1

History and Terminology of Crude Oil

Geology and time have created reservoirs of crude oil (petroleum) in various parts of the world. Until the mid-1800s, this vast untapped wealth lay mostly hidden below the surface of the earth. Some oil naturally seeped to the earth's surface and formed shallow pools that were used as a source of medicinal liquids, illuminating oil, and, after evaporation of the volatile components, as a caulking for boats and a building mastic (Speight, 2007). For centuries, demand was limited but better refining techniques and surging demand for kerosene and lubricants in the late 19th century changed this.

Crude oil is the major source of fuel used by people today. Because crude oil is liquid, it is easy to recover by drilling and pumping, rather than excavation, and it is easy to transport in tankers and pipelines. In fact, the rapid rise in crude prices in the past years has strengthened calls for renewed initiatives on energy security for petroleum importing countries. While there has been a convergence of factors contributing to the current high oil prices, oil supply and demand fundamentals, the role of speculative forces, and structural bottlenecks in the downstream sector have emerged as the main areas of concern.

The demand for gasoline and middle distillates (including aviation fuels) has risen significantly while refining capacity has only shown a modest increase, if any. This growth in demand over and above the increase in refining capacity has significantly raised refinery utilization rates and tightened the downstream market, raising serious concerns over a potential supply gap in the downstream oil market. This issue is particularly prevalent in the United States, where low surplus refining capacity and stringent oil product specifications have resulted in reduced flexibility in the refining sector to adjust to changes in seasonal demand patterns.

The economics of oil must take into account that it is a depleting non-renewable resource and the cost of extraction of a non-renewable resource depends not only on the current rate of production but also on the amount of cumulative production. Crude oil prices behave much as any other commodity with wide price swings in times of shortage or oversupply. The crude oil price cycle may extend over several years responding to changes in demand as well as supply. Many pundits believe that the projections of running out of oil are based on geology, not price. Every existing oil reservoir has more than half of the original oil in place, many with more. These are resources that we know exist; we know where they are and what the oil looks like. Much of the crude oil that is left is trapped in tiny pores and cannot be recovered by simple pumping, and more advanced and expensive procedures are necessary to recover the crude oil.

Another aspect of crude oil economics is the cost of refining. Refining high-sulfur crude oil also requires greater expenditures for energy. In fact, energy accounts for approximately half of the refinery cost. Refinery location is yet another variable. The closer a refinery is to the crude oil source and the demand, the lower the transportation costs . Otherwise, the refinery must factor in the added cost of getting the products to market. Obviously, the ultimate variable in crude oil economics is the price of crude oil. Crude oil quality is another key variable. High viscosity, high-sulfur crude oil can cost up to one-third less than low viscosity, low-sulfur crude oil. However, because high-sulfur crude oil requires more processing, refineries that buy primarily cheap crude oil incurs more fixed expenses for equipment and labor.

While there is a growing need to address these issues, there exist barriers and constraints to the older oil person and the neophyte alike, as well as the economist. Often the terminology employed by the industry is so confusing that the ensuing issues and the issues involved in oil pricing and oil product pricing are a mystery. In addition, many economists are unable to explain the economics of oil and oil product pricing without recourse to higher mathematics. The result is the development of complex equations that are often difficult to understand, and, for the technical person in industry, appear to bear little relationship to what he understands in terms of oil properties.

Thus, it is appropriate to commence this book with a description of the historical uses of crude oil and crude oil terminology, leading the reader to a better understanding of the terminology of crude oil and the means by which it is described.

1.1 Historical Perspectives

Petroleum is the most important raw material used in modern society insofar as it provides not only raw materials for fuel manufacture and energy, but also starting materials for plastics and other products.

The word *petroleum*, derived from the Latin *petra* and *oleum*, literally means *rock oil* and refers to hydrocarbons that occur widely in the sedimentary rocks in the form of gases, liquids, semisolids, or solids. From a chemical standpoint, petroleum is an extremely complex mixture of hydrocarbon compounds, usually with minor amounts of nitrogen-, oxygen-, and sulfur-containing compounds, as well as varying amounts of metal-containing compounds (Speight, 2007).

The fuels that are derived from petroleum supply more than half of the world's total supply of energy. Gasoline, kerosene, and diesel oil provide fuel for automobiles, tractors, trucks, aircraft, and ships. Fuel oil and natural gas are used to heat homes and commercial buildings, as well as to generate electricity. Petroleum products are the basic materials used for the manufacture of synthetic fibers for clothing and in plastics, paints, fertilizers, insecticides, soaps, and synthetic rubber. The uses of petroleum as a source of raw material in manufacturing are central to the functioning of modern industry.

Petroleum is a carbon-based resource, so the geochemical carbon cycle is also of interest to fossil fuel usage in terms of petroleum formation, use, and the buildup of atmospheric carbon dioxide. Thus, the more efficient use of petroleum is of paramount importance. Petroleum technology, in one form or another, will be with us until suitable alternative forms of energy are readily available (Boyle, 1996; Ramage, 1997). Therefore, a thorough understanding of the benefits and limitations of petroleum recovery and processing is necessary, and hopefully can be introduced within the pages of this book.

The history of any subject is the means by which the subject is studied in the hopes that much can be learned from the events of the past. In the current context, the occurrence and use of petroleum, petroleum derivatives (naphtha), heavy oil, and bitumen is not new. The use of petroleum and its derivatives was practiced in pre-Christian times and is known largely through historical use in many of the older civilizations (Henry, 1873; Abraham, 1945; Forbes, 1958a, 1958b; James and Thorpe, 1994; Krishnan and Rajagopal, 2003). Thus, the use of petroleum and the development of related technology is not such a modern subject as we are inclined to believe. However, the petroleum industry is essentially a 20th century industry but to understand the evolution of the industry, it is essential to have a brief understanding of the first uses of petroleum.

The Tigris-Euphrates valley, in what is now Iraq, was inhabited as early as 4000 BC by the people known as the Sumerians, who established one of the first great cultures of the civilized world. The Sumerians devised the cuneiform script, built the temple towers known as ziggurats, an impressive law, literature, and mythology. As the culture developed, bitumen or asphalt was frequently used in construction and in ornamental works.

Although it is possible to differentiate between the words *bitumen* and *asphalt* in modern use, the occurrence of these words in older texts offers no such possibility. It is significant that the early use of bitumen was in the nature of cement for securing or joining together various objects, and it therefore seems likely that the name itself was expressive of this application.

The word *asphalt* is derived from the Akkadian term *asphaltu* or *sphallo*, meaning *to split*. It was later adopted by the Homeric Greeks in the form of the adjective ασφαλής ες signifying *firm, stable, secure*, and the corresponding verb ασφαλίζω ίσω meaning *to make firm or stable, to secure*. Just like bitumen, the first use of asphalt by the ancients was in the nature of cement for securing or joining together various objects, such as the bricks used for building, so it seems likely that the name itself was also expressive of this application. From the Greek, the word passed into Latin (*asphaltum, aspaltum*), and thence into French (*asphalte*) and English (*aspaltoun*).

The origin of the word *bitumen* is more difficult to trace and subject to considerable speculation. The word was proposed to have originated in the Sanskrit, where we find the words *jatu*, meaning *pitch*, and *jatukrit*, meaning *pitch creating*. From the Sanskrit, the word *jatu* was incorporated into the Latin language as *gwitu* and is believed to have eventually become *gwitumen* (pertaining to pitch). Another word, *pixtumen* (exuding or bubbling pitch) is also reputed to have been in the Latin language, although the construction of this Latin word form from which the word *bitumen* was reputedly derived, is certainly suspect. There is the suggestion that subsequent derivation of the word led to a shortened version, which eventually became the modern version, called *bitumen*, thence passing via French into English. From the same root is derived the Anglo Saxon word *cwidu* (mastic, adhesive), the German work *kitt* (cement or mastic) and the equivalent word *kvada*, which is found in the old Norse language as being descriptive of the material used to waterproof the long ships and other sea-going vessels. It is just as likely that the word is derived from the Celtic *bethe* or *beithe* or *bedw* that was the birch tree that was used as a source of resin. The word appears in Middle English as *bithumen*. In summary, a variety of terms exist in ancient language that from their described use in texts can be proposed as meaning bitumen or asphalt (Abraham, 1945).

Using these ancient words as a guide, it is possible to trace the use of petroleum and its derivatives as described in ancient texts. And, preparing derivatives of petroleum was well within the area of expertise of the early scientists since alchemy (early chemistry) was known to consist of four sub-routines: dissolving, melting, combining, and distilling (Cobb and Goldwhite, 1995).

Early references to petroleum and its derivatives occur in the Bible, although by the time the various books of the Bible were written, the use of petroleum and bitumen was established and it is apparent that bitumen and petroleum derivatives were items of commerce. The exact prices paid are unknown and may even have been given as a tribute to the local king. Nevertheless, in spite of the missing monetary values, these writings do offer documented examples of the use and trade of petroleum and related materials.

For example, in the Epic of Gilgamesh written more than 2,500 years ago, a great Flood causes the hero to build a boat that is caulked with bitumen and pitch (see for example, Kovacs, 1990). And, in a related story of Mesopotamia, just prior to the flood, Noah is commanded to build an ark that also includes instructions for caulking the vessel with pitch (Genesis 6:14):

> Make thee an ark of gopher wood; rooms shalt thou make in the ark, and shalt pitch it within and without with pitch.

The occurrence of *slime* (bitumen) *pits* in the Valley of Siddim (Genesis, 14:10), a valley at the southern end of the Dead Sea, is reported. There is also reference to the use of tar as a mortar when the Tower of Babel was under construction (Genesis 11:3):

> And they said one to another, Go to, let us make brick, and burn them thoroughly. And they had brick for stone, and slime had they for mortar.

In the Septuagint, or Greek version of the Bible, this work is translated as *asphaltos,* and in the Vulgate or Latin version, as *bitumen.* In the Bishop's Bible of 1568 and in subsequent translations into English, the word is given as *slime.* In the Douay translation of 1600, it is *bitume,* while in Luther's German version, it appears as *thon,* the German word for clay.

Another example of the use of pitch (and slime) is given in the story of Moses (Exodus 2:3):

> And when she could no longer hide him, she took for him an ark of bulrushes, and daubed it with slime and with pitch, and put the child therein; and she laid it in the flags by the river's brink.

Perhaps the slime was a lower melting bitumen (bitumen mixed with solvent) whereas the pitch was a higher melting material; the one (*slime*) acting as a flux for the other. The lack of precise use of the words for bitumen and asphalt as well as for tar and pitch even now makes it unlikely that the true nature of the biblical tar, pitch, and slime will ever be known, but one can imagine their nature. In fact, even modern Latin dictionaries give the word bitumen as the Latin word for asphalt.

It is most probable that, in both these cases, the pitch and the slime were obtained from the seepage of oil to the surface, which was a fairly common occurrence in the area. And during biblical times, bitumen was exported from Canaan to various parts of the countries that surround the Mediterranean (Armstrong *et al.*, 1997).

In terms of liquid products, there is an interesting reference (Deuteronomy, 32:13) to bringing oil out of flinty rock. The exact nature of the oil is not described nor is the nature of the rock. The use of oil for lamps is also referenced (Matthew, 23:3), but whether it was mineral oil (a petroleum derivative such as naphtha) or whether it was vegetable oil is not known.

Excavations conducted at Mohenjo-Daro, Harappa, and Nal in the Indus Valley indicated that an advanced form of civilization existed there. An asphalt mastic composed of a mixture of asphalt, clay, gypsum, and organic matter was found between two brick walls in a layer about 25 mm thick — probably a waterproofing material. Also unearthed was a bathing pool that contained a layer of mastic on the outside of its walls and beneath its floor.

In the Bronze Age, dwellings were constructed on piles in lakes close to the shore to better protect the inhabitants from the ravages of wild animals and attacks from marauders. Excavations have shown that the wooden piles were preserved from decay by a coating of asphalt, and posts preserved in this manner have been found in Switzerland. There are also references to deposits of bitumen at Hit (the ancient town of Tuttul on the Euphrates River in Mesopotamia) and the bitumen from these deposits was transported to Babylon for use in construction (Herodotus, *The Histories*, Book I). There is also reference to a Carthaginian story in which birds' feathers smeared with pitch are used to recover gold dust from the waters of a lake (Herodotus, *The Histories*, Book IV).

One of the earliest recorded uses of asphalt was by the pre-Babylonian inhabitants of the Euphrates Valley in southeastern Mesopotamia, present-day Iraq, formerly called Sumer and Akkad and, later, Babylonia (Thompson, 1936; Moorey, 1994). In this region there are various asphalt deposits and the uses of the material have become evident. For example, King Sargon of Akkad (Agade c. 2550 BC) was set adrift by his mother in a basket of bulrushes on the waters of the Euphrates, where he was discovered by Akki the husbandman (irrigator), who brought him up to serve as gardener in the palace of Kish. Sargon eventually ascended to the throne.

On the other hand, the bust of Manishtusu, King of Kish, an early Sumerian ruler (about 2270 BC), was found in the course of excavations at Susa in Persia, and the eyes, composed of white limestone, are held in their sockets with the aid of bitumen.

Fragments of a ring composed of asphalt have been unearthed above the flood layer of the Euphrates at the site of the prehistoric city of Ur in southern Babylonia, ascribed to the Sumerians of about 3500 BC.

An ornament excavated from the grave of a Sumerian king at Ur consists of a statue of a ram with the head and legs carved out of wood over which gold foil was cemented by means of asphalt. The back and flanks of the ram are coated with asphalt in which hair was embedded. Another art of decoration consisted of beating thin strips of gold or copper, which were then fastened to a core of asphalt mastic. An alternative method was to fill a cast metal object with a core of asphalt mastic, and such specimens have been unearthed at Lagash and Nineveh. Excavations at Tell-Asmar, 50 miles northeast of Baghdad, revealed the use of asphalt by the Sumerians for building purposes.

Mortar composed of asphalt has also been found in excavations at Ur, Uruk, and Lagash, and excavations at Khafaje have uncovered floors composed of a layer of asphalt that has been identified as asphalt, mineral filler (loam, limestone, and marl), and vegetable fibers (straw). Excavations at the city of Kish (Persia) in the palace of King Ur-Nina showed that the foundations consist of bricks cemented together with an asphalt mortar. Similarly, in the ancient city of Nippur (about 60 miles south of Baghdad), excavations show Sumerian structures composed of natural stones joined together with asphalt mortar. Excavation has uncovered an ancient Sumerian temple in which the floors are composed of burnt bricks embedded in asphalt mastic that still shows impressions of reeds with which it must have been originally mixed.

The Epic of Gilgamesh, written before 2500 BC and transcribed on to clay tablets during the time of Ashurbanipal, king of Assyria (668 to 626 BC), make reference to the use of asphalt for building purposes. In the eleventh tablet, Ut-Napishtim relates the well-known story of the Babylonian flood, stating that "he "smeared the" inside of a boat with six sar of kupru and the outside with three sar..."

Kupru may have meant that the pitch or bitumen was mixed with other materials (perhaps even a solvent such as distillate from petroleum) to give it the appearance of slime as mentioned in the Bible. In terms of measurement, *sar* is a word of mixed origin and appears to mean an interwoven or wickerwork basket. An approximate translation is:

> The inside of the boat was smeared (coated, caulked) with six baskets full of pitch and the outside of the boat was smeared (coated, caulked) with three baskets full of pitch.

There are also indications from these texts that that asphalt mastic was sold by volume, or by the gur. On the other hand, bitumen was sold by weight — by the mina or shekel — for which there is no recorded price, although the word *shekel* is often used to mean a particular type of coinage as well as the weight of a commodity. In fact, the use of petroleum in seepages and bitumen from surface tar sand deposits seems to have been widely used and it is very likely that there was a ready trade for the raw material and the products made from petroleum and bitumen were actually looked upon as commodities (Barton, 1926; Sperber, 1976; Steinsaltz, 1977; Stern *et al.*, 2007). This is a situation that did not occur again until the 1980s (Chapter 5).

For example, use of asphalt by the Babylonians (1500 to 538 BC) is also documented. In fact, the Babylonians were well versed in the art of building, and each monarch commemorated his reign and perpetuated his name by the construction of a building or other monuments. The use of bitumen mastic as a sealant for water pipes, water cisterns, and in outflow pipes leading from flush toilets cities such as Babylon, Nineveh, Calah, and Ur has been observed and the bitumen lines are still evident (Speight, 1978).

Bitumen was used as mortar from very early times, and sand, gravel, or clay was employed in preparing these mastics. Asphalt-coated tree trunks were often used to reinforce wall corners and joints, for instance, in the temple tower of Ninmach in Babylon. In vaults or arches, a mastic-loam composite was used as mortar for the bricks, and the keystone was usually dipped in asphalt before being set in place. The use of bituminous mortar was introduced into the city of Babylon by King Hammurabi, but the use of bituminous mortar was abandoned toward the end of Nebuchadnezzar's reign in favor of lime mortar to which varying amounts of asphalt were added. The Assyrians recommended the use of asphalt for medicinal purposes, as well as for building purposes, and there is some merit in the fact that the Assyrian moral code recommended that asphalt, in the molten state, be poured onto the heads of delinquents. Pliny, the Roman author, also notes that bitumen could be used to stop bleeding, heal wounds, drive away snakes, treat cataracts as well as a wide variety of other diseases, and straighten out eyelashes that inconvenience the eyes. One can appreciate the use of bitumen to stop bleeding, but its use to cure other ailments is questionable and one has to consider what other agents were being used concurrently with bitumen.

The Egyptians were the first to adopt the practice of embalming their dead rulers and wrapping the bodies in cloth.

Before 1000 BC, asphalt was rarely used in mummification, except to coat the cloth wrappings and thereby protect the body from the elements. After the viscera had been removed, the cavities were filled with a mixture of resins and spices, the corpse immersed in a bath of potash or soda, dried, and finally wrapped. From 500 to about 40 BC, asphalt was generally used both to fill the corpse cavities and to coat the cloth wrappings. The word *mûmûia* first made its appearance in Arabian and Byzantine literature about 1000 AD, signifying bitumen. It is believed that it was the spread of the Islamic Empire that brought Arabic science and the use of bitumen to Western Europe.

In Persian, the term bitumen is believed to have acquired the meaning equivalent to paraffin wax that may be symptomatic of the nature of some of the crude oils in the area. Alternatively, it is also possible that the destructive distillation of bitumen to produce pitch produced paraffins that crystallized from the mixture over time. In Syriac, the term alluded to substances used for mummification. In Egypt, resins were used extensively for purposes of embalming up to the Ptolemaic period, when asphalts gradually came into use.

Arabian physician Al Magor used Mûmûia in prescriptions for the treatment of contusions and wounds as early as the 12th century. Its production soon became a special industry in the Alexandria. The scientist Al-Kazwînî alluded to the healing properties of mûmûia, and Ibn Al-Baitâr gives an account of its source and composition. In his treatise *Amoenitates Exoticae,* Engelbert Kämpfer (1651–1716) gives a detailed account of the gathering of mûmûia, the different grades and types, and its curative properties in medicine. As the supply of mummies was limited, other expedients came into vogue. The corpses of slaves or criminals were filled with asphalt, swathed, and artificially aged in the sun. This practice continued until the French physician, Guy de la Fontaine, exposed the deception in 1564 AD.

Many other references to bitumen occur throughout the Greek Empire and the Roman Empire, and from then to the Middle Ages, early scientists frequently alluded to the use of bitumen. In later times, both Christopher Columbus and Sir Walter Raleigh (depending upon the country of origin of the biographer) have been credited with the discovery of the asphalt deposit on the island of Trinidad and apparently used the material to caulk their ships.

The use of petroleum has also been documented in China; as early as 600 BC, petroleum was encountered when drilling for salt and mention of petroleum as an impurity in the salt is also noted in documents of the third century AD (Owen, 1975). It is presumed that the petroleum that contaminated the salt may be similar to that found in Pennsylvania and was, therefore, a more conventional type rather than the heavier type.

There was also an interest in the thermal product of petroleum (nafta; naphtha) when it was discovered that this material could be used as an illuminant and as a supplement to asphalt incendiaries in warfare. For example, there are records of the use of mixtures of pitch and/or naphtha with sulfur as a weapon of war during the Battle of Palatea, Greece, in the year 429 BC (Forbes, 1959). There are references to the use of a liquid material, naft (presumably the volatile fraction of petroleum, which we now call naphtha and is used as a solvent or as a precursor to gasoline as an incendiary material during various battles of the pre-Christian era (James and Thorpe, 1994). This is the so-called Greek fire, a precursor and chemical cousin to napalm. Greek fire is also recorded as being used in the period 674 to 678 when the city of Constantinople was saved by the use of the fire against an Arab fleet (Davies, 1996). In 717 to 718 AD, Greek fire was again used to save the city of Constantinople from attack by another Arab fleet, again with deadly effect (Dahmus, 1995). After this time, the Byzantine navy of three hundred triremes frequently used Greek fire against all comers (Davies, 1996). This probably represents the first documented use of the volatile derivatives of petroleum that led to a continued interest in petroleum.

Greek fire was a viscous liquid that ignited on contact with water and was sprayed from a pump-like device on to the enemy. One can imagine the early users of the fire attempting to ignite the liquid before hurling it towards the enemy.

However, the hazards that can be imagined from such tactics could become very real, and perhaps often fatal, to the users of the Greek fire if any spillage occurred before ejecting the fire towards the enemy. The later technology for the use of Greek fire most likely incorporated a heat-generating chemical such as quicklime (CaO) (Cobb and Goldwhite, 1995) that was suspended in the liquid and which, when coming into contact with water to produce $Ca(OH)_2$, released heat that was sufficient to cause the liquid to ignite. One can assume that the users of the fire were extremely cautious during periods of rain, or, if at sea, during periods of turbulent weather.

As an aside, the use of powdered lime in warfare is also documented. The English used it against the French on August 24, 1217 with disastrous effects for the French. As was usual for that time, there was a difference of opinion between the English and the French that resulted in their respective ships meeting at the east end of the English Channel. Before any other form of engagement could occur, the lime was thrown from the English ships and carried by the wind to the French ships, where it made contact with the eyes of the French sailors. The burning sensation in the eyes was too much for the French sailors and the English prevailed with the capture of much booty (Powicke, 1962).

The combustion properties of bitumen (and its fractions) were known in Biblical times. There is the reference to these properties (Isaiah, 34:9) when it is stated:

> *And the stream thereof shall be turned into pitch, and the dust thereof into brimstone, and the land thereof shall become burning pitch.* It shall not be quenched night nor day; the smoke thereof shall go up forever: from generation to generation it shall lie waste; none shall pass through it forever and forever.

One might surmise that the effects of the burning bitumen and sulfur (brimstone) were long-lasting and quite devastating.

Approximately 2,000 years ago, Arabian scientists developed methods for the distillation of petroleum, which were introduced into Europe by way of Spain. This represents another documented use of the volatile derivatives of petroleum that led to a continued interest in petroleum and its derivatives as medicinal and warfare materials, in addition to the usual construction materials.

From 1271 to 1273, Marco Polo also reported the Baku region of northern Persia as having an established commercial petroleum industry. It is believed that the prime interest was in the kerosene fraction that was then known for its use as an illuminant. By inference, it can be concluded that the distillation, and perhaps the thermal decomposition, of petroleum were established technologies. If not, Polo's diaries may well have contained a description of the stills or the reactors.

In addition, bitumen was investigated in Europe during the Middle Ages (Bauer, 1546, 1556), and the separation and properties of bituminous products were thoroughly described. Other investigations continued, leading to a good understanding of the sources and use of this material even before the birth of the modern petroleum industry (Forbes, 1958a, 1958b).

There are also records of the use of petroleum spirit, probably a higher boiling fraction of or than naphtha that closely resembled the modern-day liquid paraffin, for medicinal purposes. In fact, liquid paraffin has continued to be prescribed up to modern times. The naphtha of that time was obtained from shallow wells or by the destructive distillation of asphalt.

Parenthetically, the destructive distillation operation may be likened to modern coking operations in which the overall objective is to convert the feedstock into distillates for use as fuels. This particular interest in petroleum and its derivatives continued with an increasing interest in nafta (naphtha) because of its aforementioned used as an illuminant and as a supplement to asphaltic incendiaries for use in warfare.

Finally, not wishing to omit the use of bitumen (and, perhaps, its recognition as a tradable commodity), in the Americas, Pre-Hispanic Mesoamerican peoples collected, processed, and used bitumen as a decoration, a sealant and an adhesive (Wendt and Lu, 2006). Among the earliest to do so were the Olmec people (flourished ca. 1200 to 500 BC) of the Southern Coastal Lowlands of Mexico. Furthermore, geochemical analyses of bitumen from the Olmec archeological sites indicate a multiple procurement network that reflected wide trade and interactions between the various groups. It is also believed that bitumen processing was an organized and specialized activity involving multiple production stages (Wendt and Cyphers, 2008).

To continue such references is beyond the scope of this book, although they do give a flavor of the developing interest in petroleum. However, it is sufficient to note that there are many other references to the occurrence and use of bitumen or petroleum derivatives up to the beginning of the modern petroleum industry (Cook and Despard, 1927; Mallowan and Rose, 1935; Nellensteyn and Brand, 1936; Mallowan, 1954; Forbes, 1958a, 1958b, 1959, 1964; Marschner *et al.*, 1978).

In summary, the use of petroleum and related materials has been observed for almost 6,000 years. During this time, the use of petroleum has progressed from the relatively simple use of asphalt from

Mesopotamian seepage sites to the present-day refining operations that yield a wide variety of products and petrochemicals (Speight, 2007).

1.2 Modern Perspectives

The modern petroleum industry began in the later years of the 1850s with its discovery in 1857 and its subsequent commercialization in Pennsylvania in 1859 (Bell, 1945). The modern refining era can be said to have commenced in 1862 with the first appearance of a commercial unit for the distillation of petroleum (Speight, 2007) (Chapter 5).

Benjamin Silliman Sr. had a degree in law but he was also as qualified for geology as he was to be Yale professor of chemistry. The geology venture prospered, and by 1820, Silliman was in great demand for field trips on which he took his son, Benjamin Silliman Jr. When Silliman Sr. retired in 1853, Silliman Jr. took up where father had left off, as professor of general and applied chemistry at Yale (this time, with a degree in the subject). After writing a number of chemistry books and being elected to the National Academy of Sciences, Silliman Jr. took up lucrative consulting posts with the Boston City Water Company and various mining enterprises.

In 1855, one of his clients asked him to research and report on some mineral samples from the new Pennsylvania Rock Oil Company. After several months of work, Silliman Jr. announced that about 50% of the black tar-like substance could be distilled into first-rate burning oils (which would eventually be called kerosene and paraffin) and that an additional 40% of what was left could be distilled for other purposes, such as lubrication and gaslight.

With the acquisition of the original lighting oil (whale oil) seeing an increased demand and becoming more dangerous to acquire and on the basis of this report, a company was launched to finance the drilling of the Drake Well at Oil Creek, Pennsylvania. In 1857, it became the first well to produce petroleum. It would be another fifty years before Silliman Jr.'s reference to the other fractions available from the oil through extra distillation would provide gasoline for the combustion engine of the first automobile. Silliman Jr.'s report changed the world because it made possible an entirely new form of transportation and helped turn the United States into an industrial superpower. But, back to the future.

After completion of the first well by Edwin Drake, the surrounding areas were immediately leased and extensive drilling took place. Crude oil output in the United States increased from approximately 2000 barrels (1 barrel, bbl = 42 US gallons = 35 Imperial gallons = 5.61 foot^3 = 158.8 liters) in 1859 to nearly 3,000,000 barrels in 1863 and approximately 10,000,000 barrels in 1874. In 1861 the first cargo of oil, contained in wooden barrels, was sent across the Atlantic to London, and by the 1870s, refineries, tank cars, and pipelines had become characteristic features of the industry, mostly through the leadership of Standard Oil that was founded by John D. Rockefeller (Johnson, 1997). Throughout the remainder of the 19th century, the United States and Russia were the two areas in which the most striking developments took place.

At the outbreak of World War I in 1914, the two major producers of petroleum were the United States and Russia, but supplies of oil were also being obtained from Indonesia, Rumania, and Mexico. During the 1920s and 1930s, attention was also focused on other areas for oil production, such as the United States, the Middle East, and Indonesia. At this time, European and African countries were not considered major oil-producing areas. In the post-1945 era, Middle Eastern countries continued to rise in importance because of new discoveries of vast reserves. The United States, although continuing to be the biggest producer, was also the major consumer and not a key exporter of oil.

In the United States, approximately 20% of domestic production currently comes from marginal wells, which are the most vulnerable to low prices. Since 1998, domestic production has dropped to approximately 5.5 million barrels/day, with approximately twice that amount being imported.

At this time, oil companies are beginning to roam much farther afield in the search for oil, and, as a result, there have been significant discoveries in several countries.

1.3 Oil Companies

The term oil company is taken to mean a company that deals with the exploration, recovery, and refining of oil. Furthermore, in the United States, the term "big oil company" is taken to mean the major private international oil companies, largely based in Europe or North America (Pirog, 2007).

However, while some of those companies are indeed among the largest in the world, by many important measures, a majority of the largest oil companies are state-owned, national oil companies. By conventional definitions, national oil companies hold the majority of petroleum reserves and produce the majority of the world's supply of crude oil. Because national oil companies generally hold exclusive rights to the exploration and development of petroleum resources within the home country, they also can decide on the degree to which they require participation by private companies in those activities.

Rankings of oil companies can be based on current production (Table 1.1) to generate current earnings, and several standards need to be applied to assess the evolving nature of the companies in the industry to ensure the future viability of the enterprise on reserve positions (Table 1.2). Investment, in the form of exploration and development expenditures, serves as an indicator of the potential reserve and production positions of an oil company.

Privately held companies have the goal of maximizing shareholder value. The management of the company may accomplish

Table 1.1 Comparative ranking of the top ten oil companies based on current liquids production.

Rank 2006	Company	Production	Rank 2000	Company	Production
1	Saudi Aramco	11,035	1	Saudi Aramco	8,044
2	NIOC	4,049	2	NIOC	3,620
3	Pemex	3,710	3	Pemex	3,343
4	PDV	2,650	4	PDV	2,950
5	KPC	2,643	5	INOC	2,528
6	BP	2,562	6	ExxonMobil	2,444
7	ExxonMobil	2,523	7	Shell	2,268
8	PetroChina	2,270	8	PetroChina	2,124
9	Shell	2,093	9	BP	2,061
10	Sonotrach	1,934	10	KPC	2,025

Table 1.2 Comparative ranking of the top ten oil companies based on current reserve holdings.

Rank 2006	Company	Reserves	Rank 2000	Company	Reserves
1	Saudi Aramco	264,200	1	Saudi Aramco	259,200
2	NIOC	137,500	2	INOC	112,500
3	NIOC	115,000	3	KPC	96,500
4	KPC	101,500	4	NIOC	87,993
5	PDV	79,700	5	PDV	76,852
6	Adnoc	56,920	6	Adnoc	50,710
7	Libya NOC	33,235	7	Pemex	28,400
8	NNPC	21,540	8	Libya NOC	23,600
9	Lukoil	16,114	9	NNPC	13,500
10	QP	15,200	10	Lukoil	11,432

that goal through organizing production so that a profit is made in the current timeframe as well as in the future. The management may also make investment decisions to take advantage of opportunities to raise the company's rate of return. They also have the motivation to achieve productive efficiency to hold down costs and enhance the profitability of any given revenue level. This activity is thought to benefit consumers by assuring that physical shortages are avoided and that the good is available at the lowest price consistent with demand and supply factors.

1.4 Definitions and Terminology

Throughout the previous sections, definitions and terminology have been represented that give some insight into the terminology of the industry. However, there are many aspects of petroleum definitions and terminology that have not been covered and require further mention here because of the direct relationship to the pricing of petroleum and petroleum products.

Terminology is the means by which various subjects are named so that reference can be made in conversations and in writings and so that the meaning is passed on. Definitions are the means by which scientists and engineers communicate the nature of a material to each other and to the world, through either the spoken or the written word. Thus, the definition of a material can be extremely important and have a profound influence on how the technical community and the public perceive that material. In fact the definition of petroleum has been varied, unsystematic, diverse, and often archaic. Furthermore, the terminology of petroleum is a product of many years of growth. The long established use of an expression, however inadequate it may be, is altered with difficulty, and a new term is at best adopted slowly.

In general, the large reservoirs of light oil resources have been exploited first because larger reservoirs are easier to find and exploit and lighter oils are more valuable and require less energy to extract and refine to desirable products. Therefore, over time in mature regions, lower quality crude oil (often called heavy crude oil) has often required the exploitation of increasingly small, deep, and heavy offshore resources. Progressive depletion also means that oil in older fields that once came to the surface through natural drive mechanisms, such as gas pressure, must now be extracted using energy-intensive secondary and enhanced technologies. Another aspect of the quality of an oil resource is that oil reserves are normally defined by their degree of certainty and their ease of extraction, classed as proven, probable, possible or speculative. In addition, there are unconventional resources such as heavy oil, deep-water oil, tar sand bitumen (oil sand bitumen in Canada) and shale oil that are very energy intensive and costly to exploit.

However, the true reserves of a field will be known absolutely only on the day when it is finally abandoned — when cumulative production is know with the highest degree of certainty and subject only to counting errors. Prior to that, reserves are known only within a spectrum of uncertainty that should be expressed in terms of a probability range. The traditional method, which classifies reserves as proven, probable, or possible, tends to ignore the range of uncertainty, giving a single number for each class of reserves. The Securities and Exchange Commission only accepts the proven class for financial reporting purposes.

Petroleum is found in various countries (Table 1.3) and is scattered throughout the earth's crust, which is divided into natural

Table 1.3 Oil reserves by country (Billions of barrels, one billion = 1×10^9).

Country	Reserves* Barrels $\times 10^9$
Canada	179
Iran	126
Iraq	115
Kuwait	102
Russia	60
Saudi Arabia	262
United Arab Emirates	98
United States	21
Venezuela	79
Other	238

* Source: U.S. Energy information administration, 2006.

groups or strata, categorized in order of their antiquity (Speight, 2007). These divisions are recognized by the distinctive systems of organic debris (as well as fossils, minerals, and other characteristics), which form a chronological time chart that indicates the relative ages of the earth's strata. It is generally acknowledged that carbonaceous materials such as petroleum occur in all these geological strata from the Precambrian to the recent, and the origin of petroleum within these formations is a question that remains open to conjecture and the basis for much research.

Petroleum is by far the most commonly used source of energy, especially as the source of liquid fuels (Table 1.4). Indeed, because of the wide use of petroleum, the past 150 years could very easily be dubbed the Oil Century-and-a-Half, the Petroleum Era (c.f. the Pleistocene Era), or the New Rock Oil Age (c.f. the New Stone Age) (Ryan, 1998). For example, the United States imported approximately 6,000,000 barrels per day of petroleum and petroleum products in 1975 and now imports approximately double this amount. The majority of the products of a refinery are fuels (Pellegrino, 1998) and it is evident that this reliance on petroleum-based fuels

Table 1.4 Current and projected energy consumption scenarios (GRI, 1998).

Energy Consumption (quads)						
	1995	**1996**	**2000**	**2005**	**2010**	**2015**
	Actual		**Projected**			
Petroleum	34.7	36.0	37.7	40.4	42.6	44.1
Gas	22.3	22.6	23.9	26.3	28.8	31.9
Coal	19.7	20.8	22.3	24.1	26.2	29.0
Nuclear	7.2	7.2	7.6	7.4	6.9	4.7
Hydro	3.4	4.0	3.1	3.2	3.2	3.2
Other	3.2	3.3	3.7	4.0	4.8	5.2

and products will continue for several decades. As a result, fossil fuels are projected to be the major sources of energy for the next fifty years. In this respect, petroleum and its associates (heavy oil and residua) are extremely important in any energy scenario, especially those scenarios that relate to the production of liquid fuels.

Indeed, over the past two decades the quality of crude oil has deteriorated (Swain, 1991, 1993, 1998, 2000), which has caused the nature of refining to change considerably. This, of course, has led to the need to manage crude quality more effectively through evaluation and product slates (Waguespack and Healey, 1998; Speight, 2007). Indeed, the declining reserves of lighter crude oil have resulted in an increasing need to develop options to desulfurize and upgrade the heavy feedstocks, specifically heavy oil and bitumen (Speight, 2008). This has resulted in a variety of process options that specialise in sulfur removal during refining. Though it will not be covered in this text, it is worthy of note that microbial desulfurization is being assiduously investigated as a recognised commercial technology for desulfurization (Monticello, 1995; Armstrong *et al.*, 1997).

With the necessity of processing heavy oil, bitumen, and residua to obtain more gasoline and other liquid fuels, there has been the recognition that knowledge of the constituents of these higher boiling feedstocks is also of some importance. Indeed, the problems encountered in processing the heavier feedstocks can be equated to the chemical character and the amount of complex, higher-boiling constituents in the feedstock. Refining these materials is not just a matter of applying know-how derived from refining conventional crude oils, but also requires knowledge of the chemical behavior of these more complex constituents. Furthermore, although the elemental analysis of tar sand bitumen has also been widely reported (Wallace *et al.*, 1988; Speight, 1990), the data often suffers from the disadvantage that identification of the source is too general and not always site specific.

With all of the scenarios in place, there is no doubt that petroleum and its relatives: residua, and heavy oil, as well as tar sand bitumen will be required to produce a considerable proportion of liquid fuels into the foreseeable future. Desulfurization processes will be necessary to remove sulfur in an environmentally acceptable manner to produce environmentally acceptable products. Refining strategies will focus on upgrading the heavy oils and residua and will emphasize the differences between the properties of the feedstocks. This will dictate the choice of methods or combinations thereof for the conversion of these materials to products (Schuetze and Hofmann, 1984).

Because of the need for a thorough understanding of petroleum and the associated technologies, it is essential that the definitions and terminology of petroleum science and technology be given prime consideration. This will aid in a better understanding of petroleum, its constituents, and its various fractions. Of the many forms of terminology that have been used, not all have survived, but the more commonly used are illustrated here. Particularly troublesome and more confusing are those terms that are applied to the more viscous materials, including the use of the terms *bitumen* and *asphalt*. This part of the text attempts to alleviate much of the confusion that exists, but it must be remembered that the terminology of petroleum is still open to personal choice and historical usage.

1.4.1 Petroleum

When petroleum occurs in a reservoir that allows the crude material to be recovered by pumping operations as a free-flowing dark to light colored liquid, it is often referred to as conventional petroleum.

Petroleum is a naturally occurring mixture of diverse hydrocarbons whose physical and chemical qualities reflect the different origins and, especially, different degrees of natural processing of these hydrocarbons (Speight, 2007, 2008). In fact, the term petroleum covers a wide assortment of materials consisting of mixtures of hydrocarbons and other compounds containing variable amounts of sulfur, nitrogen, and oxygen, which may vary widely in volatility, specific gravity, and viscosity. Metal-containing constituents, notably those compounds that contain vanadium and nickel, usually occur in the more viscous crude oils in amounts up to several thousand parts per million, and can have serious consequences during processing of these feedstocks (Speight, 2007). Because petroleum is a mixture of widely varying constituents and proportions, its physical properties also vary widely and the color from colorless to black.

There is also another type of petroleum that is different from the conventional petroleum insofar as they are much more difficult to recover from the subsurface reservoir. This material, or heavy oil, has a much higher viscosity and lower API gravity than conventional petroleum and recovery of heavy oil usually requires thermal stimulation of the reservoir (Speight, 2007; Speight, 2008).

The majority of crude oil reserves identified to date are located in a relatively small number of very large fields, known as giants. In fact, approximately 300 of the largest oil fields contain almost 75% of the available crude oil. Although most of the world's nations produce at least minor amounts of oil, the primary concentrations are in the Persian Gulf, North and West Africa, the North Sea, and the Gulf of Mexico. In addition, of the 90 oil-producing nations, five Middle Eastern countries contain almost 70% of the current, known oil reserves.

For many years, petroleum and heavy oil were very generally defined in terms of physical properties. For example, heavy oils were considered to be those crude oils that had gravity somewhat less than 20°API with the heavy oils falling into the API gravity range 10 to 15°. For example, Cold Lake heavy crude oil has an API gravity equal to 12°, and tar sand bitumen usually has an API gravity in the range 5–10° (Athabasca bitumen = 8°API). Residua would vary depending upon the temperature at which distillation was terminated, but usually vacuum residua fall into the approximate range 2 to 8°API. However, the classification of crude oil by the use of a single physical property is subject to the errors inherent in the analytical method (by which the property is determined) and must be used with caution (Chapter 4).

1.4.2 Natural Gas

The generic term natural gas applies to gases commonly associated with petroliferous (petroleum-producing, petroleum-containing) geologic formations. Natural gas generally contains high proportions of methane (a single carbon hydrocarbon compound, CH_4) and some of the higher molecular weight higher paraffins (C_nH_{2n+2}) generally containing up to six carbon atoms may also be present in small quantities (Table 1.5). The hydrocarbon constituents of natural gas are combustible, but non-flammable non-hydrocarbon components such as carbon dioxide, nitrogen, and helium are often present in the minority and are regarded as contaminants.

In addition to the natural gas fund in petroleum reservoirs, there are also those reservoirs in which natural gas may be the sole occupant. The principal constituent of natural gas is methane, but other hydrocarbons, such as ethane, propane, and butane, may also be present. Carbon dioxide is also a common constituent of natural gas. Trace amounts of rare gases, such as helium, may also occur, and certain natural gas reservoirs are a source of these rare gases. Just as petroleum can vary in composition, so can natural gas. Differences in natural gas composition occur between different reservoirs, and

Table 1.5 Constituents of natural gas.

Name	Formula	Vol. %
Methane	CH_4	>85
Ethane	C_2H_6	3–8
Propane	C_3H_8	1–5
Butane	C_4H_{10}	1–2
Pentane$^+$	C_5H_{12}	1–5
Carbon dioxide	CO_2	1–2
Hydrogen sulfide	H_2S	1–2
Nitrogen	N_2	1–5
Helium	He	<0.5

Pentane$^+$: pentane and higher molecular weight hydrocarbons, including benzene and toluene.

two wells in the same field may also yield gaseous products that are different in composition (Speight, 1990).

Natural gas (also called *marsh gas* and *swamp gas* in older texts and more recently *landfill gas*) is a gaseous fossil fuel that is found in oil reservoirs, natural gas reservoirs, coal seams. It is a vital component of the world's supply of energy. It is one of the cleanest, safest, and most useful of all energy sources. While it is commonly grouped in with other fossil fuels and sources of energy, there are many characteristics of natural gas that make it unique.

Natural gas is the result of the decay of animal remains and plant remains, or organic debris, that has occurred over millions of years. Over time, the mud and soil that covered the organic debris changed to rock and trapped the debris beneath the newly formed rock sediments. Pressure, and to some extent, heat (as yet undefined) changed some of the organic material into coal, some into oil (petroleum), and some into natural gas. Whether or not the debris formed coal, petroleum, or gas depended upon the nature of the debris and the localized conditions under which the changes occurred.

Natural gas has been known for many centuries, but its initial use was probably more for religious purposes rather than as a fuel. For example, gas wells were an important aspect of religious life in ancient Persia because of the importance of fire in their religion. In classical times, these wells were often flared and must have been awe-inspiring (Scheil and Gauthier, 1909; Schroder, 1920; Lockhart, 1939; Forbes, 1964). Furthermore, just as petroleum was used in antiquity, natural gas was also known in antiquity. However, the use of petroleum has been relatively well documented because of its use in warfare and as mastic for walls and roads (Henry, 1873; Abraham, 1945; Forbes, 1958a, 1958b; James and Thorpe, 1994).

Natural gas was first discovered in the United States in Fredonia, New York, in 1821. In the years following this discovery, natural gas usage was restricted to its environs because the technology for storage and transportation (bamboo pipes notwithstanding) was not well developed and, at that time, natural gas had little or no commercial value. In fact, in the 1930s when petroleum refining was commencing — an expansion in technology that is still continuing — natural gas was not considered a major fuel source and was only produced as an unwanted by-product of crude oil production and/or refining. It is only during the last several decades that natural gas has been seen as a major contributor to energy production.

There are several general definitions that have been applied to natural gas. For example, associated or dissolved natural gas occurs either as free gas or as gas in solution in the petroleum. Gas that occurs as a solution in the petroleum is dissolved gas, whereas the gas that exists in contact with the petroleum (gas cap) is associated gas. In addition, lean gas is gas in which methane is the major constituent and wet gas contains considerable amounts of the higher molecular weight hydrocarbons. Sour gas contains hydrogen sulfide, whereas sweet gas contains very little, if any, hydrogen sulfide. In direct contrast to the terminology of the petroleum industry where the residue (residuum, resid) is the high boiling material left after distillation, residue gas is natural gas from which the higher molecular weight (higher boiling) hydrocarbons have been extracted and so is the lowest boiling hydrocarbon in natural gas. Finally casing head gas (casinghead gas) is derived from petroleum, but is separated at the well-head separation facility.

To further define the terms dry and wet in quantitative measures, the term dry natural gas indicates that there is less than 0.1 gallon (1 gallon, US, = 264.2 m^3) of gasoline vapor (higher molecular weight paraffins) per 1000 ft^3 (1 ft^3 = 0.028 m^3). The term wet natural gas indicates that there are such paraffins present in the gas — in fact, more than 0.1 gal/1000 ft^3.

Other components such as carbon dioxide (CO_2), hydrogen sulfide (H_2S), mercaptans (thiols; R-SH), as well as trace amounts of other constituents may also be present. Thus, there is no single organization of components that maybe termed typical natural gas.

1.4.3 Heavy Oil

Heavy oil is a type of petroleum that is different from conventional petroleum insofar as it is much more difficult to recover from the subsurface reservoir and has a much higher viscosity (and lower API gravity) than conventional petroleum, and primary recovery of heavy oil usually requires thermal stimulation of the reservoir.

Petroleum and heavy oil have been very generally defined in terms of physical properties (Section 1.2). For example, heavy oil was considered to be crude oil that had gravity somewhat less than 20°API with tar sand bitumen falling into the API gravity range <10°. For example, Cold Lake heavy crude oil has an API gravity equal to 12° and tar sand bitumen, usually has an API gravity in the range of 5–10° (Athabasca bitumen = 8°API). However, classification of crude oil by the use of a single physical property is subject to the errors inherent in the analytical method by which the property is determined and must be used with caution (Chapter 4).

While conventional crude oil flows naturally and can be pumped without being heated or diluted, heavy crude oil usually requires thermal stimulation to cause recovery. In fact, a more appropriate definition of heavy oil is that it is it is recoverable in its natural state by conventional oil well production methods including currently used enhanced recovery techniques. By analogy, tar sand bitumen it is not recoverable in its natural state using enhanced (tertiary) recovery techniques (Section 5.4).

The term extra heavy oil has been introduced fairly recently without reasonable justification and often serves to confuse the real issues of nomenclature. It is used to define the material (such as tar sand bitumen) that occurs in the near-solid state and is incapable of free flow under ambient conditions. Yet a definition of such material has been available for four decades (Section 1.5) and use of the term extra heavy oil only serves to confuse matters even further by introducing another unknown in the simple arena of terminology and definitions.

1.4.4 Tar Sand Bitumen

Throughout this text, frequent reference is made to tar sand bitumen, but because commercial operations have been in place for over 40 years (Spragins, 1978; Speight, 1990) it is not surprising that more is known about the Alberta, Canada tar sand reserves than any other reserves in the world. Therefore, when discussion is made of tar sand deposits, reference is made to the relevant deposit, but when the information is not available, the Alberta material is used for the purposes of the discussion.

The term bitumen (also, on occasion, referred to as native asphalt) includes a wide variety of naturally occurring reddish brown to black materials of semisolid, viscous to brittle character that can exist in nature with no mineral impurity or with mineral matter contents that exceed 50% by weight. Bitumen is frequently found filling pores and crevices of sandstone, limestone, or argillaceous sediments, in which case the organic and associated mineral matrix is known as rock asphalt (Abraham, 1945; Hoiberg, 1964). Tar sand bitumen is a high-boiling material with little, if any, material boiling below 350°C (660°F). The term oil sand is also used in the same way as the term tar sand, and these terms are used interchangeably throughout this text.

Bitumen is also a common term used in many European countries for the mastic that makes up road asphalt — a mixture of asphalt and aggregate. The term bitumen is not used in any such sense in this book.

Furthermore, it is incorrect to refer to naturally occurring bitumen as tar or pitch. Although the word tar is somewhat descriptive of the black bituminous material, it is best to avoid its use with respect to natural materials. More correctly, the name tar is usually applied to the heavy product remaining after the destructive distillation of coal or other organic matter. Pitch is the distillation residue of the various types of tar. Alternative names, such as bituminous sand or oil sand, are gradually finding usage, with the former name more technically correct.

For the purposes of this text, the definition of tar sand bitumen is derived from the definition of tar sand that has been defined by the United States government (FE-76-4):

> [Tar sands]...the several rock types that contain an extremely viscous hydrocarbon which is not recoverable in its natural state by conventional oil well production methods including currently used enhanced recovery techniques. The hydrocarbon-bearing rocks are variously known as bitumen-rocks oil, impregnated rocks, oil sands, and rock asphalt.

By inference, heavy oil (Section 3.1) is a resource that can be recovered in its natural state by conventional oil well production methods including currently used enhanced recovery techniques. The term natural state means without conversion of the heavy oil or bitumen as might occur during thermal recovery processes.

Because of the diversity of available information and the continuing attempts to delineate the various world tar sand deposits, it is virtually impossible to present accurate numbers that reflect the extent of the reserves in terms of the barrel unit. The term extra heavy oil (Section 1.4) is often invoked without explanation or adequate description, leaving the reserves of heavy oil and tar sand bitumen open to speculation. Indeed, investigations into the extent of many of the world's deposits are continuing at such a rate that the numbers vary from one year to the next. Accordingly, the data quoted here must be recognized as approximate with the potential of being quite different at the time of publication.

Nevertheless, whatever numbers are used, bitumen in tar sand deposits represent a potentially large supply of energy (Chapter 2). However, many of these reserves are only available with some difficulty and optional refinery scenarios will be necessary for conversion of these materials to low-sulfur liquid products because of the substantial differences in character between conventional petroleum and tar sand bitumen. Bitumen recovery requires the prior application of reservoir fracturing procedures before the introduction of thermal recovery methods. Currently, commercial operations in Canada use mining techniques for bitumen recovery.

Even though tar sand deposits are widely distributed throughout the world (Speight, 1990, 2007), the fact that commercialization has taken place in Canada does not mean that commercialization is imminent for other tar sands deposits. There are considerable differences between the Canadian and the US deposits that could preclude across-the-board application of the Canadian principles to the US sands (Speight, 1990). Whilst Canadian scientist and engineers know much about the Athabasca (Alberta) deposits, the knowledge is not generally applicable to other deposits — the key is site specificity in terms of accessibility and recoverability.

1.5 References

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