chapter

9 Hydrocarbons from Petroleum

In this chapter

The most widely accepted explanation of the origin of fossil fuels is that they come from decaying plant and animal material. The carbon cycle is a model connecting the organic reactions of photosynthesis, digestion, and respiration (**Figure 1**). The formation of fossil fuels can be seen as the end of the natural processes in the carbon cycle and the beginning of the technological processes described in this chapter.

Humans have invented methods to extract fossil fuels from below the surface of Earth. We mostly burn fossil fuels to produce heat and useful energy. These combustion reactions produce carbon dioxide, which feeds back into the carbon cycle.

Recently, we have developed many other technological uses of fossil fuels. We now produce vast quantities of petrochemicals (chemicals created from fossil fuels), most of which are not meant to be burned. Petrochemicals include methanol (windshield antifreeze), ethylene glycol (radiator antifreeze), chlorofluorocarbons (CFCs: refrigerator and air conditioner coolants), plastics (polyethylene and polyvinylchloride (PVC)), and pesticides. In this chapter, you will learn about the extraction and refining of fossil fuels. In the next chapter, you will learn about the use of fossil fuels to create petrochemicals. For both uses, fossil fuels are a very valuable nonrenewable resource. The impact of fossil fuel use on our lives and our planet is everywhere around us.

Historically, natural resources were seen as assets to be developed, and it was usual to imagine technological solutions to problems. In recent times, however, we have come to realize that technology is limited in its ability to cope with resource depletion and pollution. Many people, including scientists, believe we need to move toward an Aboriginal viewpoint that sees natural resources as gifts to be treasured for future generations. In order to save our planet from irreparable harm, we have a responsibility to live in harmony with nature for the mutual benefit of nature and humanity.

STARTING Points

Answer these questions as best you can with your current knowledge. Then, using the concepts and skills you have learned, you will revise your answers at the end of the chapter.

1. What are the origins and sources of fossil fuels?
2. How are fossil fuels extracted and refined?
3. What are the main hydrocarbon families, and how do they differ?
4. What are some uses of fossil fuels and their components?

Career Connections:
Petroleum Engineer; The Petroleum Industry

9.1 Fossil Fuels

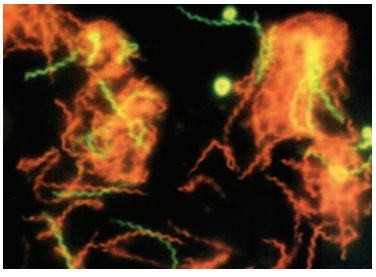


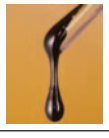
Figure 1
Extremophiles are microoganisms that thrive in harsh environments, such as boiling water, acid, rocks, the coolant of a nuclear reactor, and toxic wastes. Identification of these carbon-based organisms raises the hopes of astrobiologists that basic life forms may exist on moons and planets in the universe. On Earth, the study of organic chemistry began with living things. Beyond Earth, scientists look for evidence of living things.

Life as we know it is based on carbon chemistry (**Figure 1**). Therefore, it is not surprising that the early definition of organic chemistry was related to compounds obtained only from living things. Today, **organic chemistry** is a major branch of chemistry that deals with compounds of carbon, excluding oxides (such as CO(g)) and ionic compounds of carbon-based ions such as carbonate, cyanide, and carbide ions, for example, $Na_2CO_3(s)$, NaCN(s), and SiC(s), respectively. In spite of this broader definition, the major source of carbon compounds is still living or previously living things, such as plants, animals, and all types of fossil fuels.

Coal, oil sands, heavy oil, crude oil, and natural gas are nonrenewable sources of fossil fuels. They are also the primary sources of **hydrocarbons**—compounds containing carbon atoms bonded to hydrogen atoms. Hydrocarbons are the starting points in the synthesis of thousands of products, including specific fuels, plastics, and synthetic fibres. Some hydrocarbons are obtained directly by physically refining oil and natural gas (both called petroleum), whereas others come from further (chemical) refining (**Table 1**).

Refining is the technology that includes physical and chemical processes for separating complex mixtures into simpler mixtures or near-pure components. The refining of coal and natural gas involves physical processes; for example, coal may be crushed. Components of natural gas are separated either by solvent extraction or by condensation and distillation. Oil sands refining involves a chemically enhanced physical process followed by the complex refining of the bitumen/tar. Crude oil refining is more complex than coal or gas refining, but many more products are obtained from crude oil.

Table 1 Refining of Fossil Fuels—a Preview

Fossil fuel[1]	Extraction	Physical processing[2]	Chemical processing	Sample uses
Natural gas[3] 	natural pressure underground	condensation and distillation	removal of hydrogen sulfide and carbon dioxide at a gas plant	heating buildings; source of ethane, propane, and butane
Coalbed methane 	water removed from underground, if necessary	removal and disposal of saline water, if necessary	removal of non-combustibles at a gas plant	same as natural gas, including production of hydrogen and methanol
Crude oil 	water or gas injection underground	water, sand, and salt removal, and fractional distillation in a tower	hydrocracking and catalytic reforming	gasoline, jet fuel, and asphalt
Heavy oil 	steam injection underground	separation from water and solids; fractional distillation	heavy oil hydrocracking and catalytic reforming	same as crude oil
Oil sands (bitumen) 	physical mining and in situ steam or hot water injection	hot water extraction and floatation; centrifugation; fractional distillation	coking, hydrocracking, hydrotreating	synthetic crude used as crude oil
Coal 	surface and underground mines	sorting, crushing, and/or grinding	none or gasification for alternative delivery	energy for producing electricity

1. These Alberta fossil fuels are listed in order of increasing density. 2. In many cases, physical processing also includes removing water and solid contaminants from the raw material. 3. For natural gas, the chemical processing precedes the physical processing.

INVESTIGATION 9.1 *Introduction*

Classifying Fossil Fuels

Alberta has many different fossil fuels. Samples of fossil fuels can be described and classified in terms of their physical properties of colour, transparency, viscosity, and density. In this investigation, the focus is on density.

Purpose

The purpose of this investigation is to use the known properties of fossil fuels to analyze the provided samples.

Problem

What are the classes of the fossil fuel samples provided?

Report Checklist

○ Purpose	○ Design	● Analysis
○ Problem	○ Materials	● Evaluation (1, 3)
○ Hypothesis	● Procedure	
○ Prediction	● Evidence	

Design

Equal-volume samples of fossil fuels are provided in sealed containers of equal mass. The mass of each sample, including the container, is determined. The fossil fuel samples are classified based on their densities.

To perform this investigation, turn to page 401.

Case Study

Fossil Fuel Industries in Alberta

Alberta is very rich in fossil fuels. The most widely accepted hypothesis for the origin of these fossil fuels is that they formed from sand, silt, and plant and animal remains starting about 500 Ma ago. The majority of hydrocarbons found in Canada exist in the Western Canada Sedimentary Basin, which covers all but the northeast corner of Alberta (**Figure 2**).

Coal, oil sands, heavy oil, crude oil, natural gas, and coalbed methane are fossil fuels found in significant quantities in Alberta. From a technological perspective, each of these fuels has historically had to go through several cycles of discovery, research, and development.

Discovery, Research, and Development

Discovery has occurred throughout history, from Aboriginal peoples discovering oil sands along the banks of the Athabasca River and farmers digging fence-post holes and finding coal, to today's sonar equipment used for conducting underground seismic surveys. Research and development (R & D) has historically been conducted separately and sequentially: research by universities and development by industry. However, this model of R & D has changed and continues to change, with more overlap of the roles of universities and industries. For example, on a small scale, government (the Alberta Research Council) scientists did research and development on the hot-water process for extracting oil from the oil sands. Industry and engineers then ran larger-scale tests and developed the sophisticated technologies required for economical world-scale plants. Researchers continue the R & D cycle in their attempts to extract oil from deep oil sands and depleted oil wells.

Petroleum Discoveries

Natural gas was first discovered by chance near Medicine Hat, Alberta, in 1883. The drillers were looking for water, and found a methane-rich flammable gas. The discovery, and the many subsequent fires, prompted author Rudyard Kipling to refer to

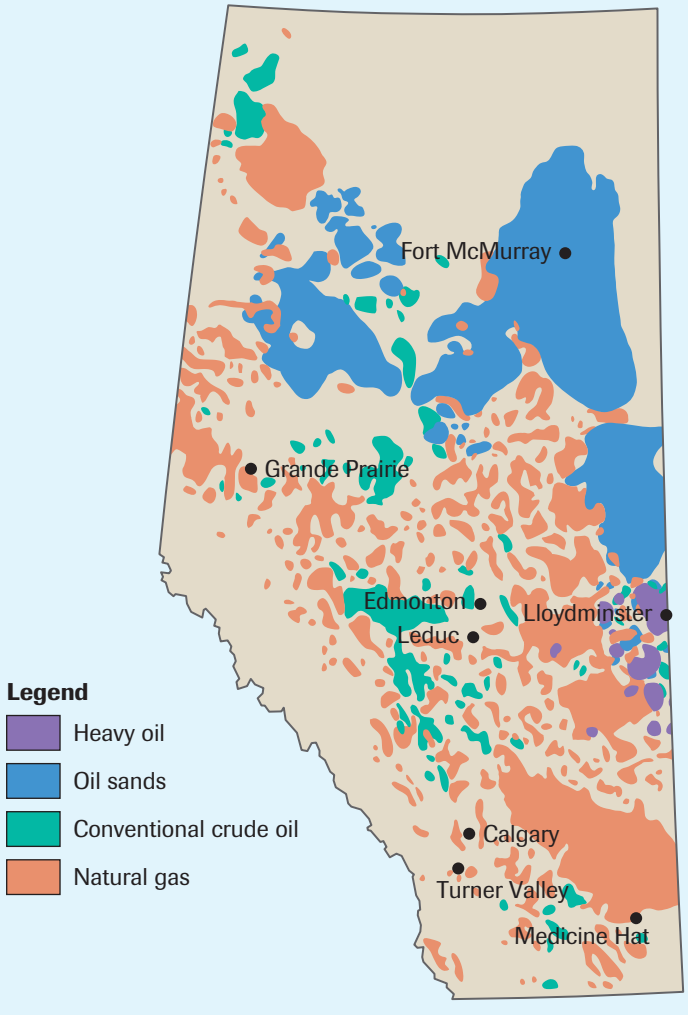


Figure 2
Fossil fuels in Alberta

Medicine Hat as Hell's Kitchen. The plentiful gas made Medicine Hat famous for natural gas street lights and pottery furnaces. Natural gas was then discovered in Cessford, Turner Valley, Suffield, Bow Island, and Viking, Alberta.

Hell's Half Acre was the nickname for Turner Valley, Alberta, where oil was discovered in 1914 and in 1936—beneath the natural gas. The next important discovery of crude oil was Leduc 1 on February 13, 1947 (**Figure 3**). This gusher near Devon, south of Edmonton, started an oil rush. Oil was struck in the Devonian Formation after Imperial Oil had drilled 133 unsuccessful wells. Perseverance, it appears, is just as important for technologists as it is for scientists (and students).

Figure 3
Leduc 1

The largest oil field in Canada is the Pembina field, near Drayton Valley, Alberta. Geologists continue to search for oil and gas in the sedimentary basin to Rainbow Lake, Norman Wells, and the Beaufort Sea. Much of the exploration in Alberta today is to find coalbed methane gas and oil sands (see the Explore an Issue on page 365 and the Case Study on page 395). The search for crude oil also continues.

Infrastructure

With the discovery and production of oil and natural gas came the need for infrastructure: oil and gas pipelines, gas plants, and oil refineries. Pipelines are needed to transport the oil or gas to a refinery, to local consumers, and to national and international consumers. These pipelines criss-cross Alberta—as evidenced by cut-lines and road-crossing signs. Pipelines were, and continue to be, built to eastern Canada, the west coast, and the United States.

Oil refineries were first built in 1923 and 1939 in Calgary. As the discovery of oil moved northward, so did the refineries. As the size of the discoveries grew, so did the size of the refineries. Refineries continue to be built, especially for the refining of bitumen (from oil sands) and heavy oil. The refining of natural gas in Alberta requires over 800 gas plants to remove impurities (such as hydrogen sulfide) and to extract the valuable components from the gas (including ethane, propane, and butane).

Social and Environmental Challenges

The advantages to Albertans of the large quantities of fossil fuels found in Alberta are numerous. Major examples include using gasoline (from crude oil) to propel our cars and trucks, using natural gas to heat our homes, and using coal to produce our electricity. In general, the fossil fuel industry in Alberta has important effects on our economy and our lifestyles.

Our fortune of fossil fuels also presents challenges. Some of these challenges include the effects on communities and infrastructure. For example, in fast-growing communities close to fossil fuel extraction and refining plants, there is a higher probability of a shortage of housing and social services. Rapid and extensive development of resources also presents environmental challenges. For example, the extraction and refining of many fossil fuels requires water. The extraction process disturbs surface land and air, and creates water pollution to varying degrees.

There are nearly always trade-offs (a negative for a positive result) when we decide to develop a natural resource. Research and technological fixes can only solve so many problems. The demands (needs and wants) of society and of individuals may be justified in our minds, but we also need to consider the potential negative consequences of our everyday actions.

Case Study Questions

1. (a) Based upon Figure 2 on the previous page, which are the most widespread fossil fuel deposits in Alberta?
   (b) What fossil fuels found in Alberta are not depicted in Figure 2?
2. (a) What is the classical relationship between research and development?
   (b) Which group of people performed each of the R & D?
3. What technological infrastructure is necessary for processing and transporting fossil fuels?
4. Give an example of a trade-off between a positive and a negative consequence of fossil fuel production.

Extension

5. Research and report alternative hypotheses to the currently accepted hypothesis for the formation of fossil fuels, such as the organic and the inorganic hypotheses.

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6. In what general regions of Alberta have we found
   (a) oil sands, heavy oil, crude oil, and natural gas?
   (b) coal and coalbed methane?
   (c) significant wind, solar, biomass, and geothermal energy production?

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7. Research when and where natural gas was discovered in Canada's Northwest Territories.

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8. Continue your research on the Resolution in the Exploration on page 357: The burning of fossil fuels for heat and transportation should be significantly reduced. Gather statements, pro and con, from a variety of perspectives. Focus on the effects of the discovery and extraction of fossil fuels in Alberta.

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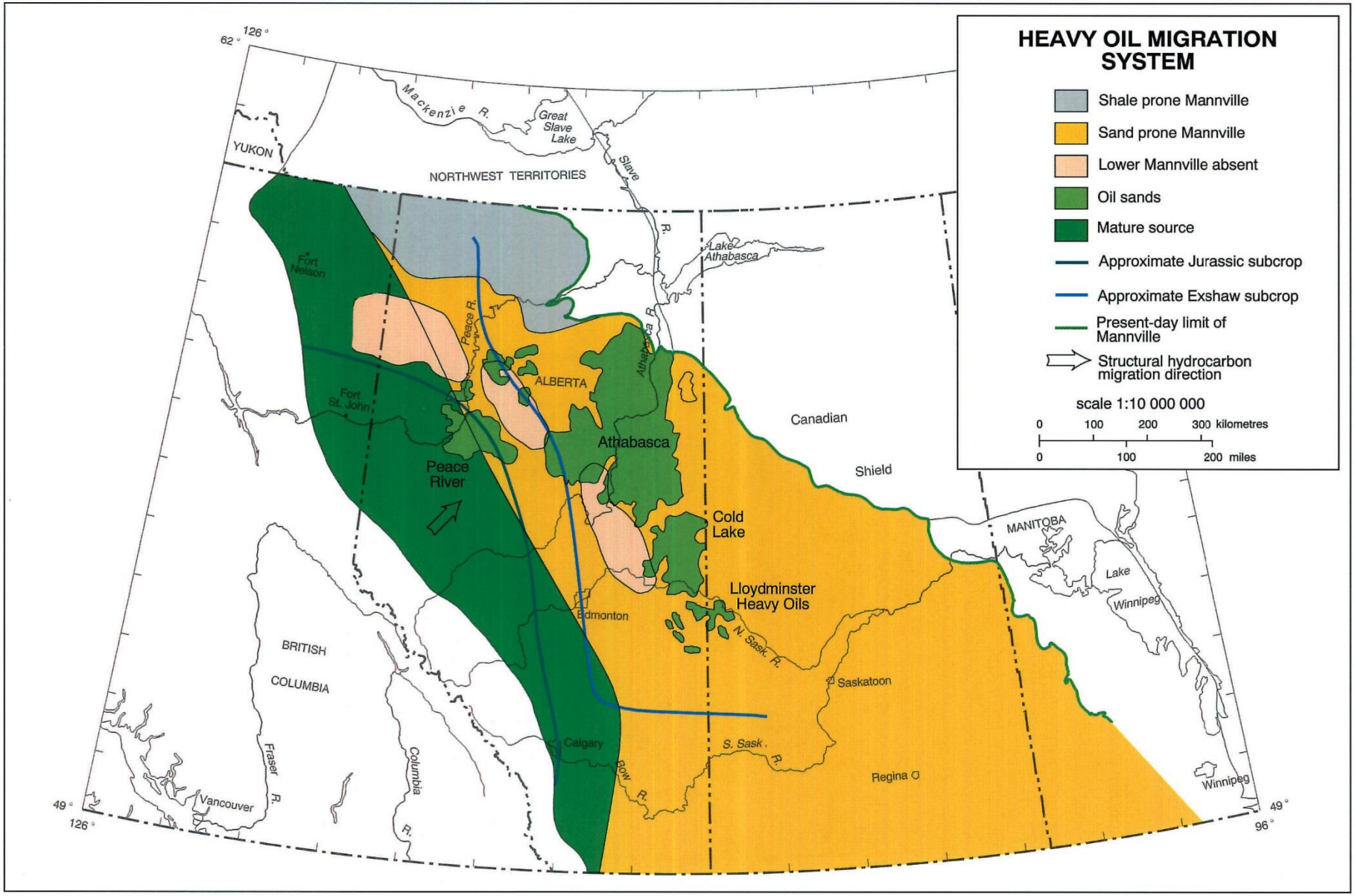
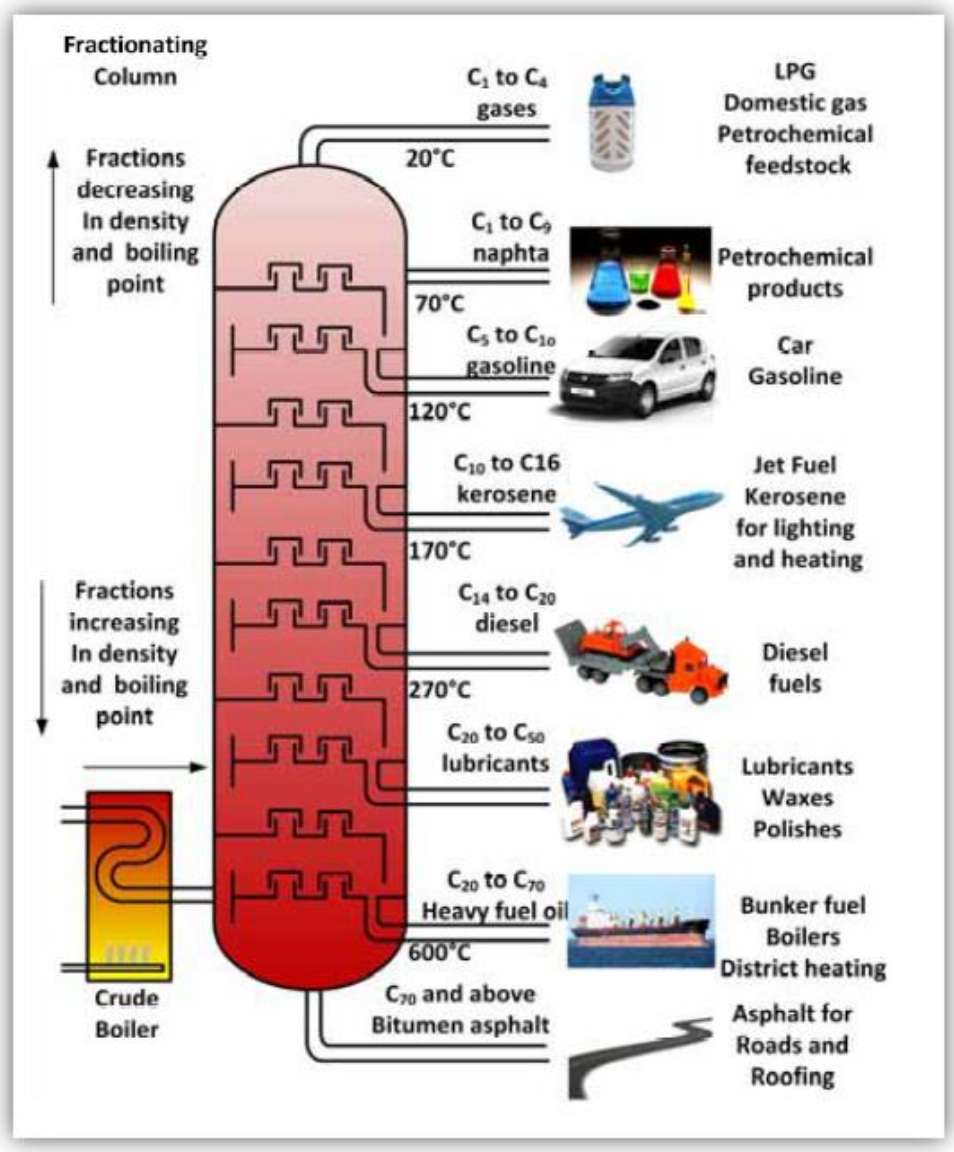


Figure 31.21 Postulated petroleum migration pathways for the heavy oils of the Western Canada Sedimentary Basin.

The **Mannville Group** is a stratigraphical unit of Cretaceous age in the Western Canadian Sedimentary Basin. It takes the name from the town of Mannville, Alberta, and was first described 1945.

Fractional Distillation

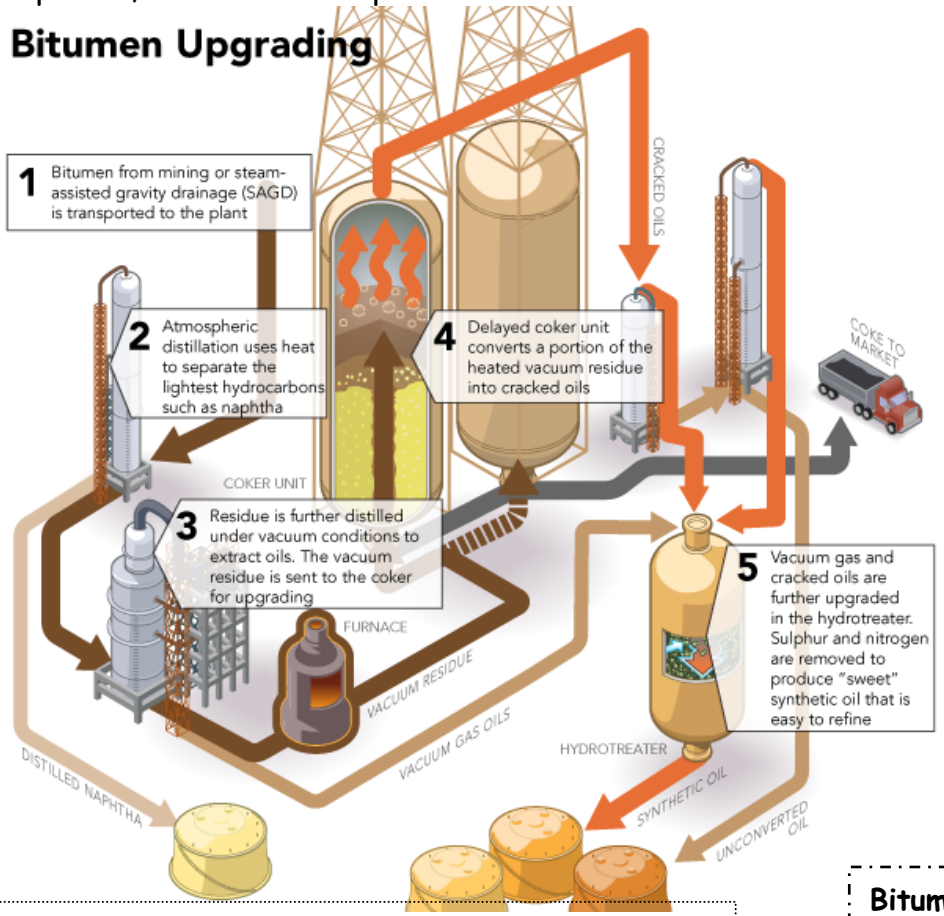
This is used within the petroleum industry to separate different petrochemicals based on their molecular mass and boiling point. The lighter, less branched hydrocarbons are heated and will boil first, rising to the highest outlet, followed in turn by heavier products. This separation is important for industry.

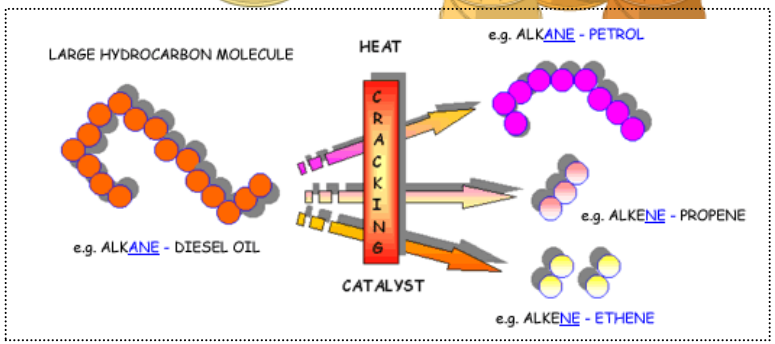


Crude oil is created through the heating and compression of organic materials over a long period of time. Most of the oil we extract today comes from the remains of prehistoric algae and zooplankton whose remains settled on the bottom of an Ocean or Lake. Over time this organic material combined with mud and was then heated to high temperatures from the pressure created by heavy layers of sediment. This process, known as diagenesis, changes the chemical composition first into a waxy compound called kerogen and then, with increased heat, into a liquid through a process called catagenesis.

Crude oil, commonly known as petroleum, is a liquid found within the Earth comprised of hydrocarbons, organic compounds and small amounts of metal. While hydrocarbons are usually the primary component of crude oil, their composition can vary from 50%-97% depending on the type of crude oil and how it is extracted. Organic compounds like nitrogen, oxygen, and sulfur typically make-up between 6%-10% of crude oil while metals such as copper, nickel, vanadium and iron account for less than 1% of the total composition.

Oil can also be extracted from oil sands, often called tar sands. Oils sands are typically sand or clay mixed with water and a very viscous form of crude oil known as bitumen. The extraction process for oil sands is quite different from drilling due to the high viscosity of this extra-heavy oil. Rather than using drills, crude oil is extracted from oil sands through strip mining or a variety of other techniques used to reduce the viscosity of the oil. This process can be far more expensive than traditional drilling and is found in high abundance only in Canada and Venezuela. As oil demand continues to rise, and reserves become depleted, oil sands could provide one of the last viable methods for extracting crude oil from the Earth.





While just about every country in the world depends on oil, not all countries produce it. The top five oil producing countries are: Saudi Arabia, Russia, United States, Iran, and China. It is important to note that the term production here refers to crude oil extracted from oil reserves. The top five oil consuming countries are: United States, China, Japan, Russia, and Germany.
At the current rate of consumption it is estimated that worldwide reserves will become extinguished by 2039. Scientists and engineers are working hard to find ways of more efficiently extracting and processing crude oil to delay what could become a global energy crisis.

Bitumen is oil that is too heavy or thick to flow or be pumped without being diluted or heated. At 10° C/50° F, bitumen is hard as a hockey puck. Some bitumen is found within 70 metres (200 feet) of the surface, but the majority is deeper underground.

Name:_____

Organic Chem Petrochemical Questions

1. What are the origins and sources of fossil fuels?

2. What are petrochemicals? Give some examples.

3. How are fossil fuels extracted and refined?

4. How are fossil fuels related to organic chemistry?

5. What are some uses of fossil fuels and their components?

6. All fossil fuels require some refining after being extracted from the ground. State the two major kinds of refining and describe how, in general, they are different.

7. Based upon Figure 2 on page 3 of the document, which are the most widespread fossil fuel deposits in Alberta? What fossil fuels found in Alberta are not depicted in Figure 2?

8. What is the historical relationship between research and development? Which group of people performed each of the R & D?

9. What technological infrastructure is necessary for processing and transporting fossil fuels?

10. Give an example of a trade-off between a positive and a negative consequence of fossil fuel production.

11. What are the main hydrocarbon families, and how do they differ?

12. List three renewable sources of energy naturally available in Alberta.

13. What kinds of energy sources do you use in your home and from what fossil fuels do they come?

14. What is fractional distillation used for in the petroleum industry?

15. What is diagenesis?

16. What is catagenesis?

17. What is another name for crude oil?
18. What other country besides Canada have oil sands and require strip mining and other techniques to reduce the viscosity of the oil to extract it?
19. At the current rate of consumption, when is it estimated that the oil reserve will run out?
20. What is bitumen?