3.4 Everyday Use of Hydrocarbons

Figure A3.17: Most people use hydrocarbons as fuel for basic transportation.

Previous periods in human history have been identified as the Stone Age, the Bronze Age, and the Iron Age. The name of each of these periods is based upon the primary raw material that was the basis for making the culture's most advanced tools. What name would you give to the period of human history in which you live?

Figure A3.18: Items purchased at a grocery store are packaged using hydrocarbons.

petrochemical: a chemical made from petroleum

Some would argue that we are still in the Iron Age, since iron is the main ingredient of steel—an essential raw material for the tools used in modern society. If you broaden the definition to include the materials that power the tools, it could be argued that you are currently living in the Hydrocarbon Age. Virtually every human activity in modern society is somehow dependent upon **petrochemicals**.

Practice

42. Carefully examine all the objects shown in Figures A3.17 and A3.18.

- **a.** List specific examples that illustrate the use of hydrocarbons in each photograph.
- **b.** Consider the items you identified in question 42.a. Which of these items would be difficult to substitute with materials that were not petrochemicals?

43. What is meant if someone were to say that we were entering the Silicon Age?

Tracing the Path of Petrochemicals

In Lesson 3.3 you studied the processes used to separate specific types of hydrocarbons from the hydrocarbon soup that is petroleum. The petrochemical industry pumps hydrocarbons from deep in the ground and sends them to a refinery. Using fractional distillation, the petroleum is vaporized and the individual fractions are separated from the large mixture of other hydrocarbons they have been mixed with for millions of years. What happens next to the individual fractions?

In some ways, the answer to this question lies in the hands of consumers. What products from this process are in demand? In general, there are two possible outcomes for hydrocarbons once they have been refined:

- They may be combusted or burned for energy.
- They may become the raw material for making products (e.g., plastics, synthetic fabrics, cosmetics, medicines).

In this lesson you will explore both of the outcomes for refined hydrocarbon molecules. You will also explore some of the benefits and risks associated with each of these outcomes.

Hydrocarbons as Fuel

As a consumer, you primarily use hydrocarbons as fuel. Whenever you ride in a car or bus, cook on the barbecue, or turn up the furnance in your house, the energy you use comes from the burning of hydrocarbons. Hydrocarbons make excellent fuels because they

- are relatively stable and easily transported
- have bonds that store much energy
- are readily available (for the time being)

combustion: a rapid reaction with oxygen that produces energy and oxides

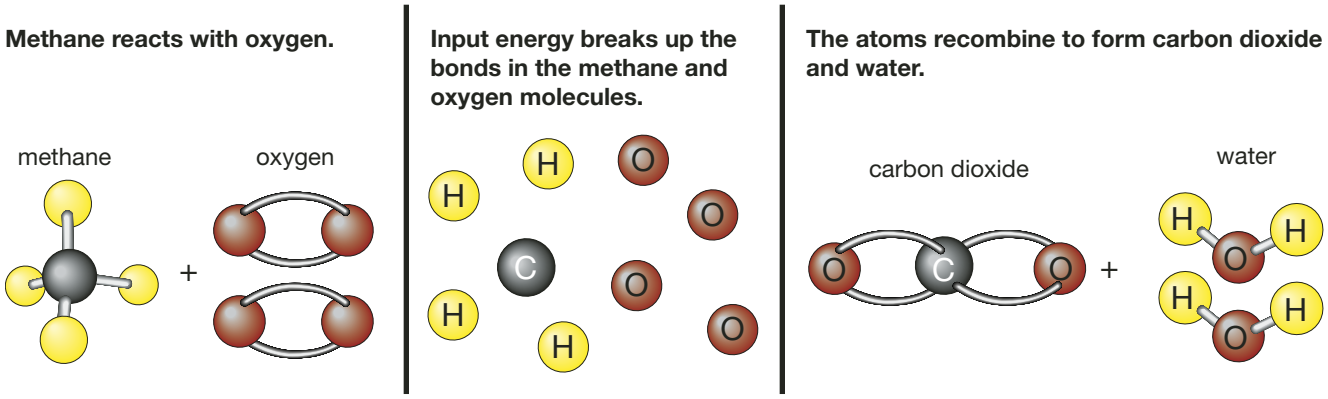
Figure A3.19: When the ratio of oxygen to fuel is right, hydrocarbons burn with a blue flame.

When something burns, it is reacting with oxygen. Another term for burning is **combustion**. When hydrocarbons are combusted, carbon dioxide and water are the most common oxides formed. During a hydrocarbon combustion reaction, oxygen reacts with the hydrocarbon fuel to produce carbon dioxide and water vapour. Here is the combustion reaction for methane:

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

This reaction happens in nearly every home in Alberta during the winter, as most homes are heated by the combustion of natural gas in a furnace. Since natural gas is mostly methane, the simplest hydrocarbon, this combustion reaction is a good place to begin.

For these molecules to react, energy has to be added to break the carbon-hydrogen single bonds and the oxygen-oxygen double bonds. In more modern furnaces, this is provided by the spark from an electronic igniter; in older models, the initial energy is provided by the spark of a pilot light. With this input energy, the bonds are broken and the individual atoms temporarily move into an unstable and energized state. When the atoms recombine to form carbon dioxide and water, they become more stable and energy is released.



Since the output energy from forming bonds of carbon dioxide and water is greater than the input energy to break the bonds of methane and oxygen, the overall effect of this reaction is to release energy to the environment. A furnace captures as much of this energy as possible, making a home comfortable for people on cold days.

When natural gas comes out of the ground, in addition to methane, it also contains ethane, propane, and butane. Impurities—such as nitrogen, sulfur, water, oil, and carbon dioxide—may also be present in the natural gas; but these impurities are removed before the natural gas is delivered to homes in Alberta. This helps make natural gas one of the cleanest hydrocarbon fuels.

Practice

44. Explain why it takes energy to separate the atoms joined by a covalent bond.

45. Explain why energy is released when atoms join and form a covalent bond.

Comparing Combustion Reactions

The concepts that explained the combustion of the simplest hydrocarbon can also be applied to the combustion of larger hydrocarbons. Longer hydrocarbon chains have more bonds than shorter hydrocarbon chains; therefore, longer hydrocarbon chains

- store a greater amount of energy than shorter hydrocarbon chains
- require greater amounts of oxygen to be combusted than shorter hydrocarbon chains
- will produce a greater amount of carbon dioxide, water vapour, and energy when combusted than shorter hydrocarbon chains

Example Problem 3.6

Propane and octane are both hydrocarbons that are used as fuels. Propane is used to cook food, and octane is a component of gasoline for automobiles.

a. Write the balanced chemical equation for the hydrocarbon combustion of propane.

b. For every mole of propane, determine the number of moles of oxygen required and the number of moles of carbon dioxide produced.

c. Write the balanced chemical equation for the hydrocarbon combustion of octane.

d. For every mole of octane, determine the number of moles of oxygen required and the number of moles of carbon dioxide produced.

e. Which combustion reaction uses more oxygen and produces more carbon dioxide per mole of fuel?

f. Energy is required to break chemical bonds, and energy is released when bonds are formed. Given this information, would you expect more energy to be released by the combustion of a mole of propane or a mole of octane?

Solution

a. ____ $C_3H_8(g)$ + ____ $O_2(g)$ → ____ $CO_2(g)$ + ____ $H_2O(g)$

↓ Add coefficients to balance the carbon atoms.

__**1**__ $C_3H_8(g)$ + ____ $O_2(g)$ → __**3**__ $CO_2(g)$ + ____ $H_2O(g)$

↓ Add a coefficient to balance the hydrogen atoms.

__1__ $C_3H_8(g)$ + ____ $O_2(g)$ → __3__ $CO_2(g)$ + __**4**__ $H_2O(g)$

↓ Add a coefficient to balance the oxygen atoms.

__1__ $C_3H_8(g)$ + __**5**__ $O_2(g)$ → __3__ $CO_2(g)$ + __4__ $H_2O(g)$

Recall that coefficients of 1 are normally not shown. Therefore, the balanced chemical equation is

$$C_3H_8(g) + 5\ O_2(g) \rightarrow 3\ CO_2(g) + 4\ H_2O(g)$$

continued on next page

b. Every mole of propane requires 5 mol of oxygen and produces 3 mol of carbon dioxide.

c. ____ $C_8H_{18}(l)$ + ____ $O_2(g)$ → ____ $CO_2(g)$ + ____ $H_2O(g)$

↓ Add a coefficient to balance the carbon atoms.

__1__ $C_8H_{18}(l)$ + ____ $O_2(g)$ → __8__ $CO_2(g)$ + ____ $H_2O(g)$

↓ Add a coefficient to balance the hydrogen atoms.

__1__ $C_8H_{18}(l)$ + ____ $O_2(g)$ → __8__ $CO_2(g)$ + __9__ $H_2O(g)$

↓ Add a coefficient to balance the oxygen atoms.

__1__ $C_8H_{18}(l)$ + __12.5__ $O_2(g)$ → __8__ $CO_2(g)$ + __9__ $H_2O(g)$

↓ Multiply all coefficients by 2.

__2__ $C_8H_{18}(l)$ + __25__ $O_2(g)$ → __16__ $CO_2(g)$ + __18__ $H_2O(g)$

The balanced chemical equation is

$$2\ C_8H_{18}(l) + 25\ O_2(g) \rightarrow 16\ CO_2(g) + 18\ H_2O(g)$$

d. Every mole of octane requires 12.5 mol of oxygen and produces 8 mol of carbon dioxide.

e. The combustion of octane uses more oxygen and produces more carbon dioxide per mole of fuel.

f. Octane is a larger molecule with a longer carbon chain than propane and more covalent bonds in itself and in the products formed. Since the number of bonds is greater, it is reasonable to expect more energy to be released from the combustion of 1 mol of octane than 1 mol of propane.

Practice

46. Write balanced chemical equations for each reaction.

- **a.** the combustion of pentane
- **b.** the combustion of 2-pentene
- **c.** the combustion of 2,2-dimethylheptane (**Hint:** Use a condensed structural diagram.)
- **d.** the combustion of glucose, $C_6H_{12}O_6(s)$
- **e.** the combustion of sucrose, $C_{12}H_{22}O_{11}(s)$

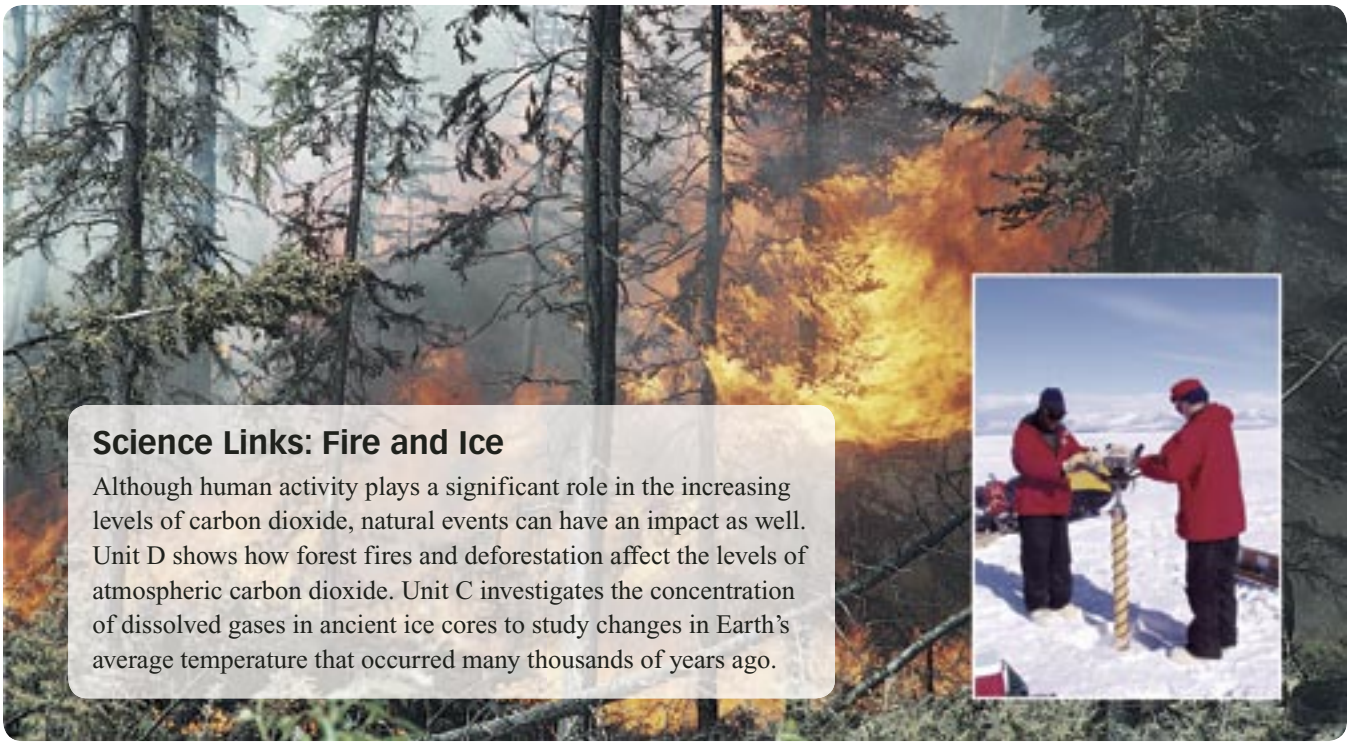
47. Carbon monoxide gas, CO(g), can reach hazardous levels if a vehicle is left to idle inside a garage. This occurs because hydrocarbons do not completely combust. Write a balanced chemical equation for the incomplete combustion of octane that produces carbon monoxide and water vapour.

The Environmental Impact of Burning Hydrocarbons

It is a fact that the combustion of hydrocarbons by humans has increased significantly in the last 200 years. Out of the exhaust of a vehicle you can usually see the water vapour produced by combustion. Even though you cannot see the carbon dioxide, it should not be surprising that the concentration of carbon dioxide in the atmosphere has increased.

Figure A3.20: It is the condensed water vapour in the exhaust from a vehicle that makes it visible.

Recall from previous science courses that carbon dioxide is a molecule that has unique properties. When it is present in the atmosphere, it helps trap heat near Earth's surface, contributing to the greenhouse effect. Many scientists believe that the increased levels of carbon dioxide are enhancing the natural greenhouse effect, warming Earth to the point that the average global temperature is rising. Evidence is mounting that increasing levels of carbon dioxide will eventually result in global climate change.



Science Links: Fire and Ice

Although human activity plays a significant role in the increasing levels of carbon dioxide, natural events can have an impact as well. Unit D shows how forest fires and deforestation affect the levels of atmospheric carbon dioxide. Unit C investigates the concentration of dissolved gases in ancient ice cores to study changes in Earth's average temperature that occurred many thousands of years ago.

Try This Activity

Voluntarily Reducing Hydrocarbon Consumption

Purpose

You will apply the chemistry you covered earlier in this chapter to investigate the impact of voluntary reduction in the use of gasoline.

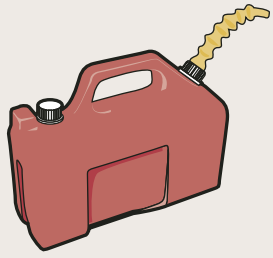
Science Skills

- ✓ Performing and Recording
- ✓ Analyzing and Interpreting

Background

Gasoline is a complex mixture of over 500 hydrocarbons. For the purpose of this activity, you will assume that gasoline only consists of iso-octane (2,2,4-trimethylpentane). Iso-octane is a major component of gasoline.

Analysis



1. Write a balanced chemical equation for the combustion of iso-octane.
2. The average car uses 28.0 kg of gasoline every week. Assuming that gasoline is made up of only iso-octane, calculate the number of moles of octane present in one week's worth of gas.
3. Using the balanced chemical equation, determine the number of moles of carbon dioxide released into the atmosphere after the combustion of 28.0 kg of gasoline.
4. There are 52 weeks in a year.
   a. Calculate the number of moles of carbon dioxide a typical car would release into the atmosphere each year.
   b. Calculate the mass (in grams) of carbon dioxide a typical car would release into the atmosphere in one year.
   c. If 1000 kg = 1 t, how many tonnes of carbon dioxide would a car release into the atmosphere in one year?
5. A small city may have as many as 70 000 cars on the road. Calculate the number of tonnes of carbon dioxide all the cars in the small city would release into the atmosphere each year.
6. Suppose the citizens of the small city described in question 5 voluntarily agreed to reduce their consumption of gasoline by 10% for one year.
   a. Calculate the number of tonnes of carbon dioxide this would prevent from entering the atmosphere.
   b. Describe the benefits that this pledge could have on the economic, social, and environmental aspects of the city.
   c. Identify why it might be difficult for some people in the city to purchase less gasoline.

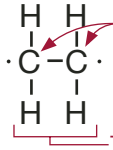
From Hydrocarbons to Polymers

Many of the products you buy result from changing hydrocarbons chemically. Products made from plastics, for example, are often made up of long carbon chains formed by joining many short, unsaturated hydrocarbon molecules.

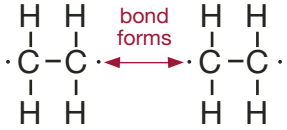
Creating Polyethylene

First, start with an ethene molecule.

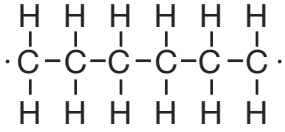
Carbons have unbonded electrons and look to bond with something else.



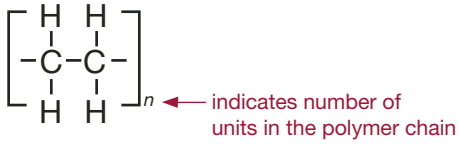
Another "broken" ethene molecule comes and forms a bond.



Many "broken" ethene molecules join together to make very long chains called polyethylene.



This results in the molecular formula of polyethylene.



polymerization: a reaction where many short hydrocarbon molecules join together to form very long hydrocarbon chains

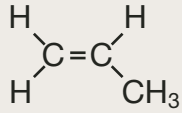
polymer: a large hydrocarbon molecule formed by a polymerization reaction

The process of joining many short, unsaturated hydrocarbon molecules is called **polymerization**. The resulting plastic is called a **polymer** (*poly* means "many," *mer* means "units"). The plastic in the preceding example is called polyethylene. It is given this name because it is created by joining many ethene molecules together. Polyethylene is the soft plastic used to make many products, including plastic bottles, plastic bags, and many toys.

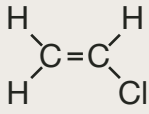
Practice

48. For each starting compound, determine the complete structural diagrams for both the repeating polymer unit and a segment of the resulting polymer chain. Use the reaction for polyethylene as a guide.

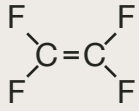
a. This is the starting compound used to make polypropylene. Polypropylene is used to make indoor-outdoor carpeting and bottles.



b. This starting compound is used to make polyvinylchloride (PVC). Plastic wrap, synthetic leather, and garden hoses are all made with PVC.



c. This starting compound is used to make polytetrafluoroethylene, also known as Teflon. Teflon is used for non-stick coatings on frying pans, cooking utensils, and electrical insulation.



Exploring Polymers

There are many different polymers, each with their own unique properties and, therefore, different uses. In the "Making an Organic Compound" activity on page 107, you made a polymer and linked its properties to possible applications. The matching of a polymer's characteristics to a useful application is done in industry as well.

The properties of polymers are a result of their chemical structure. Longer polymer chains will have different properties than shorter polymer chains. Polymers with branches will have different properties than polymers without branches. Even mixtures of polymers have different properties. The development of new types of polymers to produce plastics with unique properties is extensive.

Science Links: Helmet Design

In Unit B you will investigate helmets by designing and testing a helmet of your own design. Polymers will play a large role in this work because some types are light, hard, and make an ideal outer shell; others are soft and provide padding for the inner liner.

The Environmental Impact of Polymers

People use polymers every day. Polymers like rubbers and plastics for example, are often used either as materials for products or as a coating to protect products from other compounds in the environment. They are stable substances, which means they do not react readily with compounds they are exposed to on a daily basis.

The greatest problem associated with polymers is that they take a long time to decompose or degrade. Industry has become very good at using natural resources to produce goods that suit people's needs, but it is difficult for natural processes to return these consumer products back to Earth where they can be used again. Carbon atoms become locked in polymers for hundreds of years because polymers are resistant to natural processes that decompose or break down matter. As a result, society is facing problems with the accumulation of discarded polymers.

Countries around the world have developed many different practices to deal with the accumulation of disposed plastics. One option is to bury polymers underground in the hopes that someday they will decompose. Other countries have decided to burn disposed plastics in order to release the carbon into the air as carbon dioxide. In some places, there are recycling programs for polymers so they can be reused in their locked form. Other communities have even decided to ban the use of disposable, plastic grocery bags.

In Alberta, there is a province-wide goal to reduce the amount of polymers and other materials sent to landfills. In 2005, approximately 800 kg of municipal solid waste for every person living in the province was sent to landfills. The goal is to reduce this average to 500 kg per person by 2010.

One way that every Albertan can contribute to the goal of waste reduction is to apply the three Rs: Reduce, Re-use, and Recycle. Here are some specific things that you can do to reduce the amount of polymer waste that you produce.

Reduce

Buy products that do not have excessive packaging. Try to look for a similar product that is available with no packaging or re-usable containers.

Vote with your wallet—buy products from retailers and manufacturers who are making an effort to use less packaging.

Take re-usable shopping bags to the store so you don't need disposable bags.

Re-use

Margarine containers, ice cream pails, and other containers could be re-used around your home as storage bins.

Toys, sporting goods, and other plastic items can be used by someone else instead of being thrown away. You can take them to the donation centre for a local charity, give them to a neighbour, or have a yard sale.

Recycle

Choose materials that can be recycled or that are made from recycled materials, such as glass and metal. Unfortunately, less than 5% of plastics are currently recycled. Because there are so many different types of plastics, these plastic items have to be sorted and separated before the plastic can be reprocessed. However, the plastics that can be recycled should be diverted away from garbage cans.

As you'll learn in Unit D, an even more powerful approach to solving these problems is to **rethink** many of your basic assumptions. Is it really necessary for our entire society to be so focused on the consumption of goods?

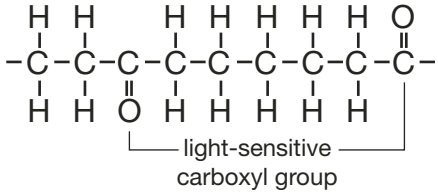
Practice

Beverages in aluminium cans are sometimes sold in sets of six that are held together by a plastic collar.

This form of plastic packaging is not only a litter problem, but birds and small animals have snared themselves in the plastic rings. Several solutions have been proposed to deal with this problem.

Option 1: Consumers should cut each of the plastic rings with scissors before discarding this form of packaging.

Option 2: Manufacturers should make this form of packaging from biodegradable polyethylene. This polymer has light-sensitive carboxyl groups inserted into the polymer chain.



When this polymer is exposed to light, the long chains break at each carboxyl group. The remaining shorter sections can then be effectively broken down by natural processes.

49. Explain why Option 1 does not address all of the environmental concerns regarding this form of packaging.

50. Although two options were outlined in the information box, there are other approaches to solving the environmental problems associated with this form of packaging. Describe two additional options that could be used. In each case, list the positive and negative aspects of your proposal.

51. Reread your answers to questions 42, 49, and 50. Given what you learned about the environmental impact of hydrocarbons in this lesson, what recommendations would you make regarding the use of petrochemicals?

3.4 Summary

Hydrocarbons produced from the fractional distillation of petroleum are used either as fuels in combustion reactions or as starting compounds to produce polymers. Hydrocarbon combustion is a reaction with oxygen that produces carbon dioxide and water vapour. As the hydrocarbon chain gets longer, larger amounts of oxygen are required, more carbon dioxide and water are produced, and more energy is released. Since carbon dioxide is a greenhouse gas, the combustion of hydrocarbons has raised concerns about the links to global warming and climate change.

A polymer is a very long carbon chain produced by linking together smaller units in a polymerization reaction. The structure of the polymer chain determines the properties of the molecule, which, in turn, indicates the particular applications that are best suited to that particular polymer. The fact that polymers tend to be quite resilient compounds means that products made from these materials decompose very slowly and become a disposal problem.

3.4 Questions

Knowledge

1. Define the following terms.

- **a.** hydrocarbon combustion
- **b.** polymerization
- **c.** polymer

2. Describe the steps that occur during a hydrocarbon combustion reaction.

3. Describe the steps that occur during a polymerization reaction.

Applying Concepts

4. Write the balanced chemical equations for the combustion of each hydrocarbon listed.

a. hexane **b.** 2-methylhexane

5. Refer to question 4 as you answer the following.

- **a.** Which hydrocarbon molecule requires more oxygen to combust? Provide a reason to support your choice.
- **b.** Which hydrocarbon molecule produces more carbon dioxide and water vapour? Support your choice.
- **c.** Which hydrocarbon molecule releases more energy? Provide a reason to support your choice.

6. Show the structures of the polymers that will be produced with the polymerization of each of the following compounds: 1-butene and 2-butene.

7. Explain why each country should use hydrocarbons wisely.

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Legend: t = top, m = middle, b = bottom, l = left, r = right

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