1

Energy Sources and Energy Supply

1.1 Introduction

The Earth contains a finite supply of fossil fuels – the major fossil fuels are natural gas, crude oil, and coal – although there are debates related to the actual amounts of these fossil fuels remaining and the time left for use of these fuels (Speight, 2011c; Speight and Islam, 2016). In fact, at the present time, the majority of the energy consumed worldwide is produced from the fossil fuels (crude oil: approximately 38 to 40%, coal: approximately 31 to 35%, natural gas: approximately 20 to 25%) with the remainder of the energy requirements to come from nuclear sources and from hydroelectric sources. As a result, fossil fuels (in varying amounts depending upon the source of information) are projected to be the major sources of energy for the next fifty years (Crane *et al.*, 2010; World Energy Council, 2008; Gudmestad *et al.*, 2010; Speight, 2011a, 2011b, Khoshnaw, 2013; BP, 2014; Speight, 2014a; BP, 2019).

The current estimates for the longevity of each fossil fuel is estimated from the reserves/production ratio (BP, 2019) which gives an indication (in years) of how long each fossil fuel will last at the current rates of production. The estimates vary from at least fifty years of crude oil at current rates of consumption with natural gas varying upwards of 100 years. On the other hand, coal remains in adequate supply and at current rates of recovery and consumption, the world global coal reserves have been variously estimated to have a reserves/production ratio of at least 155 years. However, as with all estimates of resource longevity, coal longevity is subject to the assumed rate of consumption remaining at the current rate of consumption and, moreover, to technological developments that dictate the rate at which the coal can be mined. But most importantly, coal is a fossil fuel and an *unclean* energy source that will only add to global warming. In fact, the next time electricity is advertised as a clean energy source just consider the means by which the majority of electricity is produced – almost 50% of the electricity generated in the United States derives from coal (EIA, 2007; Speight, 2013).

In addition, the amounts of natural gas and crude oil located in tight sandstone formations and in shale formations has added a recent but exciting twist to the amount of these fossil fuels remaining. Peak energy theory proponents are inclined to discount the tight formations and shale formation as a mere aberration (or a hiccup) in the depletion of these resources while opponents of the peak energy theory take the opposite view and consider tight formations and shale formations as prolonging the longevity of natural gas and crude oil by a substantial time period (Speight and Islam, 2016). In addition, some areas of the Earth are still relatively unexplored or have been poorly analyzed and (using crude oil as the example) knowledge of in-ground resources increases dramatically as an oil reservoir is exploited.

James G. Speight. Handbook of Gasification Technology: Science, Processes, and Applications, (3–34)

Energy sources have been used since the beginning of recorded history and the fossil fuel resources will continue to be recognized as major sources of energy for at least the foreseeable future (Crane *et al.*, 2010; World Energy Council, 2008; Gudmestad *et al.*, 2010; Speight, 2011a, 2011b, Khoshnaw, 2013; Speight, 2014a; BP, 2019). Fossil fuels are those fuels, namely natural gas, crude oil (including heavy crude oil), extra heavy crude oil, tar sand bitumen, coal, and oil shale produced by the decay of plant remains over geological time represent an unrealized potential, with liquid fuels from crude oil being only a fraction of those that could ultimately be produced from heavy oil and tar sand bitumen (Speight, 1990, 1997, 2011a; 2013d, 2013e, 2014a).

Fuels from fossil fuels (especially the crude oil-based fuels) are well-established products that have served industry and domestic consumers for more than one hundred years and for the foreseeable future various fuels will still be largely based on hydrocarbon fuels derived from crude oil. Although the theory of peak oil is questionable (Speight and Islam, 2016), there is no doubt that crude oil, once considered inexhaustible, is being depleted at a measurable rate. The supposition by peak oil proponents is that supplies of crude oil are approaching a precipice in which fuels that are currently available may, within a foreseeable short time frame, be no longer available. While such a scenario is considered to be unlikely, the need to consider alternate technologies to produce liquid fuels that could mitigate the forthcoming effects of the shortage of transportation fuels is necessary and cannot be ignored.

Alternate fuels produced from source other than crude oil are making some headway into the fuel demand. For example, diesel from plant sources (biodiesel) is similar in performance to diesel from crude oil and has the added advantage of a higher cetane rating than crude oil-derived diesel. However, the production of liquid fuels from sources other than crude oil has a checkered history. The on-again-off-again efforts that are the result of the inability of the political decision-makers to formulate meaningful policies has caused the production of non-conventional fuels to move slowly, if at all (Yergin, 1991; Bower, 2009; Wihbey, 2009; Speight, 2011a, 2011b, Yergin, 2011; Speight, 2014a).

In the near term, the ability of conventional fuel sources and technologies to support the global demand for energy will depend on how efficiently the energy sector can match available energy resources (Figure 1.1) with the end user and how efficiently and cost effectively the energy can be delivered. These factors are directly related to the continuing evolution of a truly global energy market. In the long term, a sustainable energy future cannot be created by treating energy as an independent topic (Zatzman, 2012). Rather, the role of the energy and the inter-relationship of the energy market with other markets and the various aspects of market infrastructure demand further attention and consideration. Greater energy efficiency will depend on the developing the ability of the world market to integrate energy resources within a common structure (Gudmestad *et al.*, 2010; Speight, 2011b; Khoshnaw, 2013).

As the 21st Century matures, there will continue to be an increased demand for energy to support the needs of commerce industry and residential uses – in fact, as the 2040 to 2049 decade approaches, commercial and residential energy demand is expected to rise by considerably – by approximately 30 percent over current energy demand. This increase is due, in part, to developing countries, where national economies are expanding and the move away from rural living to city living is increasing. In addition, the fuel of the rural population (biomass) is giving way to the fuel of the cities (transportation fuels, electric

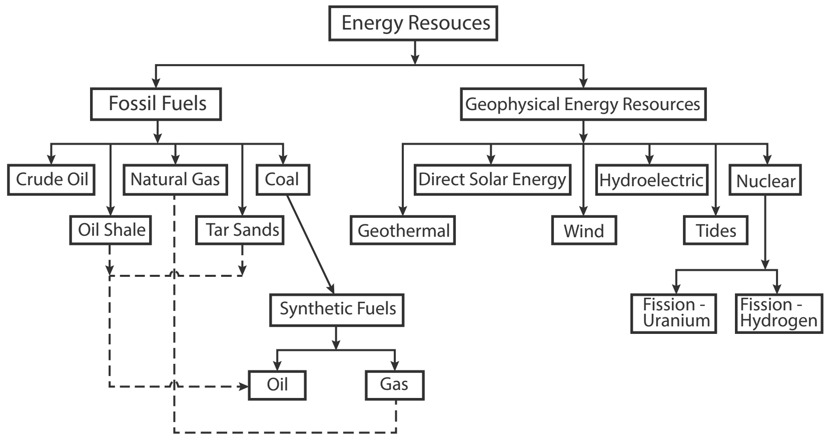

Figure 1.1 Types of energy resources.

power) as the life-styles of the populations of developing countries changed from agrarian to metropolitan. Furthermore, the increased population of the cities requires more effective public transportation systems as the rising middle class seeks private means of transportation (automobiles). As a result, fossil fuels will continue to be the predominant source of energy for at least the next fifty years.

However, there are several variables that can impact energy demand from fossil fuels. For example, coal (as a source of electrical energy) faces significant challenges from governmental policies to reduce greenhouse gas emissions and fuels from crude oil can also face similar legislation (Speight, 2013a, 2013b, 2014a) in addition to the types of application and use, location and regional resources, cost of energy, cleanness and environmental factors, safety of generation and utilization, socioeconomic factors, as well as global and regional politics (Speight, 2011a). More particularly, the recovery of natural gas and crude oil from tight sandstone and shale formations face challenges related to hydraulic fracturing.

Briefly, hydraulic fracturing is an extractive method used by crude oil and natural gas companies to open pathways in tight (low-permeability) geologic formations so that the oil or gas trapped within can be recovered at a higher flow rate (Speight, 2015a). When used in combination with horizontal drilling, hydraulic fracturing has allowed industry to access natural gas reserves previously considered uneconomical, particularly in shale formations. Although, hydraulic fracturing creates access to more natural gas supplies, but the process requires the use of large quantities of water and fracturing fluids, which are injected underground at high volumes and pressure. Oil and gas service companies design fracturing fluids to create fractures and transport sand or other granular substances to prop open the fractures. The composition of these fluids varies by formation, ranging from a simple mixture of water and sand to more complex mixtures with a multitude of chemical additives. Hydraulic fracturing has opened access to vast domestic reserves of natural gas that could provide an important stepping stone to a clean energy future. Yet questions related to the safety of hydraulic fracturing persist and the technology has been the subject of both enthusiasm and increasing environmental and health concerns in recent years, especially in relation to the possibility (some would say *reality*) of contaminated drinking water because of the chemicals used in the process and the disturbance of the geological formations (Speight, 2015a).

It is the purpose of this chapter to present to the reader an overview of the current energy sources and, hence, the need for other sources of fuels and chemicals. Therefore, a brief comment related to each of the potential energy sources is presented below. In addition, the potential for the gasification of carbonaceous feedstocks is also presented as an option for the production of fuels and chemicals (Speight, 2019a).

1.2 Typical Energy Sources

The widespread use of fossil fuels has been one of the most important stimuli of economic growth and has allowed the consumption of energy at a greater rate than it is being replaced and presents an unprecedented risk management problem (Yergin, 1991; Hirsch, 2005; Hirsch *et al.*, 2005; Yergin, 2011). A peak in the production of crude oil will happen, but whether it will occur slowly or abruptly is not certain – given appropriate warnings, the latter is likely to be the case. The adoption of alternate technologies to supplant the deficit in the production of crude oil will require a substantial time period on the order of at least ten-to-twenty years.

Global energy consumption is increasing and is expected to rise by 41% over the period to 2035 – compared to a 52% rise over the last twenty years and 30% rise over the last decade. Ninety five per cent of the growth in demand is expected to come from the emerging economies, while energy use in the advanced economies of North America, Europe and Asia as a group is expected to grow only very slowly – and begin to decline in the later years of the forecast period (BP, 2019). The data for reserve estimates indicate that there are sufficient reserves to cover this trend at least to and even beyond the year 2035.

1.2.1 Natural Gas and Natural Gas Hydrates

It is rare that crude oil and also heavy crude oil do not occur without an accompanying cover of gas (Speight, 2014a, 2019b). It is therefore important, when describing reserves of crude oil, to also acknowledge the occurrence, properties, and character of the natural *gas*. In recent years, natural gas has gained popularity among a variety of industrial sectors. Natural gas burns cleaner than coal or crude oil, thus providing environmental benefits. Natural gas is distributed mainly via pipeline, and some in a liquid phase (LNG) transported across oceans by tanker.

Assuming that the current level of natural gas consumption for the world is maintained, the reserve would be enough to last for another 64 more years. However, in this estimation of natural gas longevity, factors such as the increased in annual consumption, the discovery of new reservoirs, and advances in discovery/recovery technology, and utilization of natural gas hydrates are not included. As a result of discoveries of gas in in tight shale formations – which has offset more than the annual consumption – the world reserves of natural gas have been in a generally upward trend, due to discoveries of major natural gas fields.

Natural gas liquids (NGLs) – which are the higher boiling constituents of natural gas separated from natural gas at a gas processing plant, and includes ethane, propane, butane, and pentanes – have taken on a new prominence as shale gas production has increased and prices have fallen (Ratner and Tiemann, 2014). As a result, most producers are accepting the challenges with the opportunism and have shifted production to tight formations, such as the Bakken formation in North Dakota and Montana, to capitalize on the occurrence of natural gas liquids in shale gas development (Speight, 2013f; Sandrea, 2014; Speight, 2015a).

Methane hydrates (also often referred to as methane clathrates) is a resource in which a large amount of methane is trapped within a crystal structure of water, forming a solid similar to ice (Collett, 2009; Speight, 2014, 2019b). Methane hydrates exist as methane (the chief constituent of natural gas) trapped in a cage-like lattice of ice which, if either warmed or depressurized (with suitable caution), revert back to water and natural gas. When brought to the surface of the Earth, one cubic meter of gas hydrate releases 164 cubic meters of natural gas.

Gas hydrates occur in two discrete geological situations: (i) marine shelf sediments and (ii) on-shore Polar Regions beneath permafrost (Kvenvolden 1993; Kvenvolden and Lorenson, 2000). These two Hydrates occur in these two types of settings because these are the settings where the pressure-temperature conditions are within the hydrate stability field (Lerche and Bagirov, 1998). Gas hydrates can be detected seismically as well as by well logs (Goldberg and Saito, 1998; Hornbach *et al.*, 2003).

When drilling in crude oil-bearing and gas-bearing formations submerged in deep water, the reservoir gas may flow into the well bore and form gas hydrates owing to the low temperatures and high pressures found during deep water drilling. The gas hydrates may then flow upward with drilling mud or other discharged fluids. When the hydrates rise, the pressure in the annulus decreases and the hydrates dissociate into gas and water. The rapid gas expansion ejects fluid from the well, reducing the pressure further, which leads to more hydrate dissociation and further fluid ejection.

1.2.2 The Crude Oil Family

Crude oil and the equivalent term *petroleum*, cover a wide assortment of materials consisting of mixtures of hydrocarbon derivatives 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. Because crude oil is a mixture of widely varying constituents and proportions, its physical properties also vary widely and the color from colorless to black. The crude oil family consists of various types of crude oil: (i) conventional crude oil, (ii) crude oil from tight formations, (iii) opportunity crude oils, (iv) high acid crude oil, (v) foamy oil, and (vi) heavy crude oil.

The total amount of crude oil is indeed is finite, and, therefore, production will one day reach a peak and then begin to decline. This is common sense, as explained in the resource depletion theory which, in this case, assumes that reserves of crude oil will not be replenished (i.e. that abiogenic replenishment is negligible) and future world oil production must inevitably reach a peak and then decline as these reserves are exhausted (Hubbert, 1956, 1962). There is no doubt that crude oil and natural gas are being consumed at a steady rate but whether or not the Hubbert peak oil theory will affect the consumption of crude oil is another issue. It is a theory that is based on reserve estimates and reserve consumption. No one will disagree that hydrocarbon resources (in the form of crude oil and natural gas) are finite resources and will run out at some future point in time but the proponents of an energy precipice must recognize that this will not be the case, at least not for now (Speight and Islam, 2016). The issue is the timing of this event – whether it is tomorrow, next week, next month, next year, or in 50 or more years remains to be seen. Current evidence (Speight, 2011a, 2011c; BP, 2019) favors a 50+ years lifetime for the current reserves of crude oil and natural gas, perhaps longer if hydraulic fracturing continues to play a dominant role in crude oil and natural gas production (Speight, 2015a). Thus, controversy surrounds the theory – not so much from the theory itself which is quite realistic but from the way in which the theory is used by varying collections of alarmists – since as predictions for the time of the global peak is dependent on the past production and discovery data used in the calculation.

To date, crude oil production on a worldwide basis has come almost exclusively from what are considered to be conventional crude oil reservoirs from which crude oil can be produced using tried-and-true recovery technologies compared with non-conventional sources that require more complex or more expensive technologies to extract – example of such resources are tar sand bitumen, liquids from coal, liquids from biomass, and liquids from oil shale (Lee, 1990; Scouten, 1990; Lee, 1991; Speight, 2008, 2011b, 2012, 2013a, 2014b, 2016).

Generally, *crude oil from tight formations* (sometime referred to as unconventional tight oil resources) are found at considerable depths in sedimentary rock formations that are characterized by very low permeability. While some of the tight oil plays produce oil directly from shales, tight oil resources are also produced from low-permeability siltstone formations, sandstone formations, and carbonate formations that occur in close association with a shale source rock.

Oil from tight shale formation is characterized by a low content of high-boiling (resid) constituents, low-sulfur content, and a significant molecular weight distribution of the paraffinic wax content (Speight, 2014a, 2015b). Finally, the properties of crude oils from tight formations are highly variable. Density and other properties can show wide variation, even within the same field. The Bakken crude is light and sweet with an API of 42° and a sulfur content of 0.19% w/w. Similarly, Eagle Ford is a light sweet feed, with a sulfur content of approximately 0.1% w/w and with published API gravity between 40° API and 62° API.

There is also the need for a refinery to be configured to accommodate *opportunity crude oils* and/or *high acid crude oils* which, for many purposes are often included with heavy feedstocks (Speight, 2014a, 2014b; Yeung, 2014). *Opportunity crude oils* are either new crude oils with unknown or poorly understood properties relating to processing issues or are existing crude oils with well-known properties and processing concerns (Ohmes, 2014). Opportunity crude oils are often, but not always, heavy crude oils but in either case are more difficult to process due to high levels of solids (and other contaminants) produced with the oil, high levels of acidity, and high viscosity. These crude oils may also be incompatible with other oils in the refinery feedstock blend and cause excessive equipment fouling when processed either in a blend or separately (Speight, 2015b). There is also the need for a refinery to be configured to accommodate *opportunity crude oils* and/or *high acid crude oils* which, for many purposes are often included with heavy feedstocks.

Opportunity crude oils, while offering initial pricing advantages, may have composition problems which can cause severe problems at the refinery, harming infrastructure, yield, and profitability. Before refining, there is the need for comprehensive evaluations of opportunity crudes, giving the potential buyer and seller the needed data to make informed decisions regarding fair pricing and the suitability of a particular opportunity crude oil for a refinery. This will assist the refiner to manage the ever-changing crude oil quality input to a refinery – including quality and quantity requirements and situations, crude oil variations, contractual specifications, and risks associated with such opportunity crudes.

High acid crude oils are crude oils that contain considerable proportions of naphthenic acids which, as commonly used in the crude oil industry, refers collectively to all of the organic acids present in the crude oil (Shalaby, 2005; Speight, 2014b). In many instances, the high-acid crude oils are actually the heavier crude oils (Speight, 2014a, 2014b). The total acid matrix is therefore complex and it is unlikely that a simple titration, such as the traditional methods for measurement of the total acid number, can give meaningful results to use in predictions of problems. An alternative way of defining the relative organic acid fraction of crude oils is therefore a real need in the oil industry, both upstream and downstream.

High acid crude oils cause corrosion in the refinery – corrosion is predominant at temperatures in excess of 180°C (355°F) (Kane and Cayard, 2002; Ghoshal and Sainik, 2013; Speight, 2014c) – and occurs particularly in the atmospheric distillation unit (the first point of entry of the high-acid crude oil) and also in the vacuum distillation units. In addition, overhead corrosion is caused by the mineral salts, magnesium, calcium and sodium chloride which are hydrolyzed to produce volatile hydrochloric acid, causing a highly corrosive condition in the overhead exchangers. Therefore, these salts present a significant contamination in opportunity crude oils. Other contaminants in opportunity crude oils which are shown to accelerate the hydrolysis reactions are inorganic clay minerals and organic acids.

Foamy oil is oil-continuous foam that contains dispersed gas bubbles produced at the well head from heavy crude oil reservoirs under solution gas drive (Maini, 1999; Sheng *et al.*, 1999; Maini, 2001). The nature of the gas dispersions in oil distinguishes foamy oil behavior from conventional heavy crude oil. The gas that comes out of solution in the reservoir does not coalesce into large gas bubbles nor into a continuous flowing gas phase. Instead it remains as small bubbles entrained in the crude oil, keeping the effective oil viscosity low while providing expansive energy that helps drive the oil toward the producing. Foamy oil accounts for unusually high production in heavy crude oil reservoirs under solution-gas drive.

During primary production of heavy crude oil from solution gas drive reservoirs, the oil is pushed into the production wells by energy supplied by the dissolved gas. As fluid is withdrawn from the production wells, the pressure in the reservoir declines and the gas that was dissolved in the oil at high pressure starts to come out of solution (*foamy oil*). As pressure declines further with continued removal of fluids from the production wells, more gas is released from solution and the gas already released expands in volume. The expanding gas, which at this point is in the form of isolated bubbles, pushes the oil out of the pores and provides energy for the flow of oil into the production well. This process is very efficient until the isolated gas bubbles link up and the gas itself starts flowing into the production well. Once the gas flow starts, the oil has to compete with the gas for available flow energy. Thus, in some heavy crude oil reservoirs, due to the properties of the oil and the sand and also due to the production methods, the released gas forms foam with the oil and remains subdivided in the form of dispersed bubbles much longer.

Heavy crude oil is a *type* of crude oil that is different from conventional crude oil insofar as they are much more difficult to recover from the subsurface reservoir. Heavy crude oil, particularly heavy crude oil formed by biodegradation of organic deposits, are found in shallow reservoirs, formed by unconsolidated sands. This characteristic, which causes difficulties during well drilling and completion operations, may become a production advantage due to higher permeability. In simple terms, heavy crude oil is a type of crude oil which is very viscous and does not flow easily. The common characteristic properties (relative to conventional crude oil) are high specific gravity, low hydrogen to carbon ratios, high carbon residues, and high contents of asphaltenes, heavy metal, sulfur and nitrogen. Specialized refining processes are required to produce more useful fractions, such as: naphtha, kerosene, and gas oil.

1.2.3 Extra Heavy Crude Oil and Tar Sand Bitumen

In addition to conventional crude oil and heavy crude oil, there remains two other, even more viscous materials, that offers some relief to the potential shortfalls in supply (Meyer and De Witt, 1990; Meyer and Attanasi, 2003; Speight, 2014a; BP, 2019). This is the *bitumen* known as extra heavy crude oil and the bitumen found in *tar sand* (*oil sand*) deposits (Speight, 2014a). However, many of these reserves are only available with some difficulty and optional refinery scenarios will be necessary for conversion of these materials to liquid products because of the differences in character between conventional crude oil and tar sand bitumen (Speight, 2000; Speight, 2014a).

Extra heavy crude oil is a non-descript term (related to viscosity) of little scientific meaning that is usually applied to tar sand bitumen, which is generally capable of free flow under reservoir conditions (Speight, 2014a, 2017). Thus, general difference is that extra heavy crude oil, which may have properties similar to tar sand bitumen in the laboratory but, unlike tar sand bitumen in the deposit, has some degree of mobility in the reservoir or deposit (Delbianco and Montanari, 2009; Speight, 2014a, 2017). Extra heavy crude oils can flow at reservoir temperature and can be produced economically, without additional viscosity-reduction techniques, through variants of conventional processes such as long horizontal wells, or multilaterals. This is the case, for instance, in the Orinoco basin (Venezuela) or in offshore reservoirs of the coast of Brazil but, once outside of the influence of the high reservoir temperature, these oils are too viscous at surface to be transported through conventional pipelines and require heated pipelines for transportation. Alternatively, the oil must be partially upgraded or fully upgraded or diluted with a light hydrocarbon (such as aromatic naphtha) to create a mix that is suitable for transportation (Parkash, 2003; Gary *et al.*, 2007; Speight, 2014a; Hsu and Robinson, 2017; Speight, 2017).

Tar sand (referred to as *oil sand* in Canada) deposits are found in various countries throughout the world, but in vast quantities in Alberta and Venezuela. There have been many attempts to define tar sand deposits and the bitumen contained therein. In order to define conventional crude oil, heavy crude oil, and bitumen, the use of a single physical parameter such as viscosity is not sufficient. Other properties such as API gravity, elemental analysis, composition, and, most of all, the properties of the bulk deposit must also be included in any definition of these materials. Only then will it be possible to classify crude oil and its derivatives.

In fact, the most appropriate and workable definition of *tar sand* is found in the writings of the United States government (United States Congress, 1976), which is not subject to any variation in chemical or physical properties that can vary depending upon the method of property determination and the accuracy of that method (Speight, 2014, 2016), viz.:

> *Tar sands are 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.*

This definition speaks to the character of the bitumen through the method of recovery (Speight, 2014, 2016). Thus, the bitumen found in tar sand deposits is an extremely viscous material that is *immobile under reservoir conditions* and cannot be recovered through a well by the application of secondary or enhanced recovery techniques.

By inference and by omission, conventional crude oil and heavy crude oil are also indicated in this definition – crude oil is the material that can be recovered by conventional oil well production methods whereas heavy crude oil is the material that can be recovered by enhanced recovery methods. Extra heavy oil can also be accommodated under this definition because the properties of extra heavy crude oil approximates the properties and behavior of tar sand bitumen at ambient conditions but is mobile because the reservoir temperature is higher than the pour point of the oil (Speight, 2014a). In the early days of resource development, the sole method of the recovery of the bitumen from tar sand formations was by use of a mining process followed by separation of the bitumen by the hot water process. Current methods also include the use of advanced *in situ* processes that are not covered by the above definition. After recovery, the bitumen is then used to produce hydrocarbon derivatives by a conversion process.

1.3 Other Energy Sources

All fossil fuels are non-renewable, and as such they will get eventually depleted to the point where extraction of the remaining fossil fuels from the Earth is impossible or prohibitively expensive. Further, energy generation from fossil fuels require combustion, thus damaging the environment with pollutants and greenhouse gas emission (Speight and Lee, 2000). Also, since the fossil fuels are based on finite resources and their distributions are heavily localized in certain areas of the world, they will become expensive. In order to sustain the future of the world with clean environment and non-depletive energy, renewable energy is a right choice. Renewable energy sources include hydrgoen, biomass, solar energy, wind energy, and geothermal energy. Most renewable energy except geothermal energy comes directly or indirectly from sun. Benefits of renewable energy are variable and include: (i) environmental cleanness without pollutant emission, (ii) non-depletive nature, (iii) availability throughout the world, (iv) no cause for global warming, (v) waste reduction, (vi) stabilization of energy cost, and (vii) creation of jobs.

Alternate fuels produced from sources other than fossil fuels (particularly those from crude oil) are making some headway into the fuel demand. For example, diesel from plant sources (biodiesel) is similar in performance to diesel from crude oil and has the added advantage of a higher cetane rating than crude oil-derived diesel. However, the production of liquid fuels from sources other than crude oil has a checkered history. The on-again-off-again efforts that are the result of the inability of the political decision-makers to formulate meaningful policies has caused the production of non-conventional fuels to move slowly, if at all (Yergin, 1991; Bower, 2009; Wihbey, 2009; Speight, 2011a, 2011b, Yergin, 2011; Speight, 2014a).

Non-fossil fuels are alternative sources of energy that do not rely on continued consumption of the limited supplies of crude oil, coal, and natural gas. Examples of the non-fossil fuel energy sources include: (i) biomass, wind, solar, geothermal, tidal, nuclear, and hydrogen sources (Nersesian, 2007; Speight, 2008, 2011c). Such resources are considered to be extremely important to the future of energy generation because they are renewable energy sources that could be exploited continuously and not suffer depletion. In addition, energy production using non-fossil-based sources is claimed to generate much less pollution than the fossil fuel energy sources. This is considered crucial by many governments who are looking for ways to reduce the amount of pollution produced by their countries. The advantages of fossil fuel resources are often considered to include the know-how and ease of production, many opponents of fossil fuel use cite the adverse effects on the environment (Speight, 2008, 2013a, 2013b, 2014a) and consider non-fossil fuels as a much better way to generate energy.

While there are now methods of burning gas and similar products very efficiently, as clean fossil fuels, a certain amount of pollution is still generated. Accordingly, various initiatives now exist, especially in Western countries, to encourage corporations and energy companies to invest in methods of producing energy from renewable (non-fossil fuel).

1.3.1 Coal

Coal is a combustible organic sedimentary rock that is formed from the accumulation and preservation of plant materials, usually in a swamp environment (Speight, 2013a, 2013b). Along with crude oil and natural gas, coal is one of the three most important fossil fuels, such as for the generation of electricity and provides approximately 40% of electricity production on a worldwide basis. In many countries these data are much higher; for example Poland relies on coal for approximately 94% of the electricity production; South Africa relies on coal for approximately 92% of the electricity production; China relies on coal for approximately 77% of the electricity production; and Australia relies on coal for approximately 76% of the electricity production.

Total recoverable reserves of coal around the world are estimated at 891,531 million tons – the United States has sufficient coal reserves to last (at current rates of consumption) in excess of 250 years (BP, 2019). Even though coal deposits are distributed widely throughout the world, deposits in three countries account for approximately 57% of the world recoverable coal reserves, viz., United States (27%), Russian Federation (18%), and China (13%) and another six countries account for 30% of the total reserves and they are Australia (9%), India (7%), Ukraine (4%), Kazakhstan (4%), South Africa (3%), and Japan (3%). Coal is also very unequally and unevenly distributed in the world, just as other fossil fuels such as crude oil and natural gas.

Coal has been studied extensively for conversion into gaseous and liquid fuels as well as hydrocarbon feedstocks. Largely thanks to its relative abundance and stable fuel price on the market, coal has been a focal target for synthetic conversion into other forms of fuels, i.e., synfuels. Research and development work on coal conversion has seen peaks (highs) and valleys (lows) due to external factors including the comparative fossil fuel market as well as the international energy outlook of the era. Coal can be gasified, liquefied, pyrolyzed, and co-processed with other fuels including oil, biomass, scrap tires, and municipal solid wastes (Speight, 2008, 2011b, 2011c, 2013a, 2014b). Secondary conversion of coal derived gas and liquids can generate a wide array of petrochemical products as well as alternative fuels.

For the past two centuries, coal played this important role – providing coal gas for lighting and heating and then electricity generation with the accompanying importance of coal as an essential fuel for steel and cement production, as well as a variety of other industrial activities. On a worldwide basis, in excess of 4 billion tons (4.0×10^9 tons) of coal is consumed by a variety of sectors – including power generation (steam coal and/or lignite), iron and steel production (coking coal), cement manufacturing, and as a solid fuel or a source of liquid fuels (Speight, 2013a, 2103b). In fact, coal remains an important source of energy in many countries, and is used to provide approximately 40% of electricity worldwide but this does not give the true picture of the use of coal for electricity production. During the time the coal industry has been pressured into consideration of the environmental aspects of coal use and has responded with a variety of on-stream coal-cleaning and gas-cleaning technologies (Speight, 2013a).

Coal is the largest single source of fuel for the generation of electricity world-wide, as well as the largest source of carbon dioxide emissions, which have been implicated as the primary cause of global climate change, although the debate still rages as to the actual cause (or causes) of climate change. Coal is found as successive layers, or seams, sandwiched between strata of sandstone and shale and extracted from the ground by coal mining – either underground coal seams (underground mining) or by open-pit mining (surface mining).

Coal occurs in different forms or *types* (Speight, 2013a). Variations in the nature of the source material and local or regional the variations in the coalification processes cause the vegetal matter to evolve differently. Various classification systems thus exist to define the different types of coal. Using the ASTM system of classification (ASTM D388), the coal precursors are transformed over time (as geological processes increase their effect over time).

Chemically, coal is a hydrogen-deficient hydrocarbon with an atomic hydrogen-to-carbon ratio near 0.8, as compared to crude oil hydrocarbon derivatives, which have an atomic hydrogen-to-carbon ratio approximately equal to 2, and methane (CH_4) that has an atomic carbon-to-hydrogen ratio equal to 4. For this reason, any process used to convert coal to alternative fuels must add hydrogen or redistribute the hydrogen in the original coal to generate hydrogen-rich products and coke (Speight, 2013a).

The chemical composition of the coal is defined in terms of its proximate and ultimate (elemental) analyses (Speight, 2013a). The parameters of proximate analysis are moisture, volatile matter, ash, and fixed carbon. Elemental analysis (ultimate analysis) encompasses the quantitative determination of carbon, hydrogen, nitrogen, sulfur, and oxygen within the coal. Additionally, specific physical and mechanical properties of coal and particular carbonization properties are also determined.

Carbon monoxide and hydrogen are produced by the gasification of coal in which a mixture of gases is produced. In addition to carbon monoxide and hydrogen, methane and other hydrocarbon derivatives are also produced depending on conditions. Producing diesel and other fuels from coal can be performed through the conversion of coal to synthesis gas, a combination of carbon monoxide, hydrogen, carbon dioxide, and methane. Synthesis gas is subsequently reacted through Fischer-Tropsch Synthesis processes to produce hydrocarbon derivatives that can be refined into liquid fuels (Speight, 2019a). Thus, gasification thus offers one of the cleanest and versatile ways to convert the energy contained in coal into electricity, hydrogen, and other sources of power. Turning coal into synthesis gas isn't a new concept, in fact the basic technology dates back to pre-World War II. In fact, a gasification unit can process virtually all the residua and wastes that are produced in refineries leading to enhanced yields of high-value products (and hence their competitiveness in the market) by deeper upgrading of their crude oil.

1.3.2 Oil Shale

Just like the term *oil sand* (tar sand in the United States), the term *oil shale* is a misnomer since the mineral does not contain oil nor is it always *shale*. The organic material is chiefly *kerogen* and the *shale* is usually a relatively hard rock, called marl. *Oil shale* is a complex and intimate mixture of organic and inorganic materials that vary widely in composition and properties. In general terms, oil shale is a fine-grained sedimentary rock that is rich inorganic matter and yields oil when heated. Some oil shale is genuine shale but others have been mis-classified and are actually siltstones, impure limestone, or even impure coal. Oil shale does not contain oil and only produces oil when it is heated to approximately 500°C (approximately 930°F), when some of the organic material is transformed into a distillate similar to crude oil (Lee, 1990; Scouten, 1990; Lee, 1991; Speight, 2008, 2012).

Thus, when properly processed, kerogen can be converted into a substance somewhat similar to crude oil which is often better than the lowest grade of oil produced from conventional oil reservoirs but of lower quality than conventional light oil. *Shale oil* (*retort oil*) is the liquid oil condensed from the effluent in oil shale retorting and typically contains appreciable amounts of water and solids, as well as having an irrepressible tendency to form sediments. Oil shale is an inorganic, non-porous sedimentary marlstone rock containing various amounts of solid organic material (known as *kerogen*) that yields hydrocarbon derivatives, along with non-hydrocarbon derivatives, and a variety of solid products, when subjected to pyrolysis (a treatment that consists of heating the rock at high temperature) (Lee, 1990; Scouten, 1990; Lee, 1991; Speight, 2008, 2012).

Oil production potential from oil shale is measured by a laboratory pyrolysis method called Fischer Assay (Speight, 1994, 2008, 2012) and is reported in barrels per ton (42 US gallons per barrel, approximately 35 Imperial gallons per barrel). Rich oil shale zones can yield more than 40 US gallons per ton, while most shale zones produce 10 to 25 US gallons per ton. Yields of shale oil in excess of 25 US gallons per ton are generally viewed as the most economically attractive, and hence, the most favorable for initial development. Thus, oil shale has, though, a definite potential for meeting energy demand in an environmentally acceptable manner (Lee, 1990; Scouten, 1990; Lee, 1991; Bartis *et al.*, 2005; Andrews, 2006; Speight, 2008; 2012).

The oil shale deposits in the western United States contain approximately 15% w/w organic material (kerogen) (Lee, 1990; Scouten, 1990; Lee, 1991; Speight, 2012). By heating oil shale to high temperatures (>500°C, >930°F), the kerogen is decomposed and converted to a volatile liquid product. However, shale oil is sufficiently different from crude oil and refining processing shale oil presents some unusual problems but, nevertheless, shale oil can be refined into a variety of liquid fuels, gases, and high value products for the petrochemical industry.

The United States has vast known oil shale resources that could translate into as much as 2.2 trillion barrels of known *oil-in-place*. Oil shale deposits in the United States are concentrated mainly in the Green River Formation in the states of Colorado, Wyoming and Utah, account for nearly three-quarters of this potential (Lee, 1990; Scouten, 1990; Lee, 1991; Bartis *et al.*, 2005; Andrews, 2006; Speight, 2008; 2012). Because of the abundance and geographic concentration of the known resource, oil shale has been recognized as a potentially valuable United States energy resource since as early as 1859, the same year Colonel Drake completed his first oil well in Titusville, Pennsylvania (Speight, 2014a). Early products derived from shale oil included kerosene and lamp oil, paraffin, fuel oil, lubricating oil and grease, naphtha, illuminating gas, and ammonium sulfate fertilizer.

Since the beginning of the 20th Century, when the United States Navy converted its ships from coal to fuel oil, and the economy of the United States was transformed by gasoline-fueled automobiles and diesel fueled trucks and trains, concerns have been raised related to assuring adequate supplies of liquid fuels at affordable prices to meet the growing needs of the nation and its consumers. Thus, it is not surprising that the abundant resources of oil shale in the United States were given consideration as a major source for these fuels. In fact, the Mineral Leasing Act of 1920 made crude oil and oil shale resources on Federal lands available for development under the terms of federal mineral leases. This enthusiasm for oil shale resources was mitigated to a large extent by the discoveries of more economically producible and easy-to-refine liquid crude oil in commercial quantities caused the interest in oil shale to decline markedly.

However, the interest in oil shale resumed after World War II, when military fuel demand and domestic fuel rationing and rising fuel prices made the economic and strategic importance of the oil shale resource more apparent. After the war, the booming post-war economy drove demand for fuels ever higher Starting with the commencement of the development, in 1946, Anvil Point, Colorado, oil shale demonstration project by the United States Bureau of Mines. Significant investments were made by commercial companies to define and develop the US oil shale resource and to develop commercially viable technologies and processes to mine, produce, retort, and upgrade oil shale into viable refinery feedstocks and by-products. Once again, however, major crude oil discoveries in the lower-48 United States, off-shore, and in Alaska, as well as other parts of the world reduced the foreseeable need for shale oil and interest and associated activities again diminished.

By 1970, oil discoveries were slowing, demand was rising, and crude oil imports in to the United States, largely from the Middle Eastern oil-producing nations, were rising to meet demand. Global oil prices, while still relatively low, were also rising reflecting the changing market conditions. On-going oil shale research and testing projects were re-energized and new projects were envisioned by numerous energy companies seeking alternative fuel feedstocks (Speight, 2008, 2011c). These efforts were significantly amplified by the impacts of the 1973 Arab Oil Embargo which demonstrated the vulnerability of the oil-consuming nations, particularly the United States, to oil import supply disruptions, and were underscored by a new supply disruption associated with the 1979 Iranian Revolution.

By 1982, however, technology advances and new discoveries of offshore oil resources in the North Sea and other bodies of water provided new sources for oil imports into the United States. Thus, despite significant investments by energy companies, numerous variations and advances in mining, restoration, retorting, and *in-situ* processes, the costs of oil shale production relative to current and foreseeable oil prices, made continuation of most commercial efforts impractical.

Despite the huge resources, oil shale is an under-utilized energy resource. In fact, one of the issues that arise when dealing with fuels from oil shale is the start-stop-start episodic nature of the various projects. The projects have varied in time and economic investment and viability. The reasons comprise competition from cheaper energy sources, heavy front-end investments and, of late, an unfavorable environmental record. Oil shale has, though, a definite potential for meeting energy demand in an environmentally acceptable manner (Bartis *et al.*, 2005; Andrews, 2006; Speight, 2020).

1.3.3 Biomass

Biomass is a renewable resource that has received considerable attention due to environmental considerations and the increasing demands of energy worldwide (Brown, 2003; NREL, 2003; Wright *et al.*, 2006; Tsai *et al.*, 2007; Speight, 2008; Langeveld *et al.*, 2010; Speight, 2011c; Lee and Shah, 2013; Hornung, 2014). Biomass is produced by a photosynthetic process (photosynthesis) which involves chemical reactions occurring on the Earth between sunlight and green plants within the plants in the form of chemical energy. In the process, solar energy is absorbed by green plants and some microorganisms to synthesize organic compounds from low energy carbon dioxide (CO_2) and water (H_2O). For example,

$$6CO_2 + 6H_2 \rightarrow 6CH_2O + 3O_2$$

The general formula of the organic material produced during photosynthesis process is $(CH_2O)_n$ which is mainly carbohydrate material. Some of the simple carbohydrates involved in this process are the simple carbohydrates glucose ($C_6H_{12}O_6$) and sucrose ($C_{12}H_{22}O_{11}$) and constitute biomass, which is a renewable energy source due to its natural and repeated occurrence in the environment in the presence of sunlight. The amount of biomass that can be grown certainly depends on the availability of sunlight to drive the conversion of carbon dioxide and water into carbohydrates. In addition to limitations of sunlight, there is a limit placed by the availability of appropriate land, temperature, climate and nutrients namely nitrogen, phosphorus and trace minerals in the soil.

Biomass is clean for it has negligible content of sulfur, nitrogen and ash, which give lower emissions of sulfur dioxide, nitrogen oxides and soot than conventional fossil fuels. Biomass resources and many and varied, including (i) forest and mill residues, (ii) agricultural crops and waste, (iii) wood and wood waste, (iv) animal waste\s, (v) livestock operation residues, (vi) aquatic plants, (vii) fast-growing trees and plants, (viii) municipal waste, and (ix) and industrial waste. The role of wood and forestry residues in terms of energy production is as old as fire itself and in many societies wood is still the major source of energy. In general, biomass can include anything that is not a fossil fuel that is based on bio-organic materials other than natural gas, crude oil, heavy crude oil, extra heavy crude oil and tar sand bitumen (Lucia *et al.*, 2006; Speight, 2008, 2011c; Lee and Shah, 2013).

There are many types of biomass resources that can be used and replaced without irreversibly depleting reserves and the use of biomass will continue to grow in importance as replacements for fossil fuel sources and as feedstocks for a range of products (Narayan, 2007; Speight, 2008, 2011c; Lee and Shah, 2013). Some biomass materials also have particular unique and beneficial properties which can be exploited in a range of products including pharmaceuticals and certain lubricants. In this context, the increased use of biofuels should be viewed as *one of a range of possible measures* for achieving self-sufficiency in energy, rather than a panacea to completely replace the fossil fuels (Crocker and Crofcheck, 2006; Worldwatch Institute, 2006; Freeman, 2007; Nersesian, 2007).

Worldwide biofuels production is still small at approximately 70 billion (70 x 10^9 tons) oil equivalent. With the volatility of crude oil prices of crude oil, the relative competitiveness of renewable and alternative fuels is drastically improving. Further, technological advances in the alternative renewable energy areas as well as public awareness backed by strong governmental supports and incentives, make the outlook of the alternative and renewable energy very promising (ESLC, 2013). There are seven countries that ca be considered the leaders in biofuels (particularly bioethanol) production, the leaders are (as a percent of the total production): United States (43.5%), Brazil (24%), France (3%), Germany (4%), Argentina (3%), China (3%), and Indonesia (2.5%). But this still represents minor amounts of the total energy consumption in these countries.

Ethanol (bio-ethanol) from corn has been used in an accelerated pace as gasoline blending fuel as well as a new brand of fuel *E85*, which contains 85% ethanol and 15% gasoline. The majority of the gas stations in the United States supply E85 fuels regularly and many automakers are offering multiple lines of automobiles that can be operated on either conventional gasoline or E85. This not only contributed to cleaner burning fuels but also supplements the amount of gasoline sold.

One extremely important aspect of biomass use as a process feedstock is the preparation of the biomass (also referred to as biomass cleaning or biomass pretreatment) is the removal of any contaminants that could have an adverse effect of the process and on the yields and quality of the products. Thus, feedstock preparation is, essentially, the pretreatment of the biomass feedstock to assist in the efficiency of the conversion process. In fact, pretreatment of biomass is considered one of the most important steps in the overall processing in a biomass-to-biofuel program and can occur using acidic or alkaline reagents as well as using a variety of physical methods and the method of choice depends vary much upon the process needs (Chapter 7). With the strong advancement in developing lignocellulose biomass-based refinery and algal biomass-based biorefinery, the major focus has been on developing pretreatment methods and technologies that are technically and economically feasible (Pandey *et al.*, 2015).

Typically, the fundamental step sin the pretreatment of biomass involves processes such as (i) washing/separation of inorganic matter such as stones/pebbles, (ii) size reduction which involves grinding, milling, and crushing, and (iii) separation of soluble matter (Chapter 7). Also, the pretreatment process that is selected is, depending upon the character of the biomass and the process, likely to be different for different raw materials and desired products.

One aspect of feedstock preparation in the light of the processes in which the biomass is to be used and converted, is the concept of torrefaction which is used as a pre-treatment step for biomass conversion techniques, such as gasification and cofiring. The thermal treatment not only destructs the fibrous structure and tenacity of biomass, but is also known to increase the calorific value of the biomass (Prins *et al.*, 2006a, 2006b, 2006c). Typically, torrefaction commence when the temperature reach 200°C (390°F) and end when the process is again cooled from the specific temperature to 200°C (390°F). During the process the biomass partly devolatilizes leading to a decrease in mass, but the initial energy content of the torrefied biomass is biomass which makes it more attractive for i.e. transportation (to a conversion site). After torrefaction at, say, temperatures up to 300°C (570°F) the grindability of raw biomass shows an improvement in grindability.

A wide range of biomass feedstocks can be used in pyrolysis processes. The pyrolysis process is very dependent on the moisture content of the feedstock, which should be around 10%. At higher moisture contents, high levels of water are produced and at lower levels there is a risk that the process only produces dust instead of oil. High-moisture waste streams, such as sludge and processing wastes, require drying before subjecting to pyrolysis. Thus, the efficiency and nature of the pyrolysis process is dependent on the particle size of feedstocks. Most of the pyrolysis technologies can only process small particles to a maximum of 2 mm keeping in view the need for rapid heat transfer through the particle. The demand for small particle size means that the feedstock has to be size-reduced before being used for pyrolysis.

Moisture in the biomass is another consideration for feedstock preparation because moisture in the feedstock will simply vaporize during the process and then re-condense with the bio-oil product which has an adverse impact the resulting quality of the bio-oil. It should also be noted that water is formed as part of the thermochemical reactions occurring during pyrolysis. Thus, if dry biomass is subjected to the thermal requirements for fast pyrolysis the resulting bio-oil will still contain water (as much as 12 to 15% w/w). This water is process-originated water that is the result of the dehydration of carbohydrate derivatives in the feedstock s as well as the result of reactions occurring between the hydrogen and oxygen at the high temperature (500°C, 930°F) of the process environment.

The moisture in the feedstock acts as heat sink and competes directly with the heat available for pyrolysis. Ideally it would be desirable to have little or no moisture in the feedstock but practical considerations make this unrealistic. Moisture levels on the order of 5 to 10% w/w are generally considered acceptable for the pyrolysis process technologies currently in use. As with the particle size, the moisture levels in the feedstock biomass are a trade-off between the cost of drying and the heating value penalty paid by having moisture in the feedstock. If the moisture content in biomass feedstock is too high, the bio-oil may be produced with high moisture content which eventually reduces its calorific value. Therefore biomass should undergo a pretreatment (drying) process to reduce the water content before pyrolysis is carried out (Dobele *et al.*, 2007). In contrast, high temperature during the drying process could be a critical issue for the possibility of producing thermal-oxidative reactions, causing a cross-linked condensed system of the components and higher thermal stability of the biomass complex.

To achieve high yields of the products (gases, liquids, and solids), it is also necessary to prepare the solid biomass feedstock in such a manner that it can facilitate the required heat transfer rates in the pyrolysis process. There are three primary heat transfer mechanisms available to engineers in designing reaction vessels: (i) convection, (ii) conduction, and (iii) radiation. To adequately exploit one or more of these heat transfer mechanisms as applied to biomass pyrolysis, it is necessary to have a relatively small particle for introduction to the reaction vessel. This ensures a high surface area per unit volume of particle and, as a result of the small particle size the whole particle achieves the desired temperature in a very short residence time. Another reason for the conversion of the feedstock to small particles is the physical transition of biomass as it undergoes pyrolysis when char develops at the surface of the particle. The char can act as an insulator that impedes the transfer of heat into the center of the particle and therefore runs counter to the requirements needed for pyrolysis. The smaller the particle the less of an affect this has on heat transfer (Bridgwater *et al.*, 2001).

1.3.4 Solid Waste

Energy generation utilizing biomass and municipal solid wastes (MSW) are also promising in regions where landfill space is very limited. Technological advances in the fields have made this option efficient and environmentally safe, possibility even supplementing refinery feedstocks as sources of energy through the installation of gasification units (Speight, 2008, 2011a, 2011b, 2011c, 2013b).

Waste may be municipal solid waste (MSW) which had minimal presorting, or refuse-derived fuel (RDF) with significant pretreatment, usually mechanical screening and shredding. Other more specific waste sources (excluding hazardous waste) and possibly including crude oil coke may provide niche opportunities for co-utilization (Brigwater, 2003; Arena, 2012; Basu, 2013; Speight, 2013, 2014b). The traditional waste-to-energy plant, based on mass-burn combustion on an inclined grate, has a low public acceptability despite the very low emissions achieved over the last decade with modern flue gas clean-up equipment. This has led to difficulty in obtaining planning permissions to construct needed new waste to energy plants. After much debate, various governments have allowed options for advanced waste conversion technologies (gasification, pyrolysis and anaerobic digestion), but will only give credit to the proportion of electricity generated from non-fossil waste.

Use of waste materials as co-gasification feedstocks may attract significant disposal credits (Ricketts *et al.*, 2002). Cleaner biomass materials are renewable fuels and may attract premium prices for the electricity generated. Availability of sufficient fuel locally for an economic plant size is often a major issue, as is the reliability of the fuel supply. Use of more-predictably available coal alongside these fuels overcomes some of these difficulties and risks. Coal could be regarded as the base feedstock which keeps the plant running when the fuels producing the better revenue streams are not available in sufficient quantities.

Wood fuels are fuels derived from natural forests, natural woodlands and forestry plantations, namely fuelwood and charcoal from these sources. These fuels include sawdust and other residues from forestry and wood processing activities. Over 50% of all wood used in the world is fuelwood. Most of the fuelwood is used in developing countries. In developing countries wood makes up approximately 80% of all wood used.

Size of the wood waste resource depends upon how much wood is harvested for lumber, pulp and paper. Finally, fuelwood can be grown in plantations like a crop. Fast growing species such as poplar, willow or eucalyptus can be harvested every few years. With short-rotation poplar coppices grown in three 7-year rotations, it is now possible to obtain 10 to 13 tons of dry matter per hectare annually on soil of average or good quality. Waste wood from the forest products industry such as bark, sawdust, board ends etc. are widely used for energy production. This industry, in many cases, is now a net exporter of electricity generated by the combustion of wastes.

Overall, wood wastes of all types make excellent biomass fuels and can be used in a wide variety of biomass technologies. Combustion of woody fuels to generate steam or electricity is a proven technology and is the most common biomass-to-energy process. Different types of woody fuels can typically be mixed together as a common fuel, although differing moisture content and chemical makeup can affect the overall conversion rate or efficiency of a biomass project.

There are at least six subgroups of woody fuels: (i) forestry residues which include in-forest woody debris and slash from logging and forest management activities, (ii) mill residues which include byproducts such as sawdust, hog fuel, and wood chips from lumber mills, plywood manufacturing, and other wood processing facilities, (iii) agricultural residues which includes byproducts of agricultural activities including crop wastes, waste from vineyard and orchard pruning, and rejected agricultural products, (iv) urban wood and yard wastes which includes residential organics collected by municipal programs or recycling centers and construction wood wastes, (v) dedicated biomass crops which includes trees, corn, oilseed rape, and other crops grown as dedicated feedstocks for a biomass project, and (vi) chemical recovery fuels – some time known as black liquor) – which includes woody residues recovered out of the chemicals used to separate fiber for the pulp and paper industry. Mill residues are a much more economically attractive fuel than forestry residues, since the in-forest collection and chipping are already included as part of the commercial mill operations. Biomass facilities collocated with and integral to the mill operation have the advantage of eliminating transportation altogether and thus truly achieve a no-cost fuel.

Softwood residues are generally in high demand as feedstocks for paper production, but hardwood timber residues have less demand and fewer competing uses. In the past, as much as 50% of the tree was left on site at the time of harvest. Whole tree harvest systems for pulp chips recover a much larger fraction of the wood. Wood harvests for timber production often generates residues which may be left on the site or recovered for pulp production. Economics of wood recovery depend greatly on accessibility and local demand. Underutilized wood species include Southern red oak, poplar, and various small diameter hardwood species. Unharvested dead and diseased trees can comprise a major resource in some regions. When such timber has accumulated in abundance, it comprises a fire hazard and must be removed. Such low grade wood generally has little value and is often removed by prescribed burns in order to reduce the risk of wildfires.

Agricultural residues are basically biomass materials that are by products of agriculture. This includes materials such as cotton stalks, wheat and rice straw, coconut shells, maize and jowar cobs, jute sticks, and rice husks. Many developing countries have a wide variety of agricultural residues in ample quantities. Large quantities of agricultural plant residues are produced annually worldwide and are vastly under-utilized. The most common agricultural residue is the rice husk, which makes up approximately 25% w/w of the rice.

Corn stalks and wheat straws are the two agricultural residues produced in the largest quantities. However, many other residues such as potato and beet waste may be prevalent in some regions. In addition to quantity it is necessary to consider density and water content (which may restrict the feasibility of transportation) and seasonality which may restrict the ability of the conversion plant to operate on a year-round basis. Facilities designed to use seasonal crops will need adequate storage space and should also be flexible enough to accommodate alternative feedstocks such as wood residues or other wastes in order to operate year-around. Some agricultural residues need to be left in the field in order to increase tilth (the state of aggregation of soil and its condition for supporting plant growth and to reduce erosion) but some residues such as corncobs can be removed and converted without much difficultly.

Agricultural residues can provide a substantial amount of biomass fuel. Similar to the way mill residues provide a significant portion of the overall biomass consumption in areas that are copiously forested, agricultural residues from sugar cane harvesting and processing provide a significant portion of the total biomass consumption in other parts of the world.

One significant issue with agricultural residues is the seasonal variation of the supply. Large residue volumes follow harvests, but residues throughout the rest of the year are minimal. Biomass facilities that depend significantly on agricultural residues must either be able to adjust output to follow the seasonal variation, or have the capacity to stockpile a significant amount of fuel.

Dry animal manure, which is typically defined as having a moisture content less than 30% w/w, is produced by feedlots and livestock corrals, where the manure is collected and removed only once or twice a year. Manure that is scraped or flushed on a more frequent schedule can also be separated, stacked, and allowed to dry. Dry manure can be composted or can fuel a biomass-to-energy combustion project. Animal manure does have value to farmers as fertilizer, and a biomass-to-energy project would need to compete for the manure. However, the total volume of manure produced in many livestock operations exceeds the amount of fertilizer required for the farmlands and, in some areas/countries, nutrient management plans are beginning to limit the over-fertilization of farmlands. Therefore, although there are competitive uses for the manure and low-cost disposal options at this time, manure disposal is going to become more costly over time, and the demand for alternative disposal options, including biomass-to-energy, will only increase.

Biomass technologies present attractive options for mitigating many of the environmental challenges of manure wastes. The most common biomass technologies for animal manures are combustion, anaerobic digestion, and composting. Moisture content of the manure and the amount of contaminants, such as bedding, determine which technology is most appropriate.

Urban wastes include municipal solid waste that is generated by household and commercial activities and liquid waste or sewage. Most municipal solid waste is currently disposed of in landfill sites. However, the disposal of this waste is a growing problem worldwide. Much of the waste could be used for energy production though incineration and processes. Japan currently incinerates more than 80% of the available municipal solid waste. It is also possible to use the methane produced in landfill sites for energy production.

Urban wood and yard wastes are similar in nature to agricultural residues in many regards. A biomass facility will rarely need to purchase urban wood and yard wastes, and most likely can charge a tipping fee to accept the fuel. Many landfills are already sorting waste material by isolating wood waste. This waste could be diverted to a biomass project, and although the volume currently accepted at the landfills would not be enough on its own to fuel a biomass project, it could be an important supplemental fuel and could provide more value to the community in which the landfill resides through a biomass project than it currently does as daily landfill cover.

Municipal solid wastes are produced and collected each year with the vast majority being disposed of in open fields. The biomass resource in municipal solid waste comprises the putrescible materials, paper and plastic and averages 80% of the total municipal solid waste collected. Municipal solid waste can be converted into energy by direct combustion, or by natural anaerobic digestion in the engineered landfill. At the landfill sites the gas produced by the natural decomposition of municipal solid waste (approximately 50% methane and 50% carbon dioxide) is collected from the stored material and scrubbed and cleaned before feeding into internal combustion engines or gas turbines to generate heat and power. The organic fraction of municipal solid waste can be anaerobically stabilized in a high-rate digester to obtain biogas for electricity or steam generation.

1.4 Energy Supply

Energy supply (energy flow) is the delivery of fuels or transformed fuels to the point of consumption and the term potentially encompasses the extraction, transmission, generation distribution, and storage of fuels. This supply of energy can be disrupted by several factors, including imposition of higher energy prices due to action by OPEC (in the case of crude oil) or other cartel, war, political disputes, economic disputes, or physical damage to the energy infrastructure due to acts of terrorism. The security of energy supply is a major concern of national security and energy independence for the energy-consuming countries.

1.4.1 Economic Factors

Crude oil economics is, as might be expected if the peak oil theory is true, dominated by the of oil production to the so-called occurrence of the remaining reserves that are to be depleted in the very near future (Speight and Islam, 2016). While there may be varied volatility in the price of crude oil, when there is a belief that the price in the future will be higher than the price for immediate delivery there will be a flurry of economic activity purchase short-term contracts. This, in turn, leads to a so-called equilibrium price level that is invariable higher than the previous price level which can influence producers to defer production activities in anticipation of a rise in price (Fleming, 2000). In actual fact, the price circle is indeed a vicious circle insofar as one arc of the price circle affects the other arcs of the circle leading to what might be called economic anarchy. This anarchy might easily be laid at the feet of the peak oil theorists who base their theory on faulty or uncertain data and on speculation. Moreover, the economic principles, which explain how a market economy works, tend to break down when applied to natural resources such as crude oil. In fact, there are two ways in which the principles of market economics do not apply to crude oil: (i) the current price of oil has virtually no influence on the rate at which it is discovered and (ii) the rules of supply and demand do not always hold, and (iii) a rise in the price of crude oil does not always lead to an increase in production.

While current high oil prices may encourage development and adoption of alternatives to oil, if high oil prices are not sustained, efforts to develop and adopt alternatives may fall by the wayside. The high oil prices and fears of running out of oil in the 1970s and early 1980s encouraged investments in alternative energy sources (including synthetic fuels made from coal and oil shale) but when oil prices decrease, investments in these alternatives became uneconomic. In fact, the development of renewable energy systems needs to be supported by decisive, well-coordinated action by governments, in sustained multi-decade programs. Many oil-consuming nations are moving to alternate fuel development rather than be faced with a *destabilizing energy gap*.

1.4.2 Geopolitical Factors

The political nature of energy, linked to the sources of supply and demand, comes to public attention at moments of crisis, particularly when unstable oil markets drive up prices and politicians hear protests from their constituents. It is these very factors that have turned the market power of energy suppliers into political power. Importers have come to compete for supplies, driving up prices, supplier wealth and the capacity to play roles in regional and international politics.

In fact, the true picture of oil supply may never be known. Difficult as it is because of a variety of factors, reporting data on oil production or oil reserves is a political act (Laherrère, 2001). The US SEC (United States Securities and Exchange Commission) obliges the oil companies listed on the US stock market to report only *proved reserves* and to omit *probable reserves* that are reported in the rest of the world. This practice of reporting only proved reserves can lead to a strong reserve growth since 90% of the annual reserves oil addition come from revisions of old fields, showing that the assessment of the fields was poorly reported. In fact, reporting of production is not much better and may give a false impression of oil abundance (Simmons, 2000) – technical data do exits and must be included in any peak theory model.

1.4.3 Physical Factors

Crude oil reserves (Speight, 2011a, 2014a) are the estimated quantities of oil that are claimed to be recoverable under existing operating and economic conditions. However, because of reservoir characteristics and the limitations of current recovery technologies only a fraction of this oil can be brought to the surface; it is this producible fraction that is considered to be *reserves*. Crude oil recovery varies greatly from oil field to oil field based on the character of the field and the operating history as well as in response to changes in technology and economics.

According to current estimates, more than three-quarters of the oil reserves of the world are located in OPEC countries. The bulk of the crude oil reserves that exist in the world are controlled by the OPEC consortium of countries is located in the Middle East, with Saudi Arabia, Iran and Iraq contributing approximately 42% v/v to the OPEC total. OPEC member countries have made significant contributions to their reserves in recent years by adopting best practices in the industry. As a result, OPEC proven reserves currently stand at 1214.2 billion barrels (1214.2 x 10^9 bbls) which represented 71.9% of the total crude oil reserves (BP, 2019).

There has been surprise at the OPEC estimates of proven reserves (Campbell and Laherrère, 1998.) since OPEC estimates increased sharply in the 1980s, corresponding to a change in quota rules instituted by OPEC that linked a member production quota by a member country in part to its remaining proven reserves. Indeed, companies that are not subject to the federal securities laws in the United States and their related liability standards, include companies wholly owned by various OPEC member countries where the majority of reserves are located. In addition, many OPEC countries' reported reserves remained relatively unchanged during the 1990s, even as they continued high levels of oil production. For example, estimates of reserves in Kuwait were unchanged from 1991 to 2002, even though the country produced more than 8 billion barrels (8 x 10^9 bbls) of crude oil over that period and did not report any new oil discoveries. The potential disbelief in the data reported by OPEC is problematic with respect to predicting the timing of a peak in oil production because OPEC holds most of the current estimated proven oil reserves of the world.

The United States Geological Survey provides oil resources estimates, which are different from proved reserves estimates. Oil resources estimates are significantly higher because they estimate the total oil resource base of the world, rather than just what is now proven to be economically producible. Estimates of the resource by the United States Geological Survey base include past production and current reserves as well as the potential for future increases in current conventional oil reserves (often referred to as *reserves growth*) and the amount of estimated conventional oil that has the potential to be added to these reserves. Estimates of reserves growth and those resources that have the potential to be added to oil reserves are important in determining when oil production may peak.

Further contributing to the uncertainty of the timing of a peak is the lack of a comprehensive assessment of oil from nonconventional sources. For example, estimates of crude oil longevity have only recently started to include oil from non-conventional sources (BP, 2019) and oil from these sources was not included in early peak oil theories. Yet oil from non-conventional sources is exists in substantial amounts, which could greatly delay the onset of a peak in production. However, challenges facing this production (Speight, 2008, 2011a, 2014a, 2016) indicate that the amount of nonconventional oil that will eventually be produced is, like the peak oil theory, highly speculative. However, despite this *apparent* uncertainty, development and production of oil (synthetic crude oil) from the Alberta tar sands and Venezuelan extra-heavy crude oil production are under way now and the refining technologies are being adapted to produce liquid fuels from these sources (Speight, 2008, 2013b, 2013c, 2013d, 2013c, 2014a).

1.4.4 Technological Factors

In region after region, there are reports of (i) ageing and depleted fields, (ii) poor quality – heavy – oil, (iii) the need for enhanced recovery methods, and (iv) new areas turning out to be dry well leading to the claim that peak oil has arrived. For example, for whatever reason, the fields in Alaska, the former Soviet Union, Mexico, Venezuela, and Norway (North Sea) are all claimed to be past their peak. It is grudgingly admitted by the peak oil theorists that there is (or there may be) a (remote or even unlikely) possibility of new finds of oil fields off the coast of west Africa, but their development is still years away, and these new finds will not be on a scale capable of making a difference. It is also further claimed that the only producers with an oil resource which may be capable of keeping oil flowing into the world market at a roughly constant level are the Middle East OPEC five – Saudi Arabia, Iran, Iraq, Kuwait and the United Arab Emirates (Fleming, 2000). However, because of much speculation on the part of the peak oil theorists, there is some difficulty when it comes to projecting the timing of a peak in oil production because (i) technological advances, (ii) increased efficiency in recovery methods and hence reduced or stable recovery economics, and (iv) environmental challenges make it unclear how much additional oil can ultimately be recovered from proven reserves or from hard-to-reach locations and from non-conventional sources.

Worldwide, industry analysts report that deep water (depths of 1,000 to 5,000 feet) and ultra-deep water (5,000 to 10,000 feet) drilling efforts are concentrated offshore in Africa, Latin America, and North America, and capital expenditures for these efforts are expected to grow through at least 2020s decade. In the United States, deepwater and ultra-deepwater drilling, primarily in the Gulf of Mexico, could increase the production of crude oil but at deepwater depths, penetrating the earth and efficiently operating drilling equipment is difficult because of the extreme pressure and temperature (Speight, 2015b).

Ultimately, however, the consequences of a peak and permanent decline in oil production could be even more prolonged and severe than those of past oil supply shocks. Even then the decline rate is the subject of speculation but like death and taxes, the decline rate is happening! The most important variable is the amount of oil left in the reservoirs but, even then, this is subject to debate and error leaving the decline rate for fields in production difficult to assess (Eagles, 2006; Gerdes, 2007; Jackson, 2006, 2007). At best, generalities can be calculated. For example, for current fields in production a low decline rate would be followed by a more moderate decline rate would result in peak oil in the near future.

1.5 Energy Independence

Energy independence has been a political non-issue in the United States since the first Arab oil embargo in 1973. Since that time, the speeches of various Presidents and the Congress of the United States have continued to call for an end to the dependence on foreign oil by the United States. Nevertheless, the United States has grown more dependent on foreign oil with no end in sight. For example, in 1970 the United States imported approximately one third of the daily oil requirement. Currently, the amount of imported oil is two thirds of the daily requirement! The congressional rhetoric of energy independence continues but meaningful suggestions of how to address this issue remain few and far between. The economy of the United States feeds on oil and the country consumes far more oil than it can produce.

Generally, the concept of energy independence for the United States runs contrary to the trend of the internationalization of trade. The government of the United States continues to reduce trade barriers through policies such as the North American Free Trade Agreement (NAFTA), the elimination of tariffs, as well as other free trade agreements. As a result, the percentage of the U.S. economy that comes from international trade is steadily rising.

Increased world trade is beneficial both economically and politically insofar as it is supposed to help establish amicable relations between countries. Through mutually beneficial exchange, a great deal of this increased interrelationship will, in theory, establish opportunities for personal ties that make military war (or other forms of military action) less likely. However, there are also contrary cases where countries acquire the means to be more destructive, if they so choose, through expanded economic opportunities. This type of argument has been used with regard to Iran.

Economic interdependence also makes the domestic economy more susceptible to disruptions in distant and unstable regions of the globe, such as the Middle East, South America and Africa. In fact, in many countries with proven reserves, oil production could be shut down by wars, strikes, and other political events, thus reducing the flow of oil to the world market. If these events occurred repeatedly, or in many different locations, they could constrain exploration and production, resulting in a peak despite the existence of proven oil reserves. Using a measure of political risk that assesses the likelihood that events such as civil wars, coups, and labor strikes will occur in a magnitude sufficient to reduce the gross domestic product (GDP) growth rate of a country over the next 5 years, four countries (Iran, Iraq, Nigeria, and Venezuela) possess proven oil reserves greater than 10 billion barrels (high reserves) and which countries contain almost one-third of worldwide oil reserves, face high levels of political risk. In fact, countries with medium or high levels of political risk contain 63 percent of proven worldwide oil reserves.

Political and investment risk factors continue to affect future oil exploration and production and, ultimately, the timing of peak oil production. These factors include changing political conditions and investment climates in many countries that have large proven oil reserves. These factors important in affecting future oil exploration and production.

Even in the United States, political considerations may affect the rate of exploration and production. For example, restrictions imposed to protect environmental assets mean that some oil may not be produced. The Minerals Management Service of the United States Department of the Interior estimates that approximately 76 billion barrels (76 x 10^9 bbls) of oil lie in undiscovered fields offshore in the outer continental shelf of the United States (which is necessary for a measure of energy security). Nevertheless, Congress enacted moratoriums on drilling and exploration in this area to protect coastlines from unintended oil spills. In addition, policies on federal land use need to take into account multiple uses of the land including environmental protection. Environmental restrictions may affect a peak in oil production by barring oil exploration and production in environmentally sensitive areas.

The government must adopt policies that ensure our energy independence. The United States Congress is no longer believable when the members of the Congress lay the blame on foreign governments or events for an impending crisis. The Congress needs to look north and the positive role played by the Government of Canada in the early 1960s when the decision was made to encourage development of the Alberta tar sands. Synthetic crude oil production in no in excess of 1,000,000 million barrels per day – less than 6% of the daily liquid fuels requirement in the United States but a much higher percentage of Canadian daily liquid fuels requirement. In the United States, the issue to be faced is not so much oil reserves but oil policies.

A measure of dependency on crude oil can be viewed by various importing countries (Alhajji and Williams, 2003). In the United States, increasing crude oil imports is considered a threat to national security but there is also the line of thinking that the level of imports has no significant impact on energy security, or even national security. However, the issue becomes a problem when import vulnerability increases as crude oil imports rise which occurs when oil-consuming countries increase the share of crude oil imports from politically unstable areas of the world.

More generally, there are four measures of crude oil dependence: (i) crude oil imports as a percentage of total crude oil consumption, (ii) the number of days total crude oil stocks cover crude oil imports, (iii) the number of days total stocks cover consumption, and (iv) the percentage of crude oil in total energy consumption (Alhajji and Williams, 2003).

The dependency on foreign oil in the United States has increased steadily since 1986 and has reached record highs in the past decade – the degree of import dependence as percentage of consumption increased from approximately 50% in the early-to-mid 1980s to 60% in the early 1990s (because of higher economic growth and lower oil prices on the demand side and declining crude oil production on the supply side). Currently, the United States is an exporter of crude oil and crude oil products but the question remains related to the longevity of such a situation. In addtion, the dependence of the United States on crude oil has increased in recent years and this indicates two possible areas of concern regarding the extent to which crude oil influences energy security: (i) the increase in the crude oil share of energy use, and (ii) the inability or unwillingness of the United States to reduce dependence on oil. It is because of such variations that the potential of gasification must be considered as an option for energy production, particularly for the production of liquid fuels and chemicals.

Gasification is a process that converts organic (carbonaceous) feedstocks into carbon monoxide, carbon dioxide and hydrogen by reacting the feedstock at high temperatures (>700°C, 1290°F), without combustion, with a controlled amount of oxygen and/or steam (Luque and Speight, 2015). The resulting gas mixture (*synthesis gas*, *syngas*) is itself a fuel. The power derived from carbonaceous feedstocks and gasification followed by the combustion of the product gas(es) is considered to be a source of renewable energy if derived gaseous products are generated from a source (e.g., biomass) other than a fossil fuel.

The advantage of gasification is the use of synthesis gas (syngas) is potentially more efficient as compared to direct combustion of the original fuel because it can be (i) combusted at higher temperatures, (ii) used in fuel cells, (iii) used to produce methanol and hydrogen, and (iv) converted via the Fischer-Tropsch process into a range of synthesis liquid fuels suitable for use gasoline engines or diesel engines. The gasification process can also utilize carbonaceous feedstocks which would otherwise have been disposed of (e.g. biodegradable waste).

Synthesis gas (synthesis gas) fuel gas mixture consisting predominantly of carbon monoxide and hydrogen and is typically a product of a gasification. The gasification process is applicable to many carbonaceous feedstocks including natural gas, crude oil resids, coal, biomass, by reaction of the feedstock with steam (steam reforming), carbon dioxide (dry reforming) or oxygen (partial oxidation). Synthesis gas is a crucial intermediate resource for production of hydrogen, ammonia, methanol, a variety of chemicals, as well as synthetic hydrocarbon fuels. Thus, as the reserves of natural gas, crude oil, and other forms of conventional energy are depleted, there will be the need to seek other sources some of which are outlined in the previous sections.

For many decades, coal has been the primary feedstock for gasification units but recent concerns related to the use of fossil fuels and the resulting environmental pollutants, irrespective of the various gas cleaning processes and gasification plant environmental cleanup efforts, there is a move to feedstocks other than coal for gasification processes (Speight, 2013a, 2013b, 2014b). Moreover, in spite of claims to the contrary, coal gasification plants are cleaner with respect to standard pulverized coal combustion facilities, producing fewer sulfur and nitrogen byproducts, which contribute to smog and acid rain. For this reason, gasification appeals as a way to utilize relatively inexpensive and expansive coal reserves, while reducing the environmental impact. Indeed, the increasing mounting interest in gasification technology reflects a convergence of two changes in the electricity generation marketplace: (i) the maturity of gasification technology, and (ii) the extremely low emissions from integrated gasification combined cycle (IGCC) plants, especially air emissions, and the potential for lower cost control of greenhouse gases than other coal-based systems.

Furthermore, gasification processes can accept a variety of feedstocks but the reactor must be selected on the basis of feedstock properties and behavior in the process. The advantage of the gasification process when a carbonaceous feedstock (a feedstock containing carbon) or hydrocarbonaceous feedstock (a feedstock containing carbon and hydrogen) is employed is that the product of focus – synthesis gas – is potentially more useful as an energy source and results in an overall cleaner process. The production of synthesis gas is a more efficient production of an energy source than, say, the direct combustion of the original feedstock because synthesis gas can be (i) combusted at higher temperatures, (ii) used in fuel cells, (iii) used to produce methanol, (iv) used as a source of hydrogen, and (v) particularly because the synthesis gas can be converted via the Fischer-Tropsch process into a range of synthesis liquid fuels suitable for use gasoline engines, for diesel engines, or for wax production.

Energy production such as electricity production or combined electricity and heat production remain the most likely area for the application of gasification or co-gasification. Also, the disposal of municipal and industrial waste has become an important problem because the traditional means of disposal, landfill, are much less environmentally acceptable than previously. Much stricter regulation of these disposal methods will make the economics of waste processing for resource recovery much more favorable. A method of processing waste streams is to convert the energy value of the combustible waste into a fuel. One type of fuel attainable from waste is a low heating value gas, usually 100 to 150 Btu/scf, which can be used to generate process steam or to generate electricity. Co-processing such waste with coal is also an option (Speight, 2008, 2013, 2014b).

Co-gasification technology varies, being usually site specific and high feedstock dependent. At the largest scale, the plant may include the well proven fixed bed and entrained flow gasification processes. At smaller scales, emphasis is placed on technologies which appear closest to commercial operation. Pyrolysis and other advanced thermal conversion processes are included where power generation is practical using the on-site feedstock produced. However, the needs to be addressed are (i) core fuel handling and gasification/pyrolysis technologies, (ii) fuel gas clean-up, and (iii) conversion of fuel gas to electric power (Ricketts *et al.*, 2002).

Waste may be municipal solid waste (MSW) which had minimal presorting, or refuse-derived fuel (RDF) with significant pretreatment, usually mechanical screening and shredding. Other more specific waste sources (excluding hazardous waste) and possibly including crude oil coke, may provide niche opportunities for co-utilization. The traditional waste to energy plant, based on mass-burn combustion on an inclined grate, has a low public acceptability despite the very low emissions achieved over the last decade with modern flue gas clean-up equipment. This has led to difficulty in obtaining planning permissions to construct needed new waste to energy plants. After much debate, various governments have allowed options for advanced waste conversion technologies (gasification, pyrolysis and anaerobic digestion), but will only give credit to the proportion of electricity generated from non-fossil waste.

Co-utilization of waste and biomass with coal may provide economies of scale that help achieve the above identified policy objectives at an affordable cost. In some countries, governments propose cogasification processes as being *well suited for community-sized developments* suggesting that waste should be dealt with in smaller plants serving towns and cities, rather than moved to large, central plants (satisfying the so-called *proximity principle*).

In fact, neither biomass nor wastes are currently produced, or naturally gathered at sites in sufficient quantities to fuel a modern large and efficient power plant. Disruption, transport issues, fuel use, and public opinion all act against gathering hundreds of megawatts (MWe) at a single location. Biomass or waste-fired power plants are therefore inherently limited in size and hence in efficiency (labor costs per unit electricity produced) and in other economies of scale. The production rates of municipal refuse follow reasonably predictable patterns over time periods of a few years. Recent experience with the very limited current *biomass for energy* harvesting has shown unpredictable variations in harvesting capability with long periods of zero production over large areas during wet weather.

The potential unreliability of biomass, longer-term changes in refuse and the size limitation of a power plant using only waste and/or biomass can be overcome combining biomass, refuse and coal. It also allows benefit from a premium electricity price for electricity from biomass and the gate fee associated with waste. If the power plant is gasification-based, rather than direct combustion, further benefits may be available. These include a premium price for the electricity from waste, the range of technologies available for the gas to electricity part of the process, gas cleaning prior to the main combustion stage instead of after combustion and public image, which is currently generally better for gasification as compared to combustion. These considerations lead to current studies of co-gasification of biomass or solid waste with coal (Speight, 2008).

Use of waste materials as co-gasification feedstocks may attract significant disposal credits. Cleaner biomass materials are renewable fuels and may attract premium prices for the electricity generated. Availability of sufficient fuel locally for an economic plant size is often a major issue, as is the reliability of the fuel supply. Use of more-predictably available coal alongside these fuels overcomes some of these difficulties and risks. Coal could be regarded as the *flywheel* which keeps the plant running when the fuels producing the better revenue streams are not available in sufficient quantities.

References

Bower, T. 2009. Oil: Money, Politics, and Power in the 21st Century. Grand Central Publishing, Hachette Book Group, Inc., New York.

BP. 2019. BP Statistical Review of World Energy. BP PLC, London, United Kingdom. https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2019-full-report.pdf

Bridgwater, A.V.; Czernik, S.; Piskorz, J. 2001. An Overview of Fast Pyrolysis. Prog. Thermochem. Biomass Convers., 2: 977-997.

Campbell, C.J. and Laherrère, J.H. 1998. The End of Cheap Oil. Scientific American. 278: 78-83.

Collett, T.S. 2009. Natural Gas Hydrates: A Review. In: Natural Gas Hydrates – Energy Resource Potential and Associated Geologic Hazards. Collett, T.S. Johnson, A.H. Knapp, C.C., and Ray Boswell; R. (Editors). AAPG Memoir 89, p. 146-219. American Association of Petroleum Geologists, Tulsa, Oklahoma.

Crane, H.D., Kinderman, E.M., and Malhotra, R. 2010. A Cubic Mile of Oil: Realties and Options for Averting the Looming Global Energy Crises. Oxford University Press, Oxford, United Kingdom.

Crocker, M., and Crofcheck, C. 2006. Reducing national dependence on imported oil. Energeia Vol. 17, No. 6. Center for Applied Energy Research, University of Kentucky, Lexington, Kentucky.

Delbianco, A., and Montanari, R. 2009. Encyclopedia of Hydrocarbons, Volume III/New Developments: Energy, Transport, Sustainability. Eni S.p.A., Rome, Italy.

Dobele, G., Urbanovich, I., Volpert, A., Kampars, V., and Samulis, E. 2007. Fast pyrolysis – Effect of wood drying on the yield and properties of bio-oil. Bioresources, 2: 699-706.

Eagles, L. 2006. Medium Term Oil Market Report. OECD/International Transport Forum Roundtable. International Energy Agency, Paris, France.

ESLC, 2013. A National Strategy for Energy Security: Harnessing American Resources and Innovation. Energy Security Leadership Council, Washington, DC.

Fleming, D. 2000. After Oil. Prospect Magazine, November. Issue No. 57: pp 12-13. http://www.prospect-magazine.co.uk.

Gary, J.G., Handwerk, G.E., and Kaiser, M.J. 2007. Petroleum Refining: Technology and Economics, 5th Edition. CRC Press, Taylor & Francis Group, Boca Raton, Florida.
Gerdes, J. 2007. Modest Non-OPEC Supply Growth Underpins $60+ Oil Price. SunTrust Robinson Humphrey, Atlanta, Georgia.
Ghoshal, S., and Sainik, V. 2013. Monitor and Minimize Corrosion in High-TAN Crude Processing. Hydrocarbon Processing, 92(3): 35-38.
Goldberg, D., and Saito, S. 1998. Detection of Gas Hydrates Using Downhole Logs. In: Hydrates - Relevance to World Margin Stability and Climate Change Gas. J.-P. Henriet and J. Mienert (Editors). The Geological Society, London, United Kingdom. Page 129-132.
Gudmestad, O.T., Zolotukhin, and Jarlsby, E.T. 2010. Petroleum Resources with Emphasis on Offshore Fields. WIT Press, Billerica, Massachusetts.
Hirsch, R.L. 2005. The Inevitable Peaking of World Oil Production. The Atlantic Council of the United States Bulletin, XVI(3): 1-9.
Hirsch, R.L., Bezdek, R., and Wendling, R. 2005. Peaking Of World Oil Production: Impacts, Mitigation, and Risk Management. February. http://www.netl.doe.gov/publications/others/pdf/Oil_Peaking_NETL.pdf
Hornbach, M.J., Holbrook, W.S., Gorman, A.R., Hackwith, K.L., Lizarralde, D., and Pecher, I. 2003. Direct Seismic Detection of Methane Hydrate on the Blake Ridge. Geophysics, 68: 92-100.
Hornung, A. 2014. Transformation of Biomass: Theory to Practice. John Wiley & Sons Inc., Chichester, West Sussex, United Kingdom.
Hsu, C.S., and Robinson, P.R. (Editors). 2017. Handbook of Petroleum Technology. Springer International Publishing AG, Cham, Switzerland.
Hubbert, M.K. 1956. Nuclear Energy and the Fossil Fuels - Drilling and Production Practice. Institute, Washington, DC.
Hubbert, M.K. 1962. Energy Resources. Report to the Committee on Natural Resources, National Academy of Sciences, Washington, DC.
Jackson, P.M. 2006. Why the Peak Oil Theory Falls Down: Myths, Legends, and the Future of Oil Resources. Cambridge Energy Research Associates, Cambridge, Massachusetts. November 14.
Jackson, P.M. 2007. Finding the Critical Numbers: What Are the Real Decline Rates for Global Oil Production? Cambridge Energy Research Associates, Cambridge, Massachusetts.
Kane, R.D., and Cayard, M.S. 2002. A Comprehensive Study on Naphthenic Acid Corrosion. Corrosion 2002. NACE International, Houston, Texas.
Khoshnaw, F.M. (Editor). 2013. Crude oil and Mineral Resources, WIT Press, Billerica, Massachusetts.
Kvenvolden, K.A. 1993. Gas Hydrates as a Potential Energy Resource – A Review of Their Methane Content. In: The Future of Energy Gases. D.G. Howell (Editor). Professional Paper No. 1570. United States Geological Survey, Washington, DC. Page 555-561.
Kvenvolden, K.A., and Lorenson, T.D. 2000. The Global Occurrence of Natural Gas Hydrate. In: Natural Gas Hydrates: Occurrence, Distribution, and Dynamics. In: C.K. Paull, and W.P. Dillon (Editors). AGU Monograph, American Geophysical Union, Washington, DC. Page 55.
Laherrère, J.H. 2001. Proceedings. EMF/IEA/IEW Meeting IIASA, Laxenburg, Austria. Plenary Session I: Resources, June 19.
Langeveld, H., Sanders, J., and Meeusen, M. 2010 (Editors). The Biobased Economy: Biofuels, Materials, and Chemicals in the Post-oil Era. TJ International, Padstow, Cornwall, United Kingdom; also published by Earthscan, London, United Kingdom.
Lee, S. 1990. Oil Shale Technology. CRC Press, Taylor & Francis Group, Boca Raton, Florida.
Lee, S. 1991. Oil Shale Technology. CRC Press, Taylor & Francis Group, Boca Raton, Florida.
Lee, S., and Shah, Y.T. 2013. Biofuels and Bioenergy: Processes and Technologies. CRC Press, Taylor & Francis Group, Boca Raton Florida.
Lerche, I., and Bagirov, E. 1998. Guide to Gas Hydrate Stability in Various Geological Settings. Marine and Petroleum Geology, 15: 427-438.

Luque, R., and Speight, J.G. (Editors), 2015. Gasification for Synthetic Fuel Production: Fundamentals, Processes, and Applications. Woodhead Publishing, Elsevier, Cambridge, United Kingdom.

Maini, B.B. 1999. Foamy Oil Flow in Primary Production of Heavy Oil under Solution Gas Drive. Paper No. SPE 56541. Proceedings. Annual Technical Conference and Exhibition, Houston, Texas USA, October 3-6. Society of Petroleum Engineers, Richardson, Texas.

Maini, B.B. 2001. Foamy Oil Flow. Paper No. SPE 68885. SPE J. Pet. Tech., Distinguished Authors Series. Page 54 – 64, October. Society of Petroleum Engineers, Richardson, Texas.

Meyer, R.F., and De Witt, W. Jr. 1990. Definition and World Resources of Natural Bitumens. Bulletin No. 1944. US Geological Survey, Reston, Virginia.

Meyer, R.F., and Attanasi, E.D. 2003. Heavy Oil and Natural Bitumen - Strategic Petroleum Resources. Fact Sheet 70-03. United States Geological Survey, Washington, DC. August 2003. http://pubs.usgs.gov/fs/fs070-03/fs070-03.html.

Nersesian, R.L. 2007. Energy for the 21st Century: A Comprehensive Guide to Conventional and Alternative Fuel Sources. M.E. Sharpe Inc., Armonk, New York.

Ohmes, R. 2014. Characterizing and Tracking Contaminants in Opportunity Crudes. Digital Refining. http://www.digitalrefining.com/article/1000893,Characterising_and_tracking_contaminants_in_opportunity_crudes_.html#.VJhFjV4AA; accessed November 1, 2014.

Pandey, A., Negi, S., Binod, P., and Larroche, C. (Editors) 2015. Pretreatment of Biomass: Processes and Technologies. Elsevier BV, Amsterdam, Netherlands.

Parkash, S. 2003. Refining Processes Handbook. Gulf Professional Publishing, Elsevier, Amsterdam, Netherlands.

Prins, M,J., Ptasinski, K.J., and Janssen, F.J.J.G. 2006a. More Efficient Biomass Gasification via Torrefaction. Energy, 31(15): 3458-3470.

Prins, M.J., Ptasinski, K.J., and Janssen, F.J.J.G. 2006b. Torrefaction of Wood: Part 1. Weight Loss Kinetics. Journal of Analytical and Applied Pyrolysis, 77: 28-34.

Prins, M.J., Ptasinski, K.J., and Janssen, F.J.J.G. 2006c. Torrefaction of Wood: Part 2. Analysis of Products. Journal of Analytical and Applied Pyrolysis, 77(1): 35-40.

Ratner, M., and Tiemann, M. 2014. An Overview of Unconventional Oil and Natural Gas: Resources and Federal Actions. CRS Report. Congressional Research Service, Washington, DC. January 23.

Sandrea, I. 2014. US Shale Gas and Tight Oil: Industry Performance: Challenges and Opportunities. Oxford Institute for Energy Studies, University of Oxford, Oxford, United Kingdom. http://www.oxfordenergy.org/wpcms/wp-content/uploads/2014/03/US-shale-gas-and-tight-oil-industry-performance-challenges-and-opportunities.pdf; accessed October 14, 2014.

Scouten, C.S. 1990. Oil Shale. In: Fuel Science and Technology Handbook. J.G. Speight (Editor). Marcel Dekker, New York. Chapters 25-31. Page 795-1053.

Shalaby, H.M. 2005. Refining of Kuwait's Heavy Crude Oil: Materials Challenges. Proceedings. Workshop on Corrosion and Protection of Metals. Arab School for Science and Technology. December 3-7, Kuwait.

Sheng, J.J., Maini, B.B., Hayes, R.E., and Tortike, W.S. 1999. Critical Review of Foamy Oil Flow. Trans. Porous Media, 35: 157-187.

Simmons M.R. 2000 Fighting Rising Demand and Rising Decline Curves: Can the challenge be met? SPE Asia Pacific Oil and Gas Conference, Yokohama, April 25. http://www.simmonscointl.com/web/downloads/spe.pdf

Speight, J.G. (Editor). 1990. Fuel Science and Technology Handbook, Marcel Dekker, New York.

Speight, J.G. 1997. Tar Sands. Kirk-Othmer Encyclopedia of Chemical Technology 4th Edition. 23: 717.

Speight, J.G. 2000. The Desulfurization of Heavy Oils and Residua 2nd Edition. Marcel Dekker Inc., New York.

Speight, J.G. and Lee, S. 2000. , Environmental Technology Handbook, Taylor & Francis, Philadelphia, Pennsylvania.

Speight, J.G. 2008. Synthetic Fuels Handbook: Properties, Processes, and Performance. McGraw-Hill, New York.
Speight, J.G. 2011a. An Introduction to Petroleum Technology, Economics, and Politics. Scrivener Publishing, Salem, Massachusetts.
Speight, J.G. (Editor). 2011b. Biofuels Handbook. Royal Society of Chemistry, London, United Kingdom.
Speight, J.G. 2011c. The Refinery of the Future. Gulf Professional Publishing, Elsevier, Oxford, United Kingdom.
Speight, J.G. 2012. Shale Oil Production Processes. Gulf Professional Publishing, Elsevier, Oxford, United Kingdom.
Speight, J.G. 2013a. The Chemistry and Technology of Coal 3rd Edition. CRC Press, Taylor & Francis Group, Boca Raton, Florida.
Speight, J.G. 2013b. Coal-Fired Power Generation Handbook. Scrivener Publishing, Salem Massachusetts.
Speight, J.G. 2013c. Heavy and Extra Heavy Oil Upgrading Technologies. Gulf Professional Publishing, Elsevier, Oxford, United Kingdom.
Speight, J.G. 2013d. Oil Sand Production Processes. Gulf Professional Publishing, Elsevier, Oxford, United Kingdom.
Speight, J.G. 2013e. Heavy Oil Production Processes. Gulf Professional Publishing, Elsevier, Oxford, United Kingdom.
Speight, 2013f. Shale Gas Production Processes. Gulf Professional Publishing, Elsevier, Oxford, United Kingdom.
Speight, J.G. 2014a. The Chemistry and Technology of Petroleum 5th Edition. CRC Press, Taylor & Francis Group, Boca Raton, Florida.
Speight, J.G. 2014b. The Gasification of Unconventional Feedstocks. Gulf Professional Publishing, Elsevier, Oxford, United Kingdom.
Speight, J.G. 2014c. High Acid Crudes. Gulf Professional Publishing, Elsevier, Oxford, United Kingdom.
Speight, J.G. 2015a. Handbook of Hydraulic Fracturing. John Wiley & Sons Inc., Hoboken, New Jersey.
Speight, J.G. 2015b. Offshore Oil and Gas. Gulf Professional Publishing, Elsevier, Oxford, United Kingdom.
Speight, J.G. 2016. Introduction to Enhanced Recovery Methods for Heavy Oil and Tar Sands 2nd Edition. Gulf Professional Publishing Company, Elsevier, Oxford, United Kingdom.
Speight, J.G., and Islam, M.R. 2016. Peak Energy – Myth or Reality. Scrivener Publishing, Beverly, Massachusetts.
Speight, J.G. 2017. Handbook of Petroleum Refining. CRC Press, Taylor & Francis Group, Boca Raton, Florida.
Speight, J.G. 2019a. Handbook of Petrochemical Processes. CRC Press, Taylor & Francis Group, Boca Raton, Florida.
Speight, J.G. 2019b. Natural Gas: A Basic Handbook 2nd Edition. Gulf Publishing Company, Elsevier, Cambridge, Massachusetts.
Speight, J.G. 2020. Shale Gas and Shale Oil Production Processes, Elsevier Inc., Cambridge, Massachusetts.
United States Congress. 1976. Public Law FEA-76-4. United States Library of Congress, Washington, DC.
Wihbey, P.M. 2009. The Rise of the New Oil Order: The Facts behind the New Massive Supplies, the Exciting New Technologies, and the Emerging Powers of the XXIst Century. Academy & Finance SA, Geneva, Switzerland.

World Energy Council. 2008. World Energy Outlook: Global Trends to 2030. International Energy Agency, Paris, France.

Wright, L., Boundy, R, Perlack, R., Davis, S., and Saulsbury. B. 2006. Biomass Energy Data Book: Edition 1. Office of Planning, Budget and Analysis, Energy Efficiency and Renewable Energy, United States Department of Energy. Contract No. DE-AC05-00OR22725. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Yergin, Y. 1991. The Prize: The Epic Quest for Oil, Money and Power. Free Press, New York.

Yergin, D. 2011. The Quest: Energy Security and the Making of the Modern World. Penguin Press HC, New York.

Yeung, T.W. 2014. Evaluating Opportunity Crude Processing. Digital Refining. http://www.digitalrefining.com/article/1000644; accessed October 25, 2014.

Zatzman, G.M. 2012. Sustainable Resource Development. Scrivener Publishing LLC, Beverly, Massachusetts.