oil and natural gas consist of _____!

Slide 15: Homologous Series

- Way to classify the millions of organic _____ that exist.
- **Main features of _____ series:**
- _____ members differ by a $–CH_2–$ group
- Members of a series be _____ by presence of **functional groups**
- Members of a series can be _____ by the same general formula.
- Members of a series show a gradation in their physical _____.
- Members of a series have similar chemical _____.
- **'Families' of organic _____**
- **a group of atoms that has similar chemical _____ in various compounds**

Slide 16: Successive members differ by a $–CH_2–$ group

- **Alkanes:** _____ series with only single-bonded carbon and hydrogen atoms
- (unbranched, saturated _____)



Slide 17: You Try!

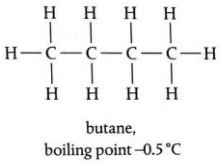
- **Draw the Structures of Pentane, Hexane, and Heptane**

Slide 18: Members show gradation in physical properties

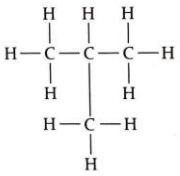
- _____ members of a homologous series have longer carbon chains.
- Compounds with longer carbon chains have _____ boiling points.
- due to increased _____ dipoles and stronger London dispersion forces between molecules.
- Density and viscosity also increase with _____ carbon number.

Slide 19: Structural Isomers

- _____ isomers are **distinct compounds** with **unique physical** and **chemical properties**
- Number of _____ isomers **increases** with **increasing size** of the molecule
- **Compounds having the same molecular formula but different _____ of atoms**



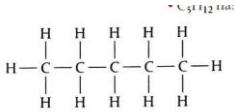
butane,
boiling point −0.5 °C



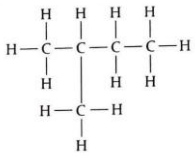
2-methylpropane,
boiling point −11.7 °C

Slide 20: Structural isomers continued

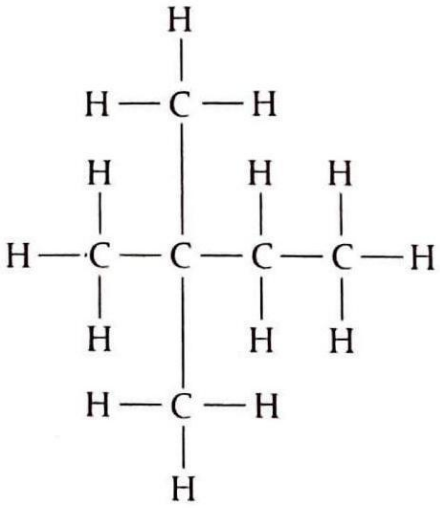
- **C_5H_{12} isomers**
- **C_6H_{14} isomers**



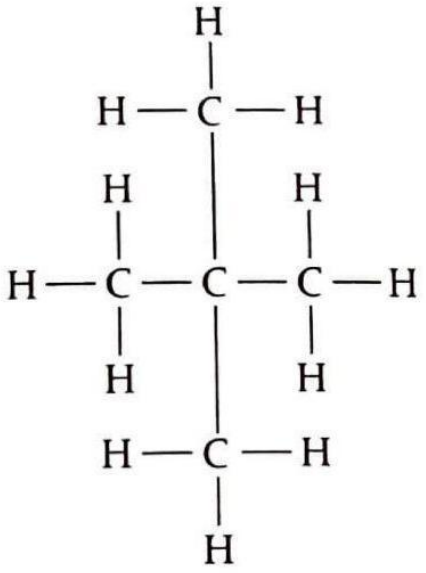
pentane



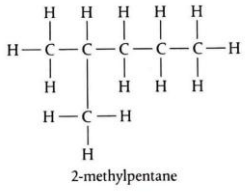
2-methylbutane



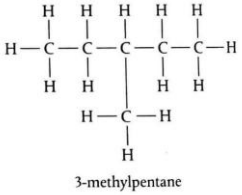
2,2-dimethylbutane



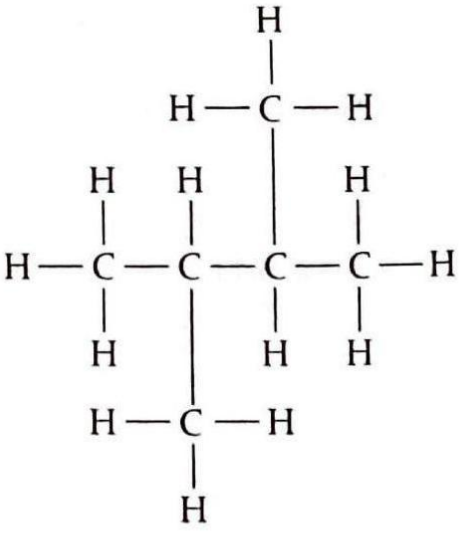
2,2-dimethylpropane



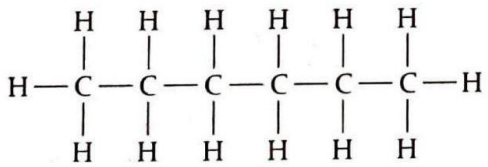
2-methylpentane



3-methylpentane



2,3-dimethylbutane



hexane

Slide 21: You Try!

- Draw at least 3 structural isomers of octane.

Slide 22: Why are isomers important?

- Branched-chain isomers burn more smoothly in internal combustion engines compared to straight-chain isomers, which make the former 'better grade', a higher octane number, and more expensive
- important in biochemistry and drug industries
- Methoxymethane and ethanol are structural isomers (C_2H_6O), but have very different functions.
- methoxymethane is a gas used in aerosol propellants
- ethanol used in alcoholic beverages

Slide 23: Octane Number

- Measure of the ability of a fuel to resist knocking when ignited in an internal combustion engine
- Calculated by comparing the fuel being measured to a standard fuel mixture of iso-octane (value of 100 and resists knocking) and heptane (value of 0 and knocks readily).
- Example: A fuel with an octane number of 96 burns as efficiently as as mixture of 96% iso-octane and 4% heptane.
- AKA "antiknock" rating
- "Knocking" results from premature ignition (when fuels ignite without the need of a spark-plug). It reduces the efficiency of the engine and damage an engine.
- **Higher octane fuels can be more highly compressed and result in more power per piston stroke.**

Slide 24: Octane Number

- Higher molecular weight _____ = lower octane number
- More branched _____ = higher octane number

Slide 25: Biofuels

- Are renewable (can be replenished at a rate equal to the rate at which it is used).
- Plants are examples of biofuels.
- When they absorb light energy, the excited chlorophyll drives photosynthetic redox reactions.
- Glucose is produced and used by the plant or stored in the form of cellulose, starch, or converted into lipids.
- Fuels derived from biological sources

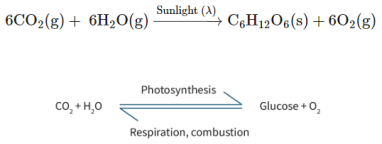


Figure 2. Photosynthesis and combustion.

Slide 26: Photosynthesis Half-Reactions

- **_____ of carbon dioxide to glucose:**
- $6CO_2 + 24H^+ + 24e^- \rightarrow C_6H_{12}O_6 + 6H_2O$
- **Oxidation of water:**
- $12H_2O \rightarrow 6O_2 + 24H^+ + 24e^-$
- **Adding the half _____:**
- $6CO_2 + 12H_2O \rightarrow C_6H_{12}O_6 + 6H_2O + 6O_2$
- Which can be simplified into the known equation for _____:
- $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$

Slide 27: Ethanol as a Biofuel

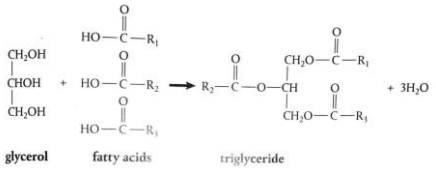
- **Ethanol can be made from biomass from fermentation of plants that are high in starch and sugar**
- $C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$
- **Yeast can be utilized to perform this reaction at 37°C.**
- **Gas is a mixture of 10% ethanol and 90% unleaded gasoline.**
- **Why add ethanol?**
- It is renewable
- Higher octane rating
- Low CO and NOx emissions
- Decreases dependence on oil

Slide 28: You Try!

- **State the equation for the complete combustion of ethanol.**
- **The enthalpy of combustion of ethanol is -1367 kJ mol^{-1}. Calculate the specific energy of ethanol in kJ g^{-1}.**
- **Compare this value with the corresponding value for octane and explain the difference. (Hint: look in your Data Booklet for the enthalpy of combustion of octane).**

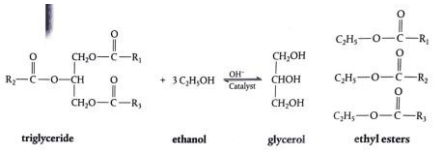
Slide 29: Vegetable Oil as Biofuel

- Vegetable oil used to be used an an engine fuel in the 1900s until crude oil diesel was _____.
- Low volatility
- 11 to 17 times more _____ than diesel fuel
- Do not burn _____ and form deposits in the fuel injector
- _____ oils are esters made from fatty acids and glycerol
- This is a type of _____ reaction (it releases water)



Slide 30: Transesterification of ethanol/methanol produces lower viscosity fuels

- Heavier glycerol product settles out and may be used for other purposes (e.g. _____, cosmetics, detergents).
- Biodiesel produced is less viscous because the ethyl esters are smaller molecules that have less van der Waals' _____ forces.
- biodegradable
- nontoxic
- fewer _____ compared to crude oil-based diesel
- Reaction of _____ and alcohol to glycerol and fatty acid esters through the use of a catalyst.
- **Ester _____ group**



Slide 31: Advantages and Disadvantages of Biofuels

Slide 32: Fuel Cells

- _____ cell in which reactants are continuously supplied to the electrodes
- $H_2(g) + ½\ O_2(g) \rightarrow H_2O(l)$ $\Delta H^{\ominus} = -286\ kJmol^{-1}$
- **Hydrogen Fuel Cell**
- Redox reaction that can be used to produce an electric current if reactants are _____ separated.

Slide 33: Hydrogen Fuel Cell: Alkaline Electrolyte

- $2H_2(g) + 4OH^-(aq) \rightarrow 4H_2O(l) + 4e^-$
- **Half-_____ at the anode: $H_2(g)$ is oxidized**
- **Half-_____ at the cathode: $O_2(g)$ is reduced**
- $2H_2O(l) + O_2(g) + 4e^- \rightarrow 4OH^-(aq)$
- **Overall Reaction:**
- $2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$
- Most common type of _____ fuel cell

Slide 34: Hydrogen Fuel Cell: Acidic Electrolyte

- $2H_2(g) \rightarrow 4H^+(aq) + 4e^-$
- **Half-_____ at the anode: $H_2(g)$ is oxidized**
- **Half-_____ at the cathode: $O_2(g)$ is reduced**
- $4H^+(aq) + O_2(g) + 4e^- \rightarrow 4H_2O(l)$
- **Overall Reaction:**
- $2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$

- Proton _____ Membrane made from Teflon that allows H^+ to move from anode the cathode

Slide 35: Methanol Fuel Cell

- $CH_3OH(g) + H_2O(l) \rightarrow CO_2(g) + 6H^+ + 6e^-$
- **Half-_____ at the anode: carbon is oxidized**
- **Half-_____ at the cathode: $O_2(g)$ is reduced**
- $6H^+(aq) + 3/2O_2(g) + 6e^- \rightarrow 3H_2O(l)$
- **Overall Reaction:**
- $CH_3OH(g) + 3/2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$
- Methanol is oxidized under acidic _____ on a catalyst layer to form carbon dioxide.
- H^+ are _____ across a proton exchange membrane from anode to cathode.

Slide 36: Advantages/Disadvantages of Fuel Cells