Shiraz University
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REPORT ON RESEARCH ABOUT LIQUID FUELS

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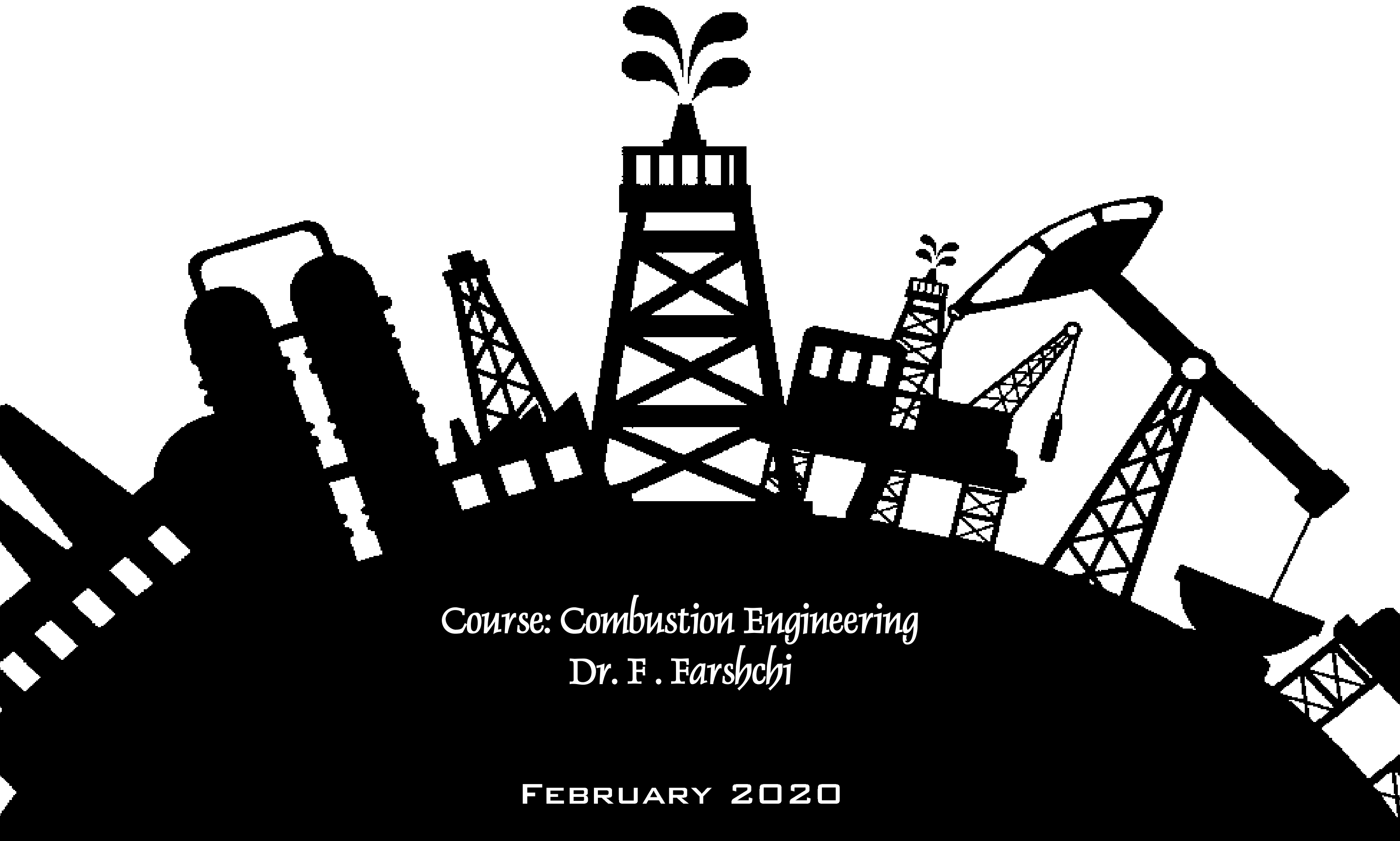

Course: Combustion Engineering
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1. Introduction

Fuels are playing an important role in human life. They are a key component in today's energy processes. Fuels have made our lives easier today than ever before. On the other hand, they have some side effects on environment, society, health, futures and etc but it's hard to imagine even a day without fuels. The major use of fuels is to make energy for daily processes and activities. The source of this energy has developed till now and it is so clear, due to technology development it will more in futures.

As you known, fuels are found in three forms: Gaseous, Liquid and Solid. They have individual properties that make different in their application. The most familiar form is liquid fuel. We have wide types of liquid fuels that some of them are use in our daily activities and others use in industrial processes and other activities.

During the *Industrial Revolution*, the major energy source used in the world changed from charcoal (wood) to various forms of coal. As technology developed, the world began moving from the use of coal to crude oil (the most abundant liquid fuel used in industry today), and its derivatives, to provide the energy and heating requirements needed.

The modern era of viable crude oil production and use began with commercial wells in the mid-1800s. An increasing need for oil products in technology (such as gasoline for the internal combustion engine and automobiles) spurred massive efforts in oil exploration and recovery in the early 1900s.

A barrel of crude oil can typically be refined to provide some products which are shown in Table 1.1.

Products	Volume(Liter)
Gasoline	42 L
Kerosene	20 L
Gas oil and Distillates	77 L
Heavier Distillates	20 L

Table 1.1Typically products of a barrel of crude oil (159 L)

The end products derived from crude oil number in the thousands. Thus, crude oil is a very important fossil fuel source. Nearly all modern energy systems are critically dependent on fossil fuels. Parts of this are due to the cost and availability of fossil fuels versus renewable energy sources, but an often overlooked reason is from the intrinsic benefits that these fuels bring.

Based on information provided by the United States Energy Information Administration, retrieved in 31 March 2019, the amount of oil production in the world in 2019 is 80,622,000 barrel per day.

According to this organization, major oil deposits found in the United States prompted it to become a major world oil producer. Second and third are Saudi Arabia and Russia, respectively. In the ranking provided by the company, I.R of Iran is the fifth largest crude oil producer in the 2019. Table 1.2 shows some of the countries in this ranking.

#Rank	Country	Oil Production 2019 (bbl/day)
1	United States	15,043,00
2	Saudi Arabia	12,000,000
3	Russia	10,800,000
4	Iraq	4,451,516
5	I.R Iran	3,990,956
6	China	3,980,650
7	Canada	3,662,694
8	United Arab Emirates	3,106,077
9	Kuwait	2,923,825
10	Brazil	2,515,459

Table1.2 Oil producer ranking in 2019 by United States Energy Information Administration

As we known it takes billions of years for oil reservoirs to form. As table 1.2 shows, this amount of oil extraction is much higher than its production, so these reservoirs will run out in the near future, and can no longer be used to generate energy.

With advances in technology and science, there is alternative source for fossil fuels reservoirs, called "Bio fuels" produced from biomass. They also called "Green Fuels".

Here we encounter some questions:

- What are the sources of fuels?
- What material do we call fuels?
- How many fuel categories do we have?
- What are properties of liquid fuels?
- How many types of liquid fuels do we have?
- How are liquid fuels produced?
- How bio fuels are created?
- What is the different between fossil fuels and bio fuels?
- What are advantages and disadvantages of fossil fuels?
- What are advantages and disadvantages of bio fuels?
- …

In this research, I attempted to find reasonable answers to these questions.

2. Fuels

First and foremost, the question arises as *What is Fuel?* Of the various definitions, the most complete is that, *any combustible substance which may be burnt (or other chemical changes) to supply energy for practical applications without the formation of excessively objectionable byproducts is called Fuel.*
Fuels have many useful applications. We use them in

- ✓ Transportation (ground roads, marine and aviation)
- ✓ Fuel internal combustion engines e.g. cars, trucks, bus, motorbikes and other vehicles.
- ✓ Heating and Cooking
- ✓ Lighting
- ✓ Power generation
- ✓ Industrial power
- ✓ Engines of some Rockets
- ✓ Jets and spacecraft
- ✓ …

This widespread use of fuels suggests that there is certainly not one type of fuel used in all of the above applications, so fuels must be of different types.

Fuels are classified into different categories. Two of its most important categories are:

1. According to physical state in which they exist in nature
   - **Gaseous Fuels**
   - **Liquid Fuels**
   - **Solid Fuels**
2. According to mode of procurement (sources)
   - **Natural**
   - **Manufactured** (Synthetic Fuels)

In this research, I have examined liquid fuels with both modes of production. (Figure 2.1)

3. Liquid Fuels

Any fuel that has the following characteristics is a liquid fuel:

- Take shapes of the container
- Able to be poured
- It can not compressed to fit into a smaller space
- They have random arrangement
- Does not have defined shape
- Has a defined volume
- Particles are close but able to flow
- Particles can slide over one another
- Density is lower than solid
- Kinetic energy of particles is more than solid

Under the term "liquid fuels" may be included all substances which are combustible and can be made liquid without serious difficulty. Taking these in seven sections, we have:

1. Animal oil and fast – neatsfoot, whale, tallow, etc.
2. Fish oil – shark, cod, herring, etc.
3. Vegetable oils – linseed, rape, cotton, etc.
4. The whole class of spirituous liquors distilled from fermenting starchy substances, such as potatoes, spirit manufactured in this way being largely used in Germany for industrial and motor car purposes.
5. Vegetable essential oils – eucalyptus, turpentine, and other distillation products of wood.
6. Coal gas tars, creosote, coke oven tars, blast furnace tars.
7. Petroleum and other mineral oils found liquid in nature or distilled from bituminous shales.

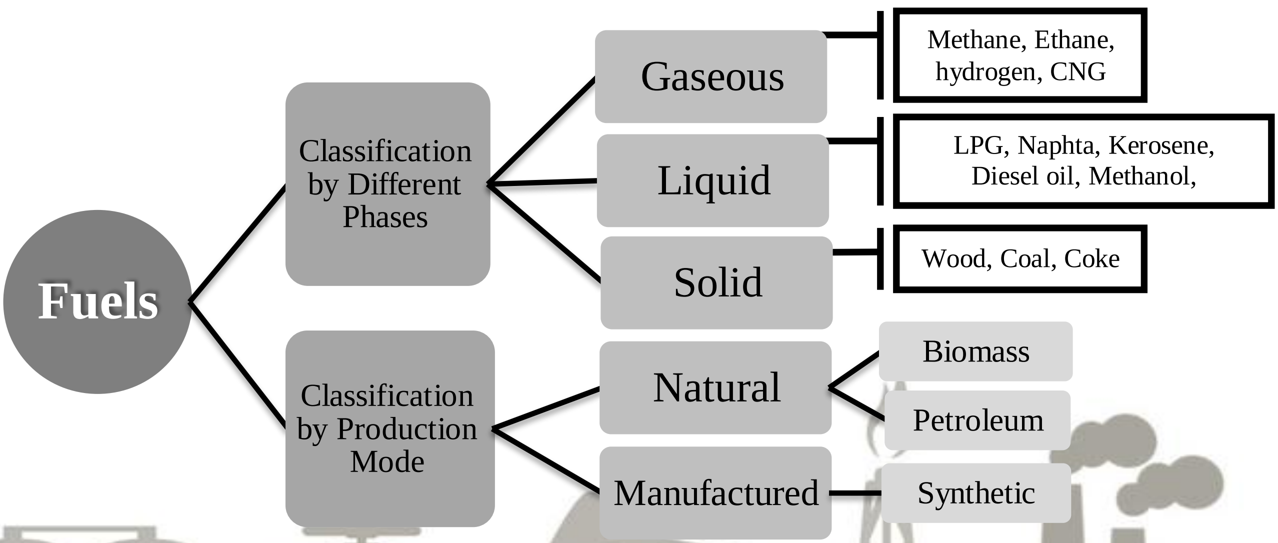


Figure 2.1 Fuels Classifications

The first five sections may be at once rejected, not so much on account of unsuitability as fuel, but by reason of price, therefore we shall only consider petroleum shales.
Liquid fuels are used more frequently among different fuels every day. The reason that liquid fuels are more used is that, these types of fuel have more *advantages* than others that are outlined below:

1. The handling of them is easier and they require less storage space.
2. They have higher heating value per unit mass
3. They burn without dust, ash, clinkers, etc.
4. They are easy to transport through pipes.
5. Easy to control the combustion
6. Ease to ignition and stopping off the operation.
7. The combustion of them is uniform.
8. They can be burnt with a fair degree of ease and attain high temperature very quickly compared to solid fuels.

As mentioned in the previous sections, liquid fuels have different types, each of which is designed for different applications. In the next sections, we discuss the types of these fuels.

4. Natural Liquid Fuels

In part 2, we saw that one of the fuel categories was the category based on mode of procurement. In this section, we analysis fuels of natural origin. Natural fuels are fuels that originate in nature and are obtained by performing processes and changes such as, extraction, distillation, refining, pyrolysis and etc on a raw materials and converting them into fuel.
The source of these fuels are *crude oil*, from which hydrocarbon fuels are derived, or *biomass* that from organic materials such as waste of trees and animals, fuels have been derived.

4.1 Liquid Fuels Derived from Crude Oil

Crude oil is a complex material whose intrinsic properties have made it a very important material in the world. The primary chemical components of crude oil are carbon, hydrogen, sulfur, oxygen, and nitrogen. The percentages of these elements found in a crude oil are most frequently used to characterize the oil. Crude oils also contain inorganic elements such as vanadium, nickel, and sodium, and usually contain some amount of water and ash (noncombustible material). The main hydrocarbon constituents of crude oils are alkanes (paraffins), cycloalkanes (naphthenes), and aromatics.
Crude oil compositions are relatively constant. However, slight deviations in composition can result in vastly different refining methods.
According to the American Standard Testing Methods (ASTM) D-396, fuel oils are divided into *grades*, based on the types of burners for which they are suitable.
The grades are determined by those values determined to be most significant in figuring performance characteristics.
The two classifications that separate these fuel oils are "**distillates**" and "**residuals**," where distillates indicate a distillation overhead product (lighter oils) and residuals indicate a distillation bottom product (heavier oils).

4.1.1 Light Oils

Grade 1 and 2 oils are light distillate (fuel) oils used primarily in applications that do not require atomization by air or steam in order to reduce droplet size for proper burning. These light distillate oils will typically distill out between 230°C and 430°C.

4.1.2 Heavy Oils

No. 4 oil is heavy distillate oil typically blended from, and thus having characteristics of, both light distillates and residual oils. These oils do not readily combust and therefore require some type of atomization, but still fall into a viscosity range that does not require preheating prior to burning.

4.1.3 Residual Oils

No. 6 oil is a heavy residual oil sometimes referred to as Bunker C oil. This oil requires significant atomization for proper combustion. Due to its high viscosity, No. 6 oil requires heating during handling and further heating prior to combustion chamber injection. No. 6 oil is usually preheated to 66°C–93°C, to decrease its viscosity, before being atomized and injected into the burner.
Table 4.1.1 helps in differentiating between these various classifications, and Table 4.1.2 reveals typical analyses for these oils.

When a crude oil is refined, the first step is, invariably, *distillation*. The purpose of distillation is to separate lighter components from heavier ones, based on their respective volatility. The target of distillation is to separate the crude oil into *different fractions*. Each fraction consists of a *boiling point range* that will yield a mixture of hydrocarbons (see Table 4.1.3).

Distillation Fraction	Temperature Range (°F)
Butanes and lighter	<90
Gasoline	90 – 220
Naphtha	220 – 315
Kerosene	315 – 450
Fuel oils	450 – 800
Residue	>800

Table 4.1.3 General Fraction Boiling Points

Some of these mixtures can then be used as product (fuels, solvents, etc.) or further refined into gasoline or other desirable mixtures.

Classification	No. 1 Distillate	No. 2 Distillate	No. 4 Distillate (Heavy)	No. 6 Residual
Density (kg/m^3) at 15°C, max	850	876	—	—
Viscosity at 40°C mm/s^2				
Min	1.3	1.9	>5.5	—
Max	2.1	3.4	24	—
Viscosity at 100°C mm/s^2, max	—	—	—	50
Flash point (°C), min	38	38	55	60
Pour point (°C), max	−18	−6	−6	—
Ash, % mass, max			0.1	
Sulfur, % mass, max	0.5	0.5		
Water and sediment, % vol., max	0.05	0.05	0.5	2.0

Table 4.1.1 Requirements for Fuel Oils (per ASTM D 396)

	No. 1 Fuel Oil	No. 2 Fuel Oil	No. 4 Fuel Oil	No. 6 Fuel Oil (sour)
Ash (%)	< 0.01	< 0.01	0.02	0.05
Hydrogen (%)	13.6	13.6	11.7	11.2
Nitrogen (%)	0.003	0.007	0.24	0.37
Sulfur (%)	0.09	0.1	1.35	2.1
Carbon (%)	86.4	86.6	86.5	85.7
Heat of combustion (HHV), Btu/lb	20187	19639	19382	18343

Table 4.1.2 Typical Analysis of Different Fuel Oils

Now let's look at fuels derived from distillation of crude oil and their applications. (Figure 4.1.1)
As mentioned earlier, after the crude oil is refined, it is distilled into the distillation tower at high temperature and after distillation; the various trays consist of different fractions of a hydrocarbons mixture with different boiling point range.
Crude oil distillation occurs on the basis of volatility. Volatile materials are vaporized earlier and placed in trays above the distillation tower and materials with less volatility are placed in the lower trays of the tower. Some of the outputs of these trays are used as liquid fuel in various applications, including:

1. Name: **LPG** (Liquified Petroleum Gas)
   Hydrocarbon range: **C_3 and C_4**
   Boiling range(°C): **< 20**
   Main uses: **Automobile fuel, heating, cooking**
   Description: Liquefied petroleum gas (LPG) is the general term used to describe a hydrocarbon that is stored as a liquid under moderate pressure but is a gas under normal atmospheric conditions.
2. Name: **Light petroleum** (petroleum ether)
   Hydrocarbon range: **C_5 to C_7**
   Boiling range(°C): **20 – 90**
   Main uses: **Solvent**
   Description: mixed paraffinic (normal and iso) and cycloparaffinic hydrocarbons
3. Name: **Crude Naphta**
   Hydrocarbon range: **C_5 to C_{14}**
   Boiling range(°C): **30 – 150**
   Main uses: **Solvent**
4. Name: **Liquid Naphta**
   Hydrocarbon range: **C_5 to C_{14}**
   Boiling range(°C): **100 – 157**
   Main uses: **Liquid Fuel**
   Description: Naphtha is categorized, based on its volatility, into light, intermediate, and heavy naphta.
   Naphtha is a major constituent of gasoline; however, it generally requires further refining to make suitable quality gasoline.
5. Name: **Gasoline (petrol)**
   Hydrocarbon range: **C_6 to C_{18}**
   Boiling range(°C): **70 – 200**
   Main uses: **Motor fuel, solvent in dry cleaning**
   Description: Gasoline or petrol is a clear petroleum derived flammable liquid that is used primarily as a fuel in most internal combustion engines.
   Characteristic: the characteristic of a particular gasoline blend to resist igniting too early (which

causes knocking and reduces efficiency in reciprocating engines) is measured by its octane rating which is produced in several grades.

6. Name: **Ligroin**

Hydrocarbon range: **C_7 to C_8**
Boiling range(°C): **90 – 120**
Main uses: **Motor fuel & solvent for fats & oils**
Description: Ligroin is a mixture of hydrocarbons, a colorless flammable liquid.

7. Name: **Aviation Fuels**

Hydrocarbon range: **C_5 to C_{15}**
Boiling range(°C): **150 – 300**
Applications: **Jet Engines & Aircrafts**
Description: It is a specialized type of petroleum-based fuel used to power aircraft. It is generally of a higher quality than fuels used in less critical applications, such as heating or road transport, and often contains additive to reduce the risk of icing or explosion due to high temperature.
There are two types of aviation fuel:

- **Jet Fuel**
  Is typically a colorless or straw-colored liquid with two most widely used categories being Jet A and Jet A-1. The main difference between the two is the freeze point.
- **Avgas (aviation gasoline**)
  Is used in spark-ignited internal combustion engines in aircraft.

Other aviation fuels:

- **TS-1**
- **Jet B**
- **JP-8**
- **JP-5**

8. Name: **Kerosene**

Hydrocarbon range: **C_{10} to C_{18}**
Boiling range(°C): **150 – 300**
Applications: **Illuminant, making oil gas, fuel for jet engines, central heating system, lamps and stoves.**
Description: Kerosene *can't use in automobile*, because kerosene doesn't vaporize quite as readily at low temperature like gasoline. This means we can have trouble starting our cars if the temperature is below that ideal range.
*The only car company that mass produced a car that could use kerosene was the Saab 99 back in 1980-ish. It used a gasoline-start and switch to kerosene afterwards.

9. Name: **Diesel Oil**

Hydrocarbon range: **C_{15} to C_{25}**
Boiling range(°C): **300 – 400**
Main uses: **Locomotive fuels**
Description: Diesel oil is used in diesel engines, whose fuel ignition take place without any spark as a result of compression of the inlet air mixture and then injection of fuel. Diesel oil is commonly used in public buses and school buses. Many industrial facilities, large buildings, institutional facilities, hospitals and electric utilities have diesel generator for backup and emergency power supply.

10. Name: **Gas Oil (Heavy oil , Fuel oil)**

Hydrocarbon range: **C_{18} to C_{38}**
Boiling range(°C): **> 300**
Main uses: **Fuel for diesel engines**
Description: Gas oil derived from the vacuum distillation of the residuum from the atmospheric distillation of crude oil. Gas oil is intended to be used in construction, farming and heating. It should not be used in vehicles that use public roads.
***Mazut** is a heavy, low quality Fuel oil, used in power plant and similar applications.

These are not the all of the fraction of crude oil distillation; there are other products such as lubricating oil, waxes, asphalt and etc but because of non0fuel applications, I have refused to review them.

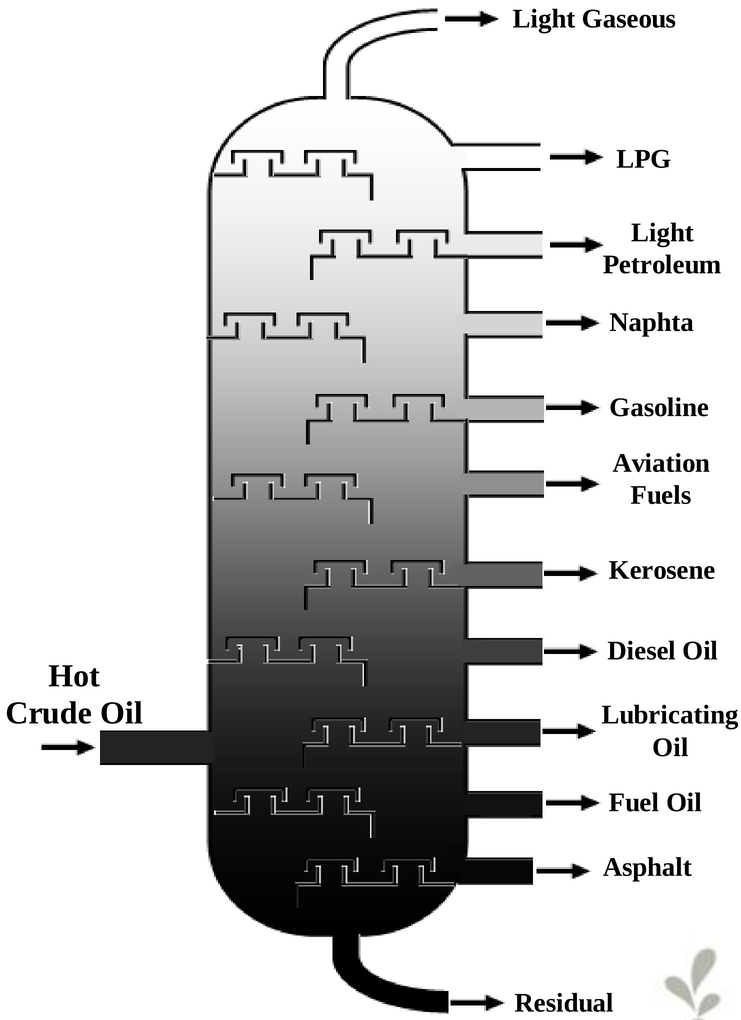


Figure 4.1.1 Crude Oil Distillation Tower

As mentioned earlier, crude oil is a very complex material and comprises a wide range of different materials, including hydrocarbons. Fuel categorization based on carbon number is not very accurate. Rather, it is approximate average of hydrocarbons that represent the fuels. As a result, crude oil is a spectrum of hydrocarbons and it is not possible to determine precisely which range of hydrocarbons belongs to which products.
Despite the advantages and benefits of liquid petroleum fuels, they also have some disadvantages:

1. Petroleum is a significant contributor to greenhouse gas emission.
2. Petroleum causes pollution and release hazardous substances like sulphur.
3. Fossil fuels are a finite resource.
4. It can help raise the temperature of the earth.
5. Hydrocarbons change the composition of ocean water and endanger aquatic life.
6. Drilling for oil is getting more difficult and expensive because we are now drilling as deep than 20,000 feet to find new reserves.

Because of these disadvantages, using fossil fuels is not wise and endangering our health, environment and futures.

A *good fuel* must:

- ❖ Be readily available
- ❖ Be cheap
- ❖ Be renewable
- ❖ Burn easily at a moderate rate
- ❖ Produce a large amount of heat
- ❖ Be environment friendly
- ❖ Not leave behind any toxic substances
- ❖ Have low moisture content
- ❖ Have low NO_x combustible matter

And so, fossil fuels are not good fuel. The best alternative fuels are clean and renewable fuels like biofuels.

4.2 Liquid Fuels Derived from Biomass

Green fuels also called green hydrocarbons, biofuels are fuels produced from biomass sources like plant waste or animal fat, through a variety of biological and thermochemical processes. These products are similar to petroleum fuels and are therefore considered fully infrastructure compatible fuels. They can be utilized in engines without engine modification.

4.2.1 Brief History of Biofuels

Biofuels in the solid form has been in use ever since man discovered fire. Wood was the first form of biofuel that was used even by the ancient people for cooking and heating. Biofuel had been used since a very long time for the production of electricity. This form of fuel was discovered even before the discovery of the fossil fuels, but with the exploration of the fossil fuel like gas, coal, and oil the production and use of biofuel suffered a severe impact. With the advantages placed by the fossil fuels they gained a lot of popularity especially in the developed countries. Liquid biofuel have been used in the automotive industry since its inception.
Rudolf Diesel (Figure 4.2.1) is the German inventor of the diesel engine. This engine could run on a variety of fuels, including vegetable oil and later Henry Ford (Figure 4.2.2) designed the Model T car which was produced from 1903 to 1926. This car was completely designed to use hemp derived biofuel as fuel.

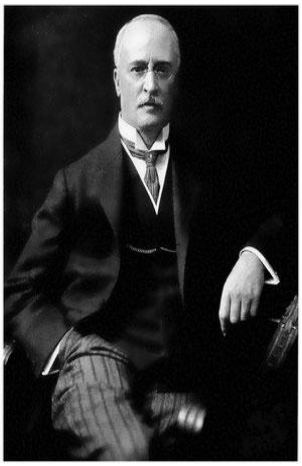


Figure 4.2.1
Rudolf Christian Kari Diesel
1858 – 1913

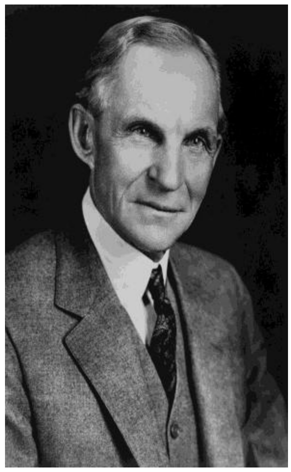


Figure 4.2.2
Henry Ford
1863 – 1947

During World War II (1939 to 1945), when petroleum fuel supplies were interrupted, vegetable oil was used as fuel by several countries, including Brazil, Argentina, China, India, and Japan. However, when the war ended and petroleum supplies were again cheap and plentiful, vegetable oil fuel was forgotten.
The first biodiesel manufacturing plant specifically designed to produce fuel was started in 1985 at an agricultural college in Austria. Since 1992, biodiesel has been commercially manufactured across Europe, with Germany being the largest producer.
Global biofuel production has gradually increased from 9.2 million metric tons of oil equivalents in 2000 to 95.37 million metric tons of oil equivalents in 2018.
Until today, the number of biofuel production has grown steadily, and the top five biofuel producers in 2018 are United States, Brazil, Indonesia, Germany and China.

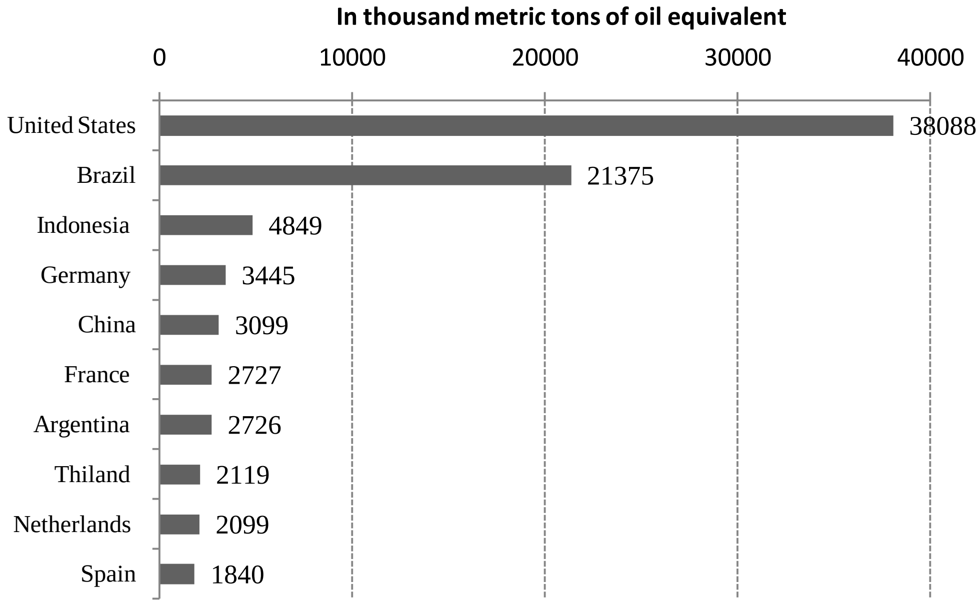


Figure 4.2.3 Leading Countries Based on Biofuels Production in 2018

Biofuels have been around as long as cars have at the start of the 20th century Henry Ford planned to fuel his model TS with ethanol, and early diesel engines were shown to run on peanut oil.
Bio Fuels are among the most promising replacement for non-renewable fossil fuels such as petroleum and coal and are derived from living organisms or from metabolic by-products such as food waste products.
Unlike other renewable energy sources, biomass (organic material) can be converted directly into combustible fuel which becomes biofuel.
Biofuels can be liquids or gases (made from sugars, starch, vegetable oil or animal fats). Gaseous biofuels produced are hydrogen and methane. They can also be solids like wood, sawdust, grass cuttings, domestic refuse, charcoal, agricultural waste, non food energy crops and dried manure.
Biomass can also be gasified to produce biogas. Hydrogen is recovered from it and catalytically converted to methanol or ethanol. The gas can also be run through a biological reactor to produce ethanol.

The two most widely used biofuels are:

- ***Ethanol***
- ***Biodiesel***

And both are found in liquid forms. Other liquid biofuels include methanol, Fischer-Tropsh diesel and gasoline.

4.2.2 Ethanol

Ethanol is an alcohol fuel produced by the fermentation of sugar found in sugarcane, rice, potato skins and is commonly made from wheat, corn and sorghum.

Ethanol fuel is the most common biofuel worldwide. It is a same type of alcohol found in alcoholic beverages who is Ron can be used as a fuel for vehicles in its pure form.
It is usually used as a gasoline additive to increase octane and control vehicle emissions.
Ethanol is most commonly used to power automobiles through it may be used to power other vehicles, such as farm tractors, boats and airplanes. It is generally seen that ethanol only engines are tuned to give slightly better power than gasoline engines.
Ethanol has smaller energy density than gasoline, this fact means that ethanol fuel tanks require more fuels stops than the gasoline tanks to travel the same distance.
The largest national use of ethanol biofuel exists in Brazil. It is also widely used in United States together both these countries amounted to 88% of the Worlds ethanol fuel production in 2010.

4.2.3 Biodiesel

Biodiesel is a renewable, cleaner burning alternative for Petroleum based diesel fuel. In its pure form it is the lowest emission diesel fuel. It is safe to handle and transport because it is as biodegradable as sugar.
Biodiesel is made from algae, animal fats or vegetable oils or recycled cooking Grease. Biodiesel is made to a chemical process called transesterification whereby the glycerin is separated from the fat or vegetable oil. The process leaves behind two products methyl esters which actors biodiesel and glycerine and valuable by-product.
When mixed with petroleum diesel, biodiesel is compatible with unmodified engines – be it a car, bus

truck, boat, construction equipment, generator or oil home heating units. It also decreases toxic emissions. Biodiesel is the most common biofuel in Europe and since it is primarily derived from plants and animals, the supply can be replenished by means of farming and recycling. Biodiesel can liberate deposits mounted up on pipes and tank walls from previous traditional diesel fuel, thus primary causing fuel filter clogs when used for the first time.

Biodiesel and ethanol are both clean grow your own fuels, which can be produced on site and local villages or communities from locally available, renewable resources.

Biofuels are grouped in three categories based on the type of feed used to produce them:
1st Generation – Food Crops
For ethanol feed stocks include sugar cane, corn maze and others.
For biodiesel feed stocks are naturally occurring vegetable oil such as soybean and canola.

2nd Generation – Cellulosic Materials
Cellulosic materials such as wood grasses and inedible parts of plants are more difficult to break down through fermentation and therefore require pre-treatment before it can be processed.

3rd Generation – Algae
Biofuels are produced using the lipid production from algae.


Algae

In addition, the term advanced biofuels is used to describe the relatively new technological field of biofuels production that uses waste such as garbage, animal fats and spent cooking oil to produce liquid fuels.

The biofuels can be produced in a number of ways.
For instants ethanol is produced using a process similar to brewing beer with starch crops are converted into sugars, the sugars are fermented into ethanol and the ethanol is then distilled into its final form which can be used as a fuel.
Apart from fermentation ethanol is also produced by the process called hydrolysis where materials that have little cellulose found in the tissues of plants and other organic materials are used.
Another process used to extract biofuel is called fast or flash pyrolysis. It accurse by heating compact solid fuels at 350 to 500 degrees C for a very short period of time (less than 2 seconds) bio oils are produced in this manner.
Discovery of huge petroleum deposits kept gasoline and diesel cheap for decades while biofuels was largely forgotten.
However with the recent rise in oil prices along with growing concern about global warming caused by carbon dioxide emissions, biofuels have been regaining popularity.
Thus making biofuels and accessible option to fossil fuels both socially and economically apart from being used as an alternative to fossil fuels in power generation.
Biofuels have several other applications. Biofuels can be used for cooking purposes and as fuel for automobiles. By-products of biofuels can be used as manure and fertilizer. It can also be used as heating fuels in domestic and commercial boilers.

Biofuels have their own set of advantages:

1. Biofuels are derived from biomass that is renewable and biodegradable (derive from organic materials) compared to other forms of renewable energy, biofuel is far more simple and easy to use.
2. This renewable source of energy helps in reducing the greenhouse gases as compared to the fossil fuels.

Clean burning energy sources reduce the toxic pollutant emissions. Bio fuel could provide significant environmental benefits by decreasing the greenhouse gas emissions because of the fact that these bio fuels are primarily derived from crops which absorb carbon dioxide. Thus the balance of carbon dioxide is sustained and maintained in the atmosphere. It is safe non-toxic and not detrimental is accidentally spilt because it breaks down very quickly.

3. Biofuel can be readily combined with conventional petroleum diesel in the fuel tank and any point in time and does not require special equipment or a modification in all engines.
4. Moreover it is capable of improving the performance of the engines as it is a quality fuel that cleans the fuel system, increasing octane and lessening harmful emissions all of which help to lengthen the life of vehicles.
5. Currently commercial biodiesel is more expensive than ethanol and in the perspective of land use and agricultural efficiency; ethanol seems to be a good option as output of gallons per acre is relatively more.
6. Biofuels are relatively affordable as compared to the other sources of energy. It is also can create numerous jobs since it can practically be made domestically.

Biofuels are not devoid of some disadvantages:

1. Biofuel production requires the increased need of growing crops to meet the demand and for this more Farmlands will require.
2. Biofuels are not readily accessible due to lack of ethanol or biodiesel pumps and existing filling stations.
3. The paint on the automobile may dissolve with the use of biodiesel in due course. However this can be prevented by immediately wiping off of washing with small amount of soap and water.
4. Depending on the type of fat sources, the biofuel was derived from at around 32 degrees F biodiesel crystallizes. In cold weather the biodiesel freezes the fuel system and injection pump. However this can be taken care of by keeping it warm.
5. Biofuel has a very promising potential. As an alternative to this traditional diesel or gasoline fuel, it is expected to yield significant energy security and environmental advantages to its consumers.

Biofuels are currently the only viable replacement to petroleum transportation fuels because they can be used in existing combustion engines.

This is an increasingly important advantage with growing concern about the environmental impacts of fossil fuels around the globe.

5. Manufactured Fuels

The need to achieve net-zero greenhouse gas emissions from all human activities has never been clearer. One area requiring urgent action is the transition from the use of fossil fuels for transport. Whilst the decarbonisation of electricity is progressing and many transport modes can feasibly be electrified, some transport modes, such as heavy-duty vehicles, aircraft and shipping will require different technological options. The cost, volume and energy density of alternative fuels are of critical importance.

Synthetic fuels can be manufactured, via chemical conversion processes from ‘defossilised’ carbon dioxide sources such as point source capture from the exhausts of industrial processes, direct capture from air or from biological sources. Whilst synthetic fuels emit carbon dioxide when burnt, this report demonstrates that synthetic fuels could, in the medium to long term (5 to 10+ years), displace fossil fuels. However, a full life cycle assessment of their manufacture has yet to be evaluated in depth.

Two methods of making carbon based sustainable synthetic fuels are explored in this briefing (Figure 5.1);

i. Electro fuels (efuels) made using captured carbon dioxide in a reaction with hydrogen, generated by the electrolysis of water, and
ii. Synthetic biofuels made through the chemical or thermal treatment of biomass or biofuels.

Growing concern about the environmental impacts of fossil fuels around the globe

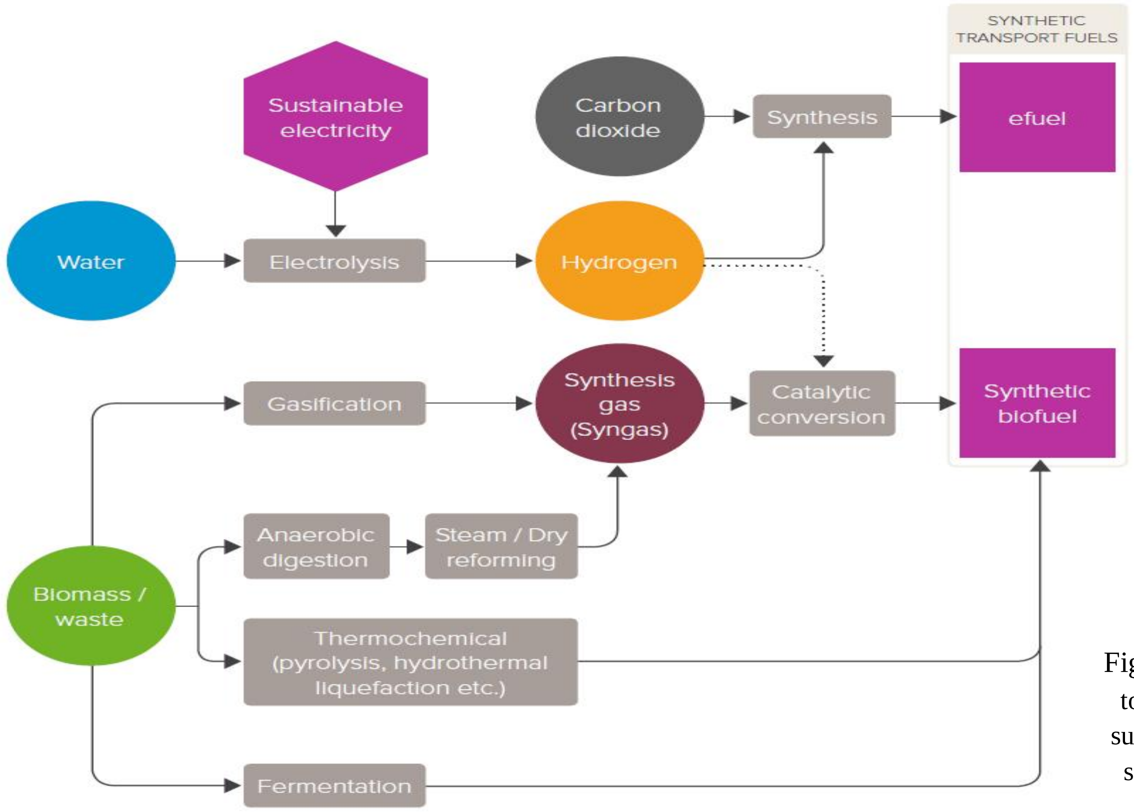


Figure 5.1 Routes to carbon based sustainable liquid synthetic fuels.

The background technology to produce synthetic fuels is well known and used at scale (e.g. Fischer Tropsch synthesis using carbon monoxide). However, these existing processes use fossil carbon sources and new technologies and further innovation will be required to enable non-fossil carbon dioxide sources to be used.

The advantages of sustainable synthetic fuels are:

1. They can be manufactured as 'drop in' replacements for fossil jet fuel, diesel and fuel oil
2. Both the volume and energy density of synthetic fuels are similar to existing fuels
3. They can be designed to burn cleanly, reducing other pollutants associated with fossil fuel use, such as particulates and nitrogen oxides
4. Existing infrastructure can be utilized for distribution, storage and delivery to the vehicle

And the disadvantages are:

1. Synthetic fuels from both biomass and carbon dioxide are currently more expensive than fossil fuels, for example around €4.50/ litre for diesel equivalent efuel and around €1/litre petrol equivalent biofuel. Innovation in each process stage has the potential to reduce these costs in the future to enable production and scale up to defossilise the current and growing future transport demands. Estimated future costs vary greatly but range from 60 cents to €1.50 per litre for diesel equivalent efuel by 2050.
2. The energy losses from manufacturing and using synthetic fuels are high due to the many processes involved. However, this might be justified where electrical propulsion is not practical and renewable electricity is cheap and plentiful.

Forecasts to 2040 predict that global energy demand will increase for all modes of transport, including these 'hard to reach' areas (Figure 5.2). The decarbonisation of transport will require the replacement of energy dense fossil fuels (diesel, aviation, bunker fuel) with low or net-zero carbon, sustainable synthetic fuels.
So in the summary we can say:

Synthetic fuels:
Carbon based liquid fuels manufactured, via chemical conversion processes, from a carbon source such as coal, carbon dioxide, natural gas, biogas or biomass. This includes established conventional fossil-based processes.

1. Electrofuels (efuels)
These are synthetic fuels manufactured using captured carbon dioxide or carbon monoxide together with low-carbon hydrogen. They are termed electro- or efuels because the hydrogen is obtained from sustainable electricity sources e.g. wind, solar and nuclear power.

2. Synthetic biofuels
In this report, these are defined as fuels synthesised from biomass or waste or biofuels using chemical or thermal processes. The production of fuels using biomass and only biological processes are outside the scope of this briefing (for example, bioethanol produced through fermentation of sugars).

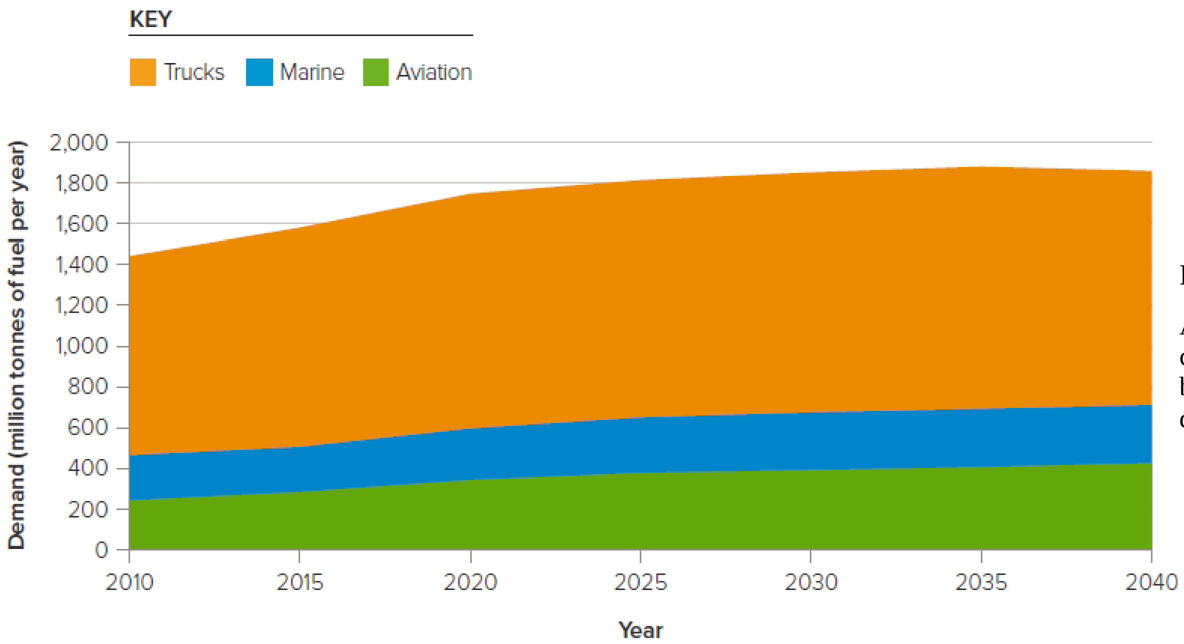


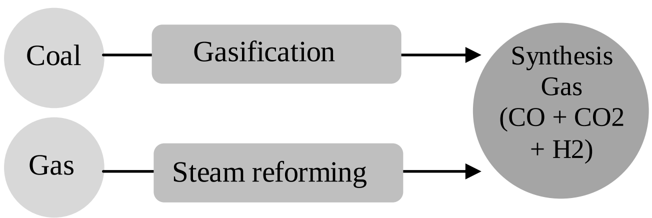
Figure 5.2

A sustainable carbon cycle utilizing biomass and carbon dioxide.

5.2 Synthesis Biofuels

Synthetic biofuels are produced from hydrocarbons from biological sources using chemical and thermal methods. A range of processes are used to convert biomass feedstock into different synthetic biofuels, as shown in Figure 5.1.

Current production of synthetic fuels:
Synthetic liquid fuels have been manufactured for many decades through a) methanol synthesis and b) the Fischer Tropsch process, both using fossil sources of carbon. For both processes, the starting point is the conversion of the fossil fuel (coal, oil or natural gas) to synthesis gas, which is a mixture of carbon monoxide, carbon dioxide and hydrogen.



a) Methanol Synthesis

Methanol is produced by reacting the synthesis gas at relatively high pressure and temperature using a copper catalyst. This process has been operated globally for over 60 years and produces more than 70 million tonnes/year. Methanol can then be converted over a catalyst to produce synthetic liquid fuel such as petrol. This process is operated at a commercial scale.
Alternatively reacting methanol over a catalyst to make alkenes, a process that is currently operated commercially, and the products can be used as precursors to synthetic liquid fuels. (Figure 5.3 a)

b) Fischer Tropsch

To use carbon dioxide in the established Fischer Tropsch (FT) synthesis, it is converted to carbon monoxide by reaction with hydrogen using the 'reverse water gas shift' reaction:
The carbon monoxide and hydrogen are then reacted over either cobalt or iron catalysts to produce a range of hydrocarbons (light gases C1-C4, petrol C5 – C9, kerosene C10 – C11, diesel C12+). (Figure 5.3 b)

The full product spectrum can be used in the energy and transport sectors following separation. The initial impetus for this process was to produce sulphur-free diesel but it is now used to exploit very low-cost natural gas, with the added benefit that the diesel is sulphur-free.
Modifying the industrial methanol synthesis and Fischer Tropsch reactions to operate with carbon dioxide and hydrogen will require innovation and research.

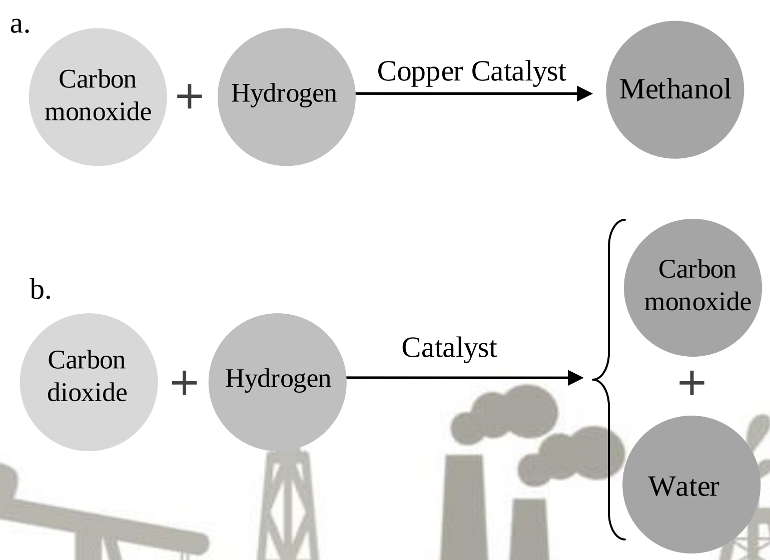


Figure 5.3 a) Methanol Synthesis b) Fischer Tropsch

Production routes to synthetic fuels, such as the Fischer Tropsch conversion and methanol synthesis, are well known and are currently applied commercially to fossil-carbon sources such as coal and natural gas (Figure 5.3). For these and other new production routes to contribute to the future decarbonisation of the transport sector, as a direct route from power (electricity) to liquid. For this to happen:

I. The carbon must be derived from sustainable non-fossil sources such as biomass, direct air capture or industrial exhaust gasses.
II. The energy input required for chemical conversion should be from sustainable electricity and/or low-carbon hydrogen (green hydrogen).

Synthetic biofuels and efuels have the potential to reduce greenhouse gas emissions through the creation of a sustainable carbon cycle (Figure 5.4).

a. With biofuels, the carbon is cycled from the atmosphere, through the growth of plants, converting into fuel, burning in an engine, releasing the carbon into the atmosphere again.

It should be noted that the timescale of this biological carbon cycle is dependent upon the growth rate of the feedstock, for example, the time taken to produce sugar cane residue versus forestry residue.

b. With efuels, captured carbon is converted into fuel and then burnt in an engine, releasing the carbon back into the atmosphere. For efuels, the origin of the carbon dioxide will change the carbon reduction benefit, for example whether it came from an otherwise unavoidable carbon dioxide by-product or from a fossil fuel flue.

The recycling of carbon, shown in Figure 5.4, would contribute to meeting net-zero targets through 'defossilisation'; replacing the need to extract and burn fossil fuels, whilst creating a pathway to the longer-term options that would completely remove carbon dioxide emissions.

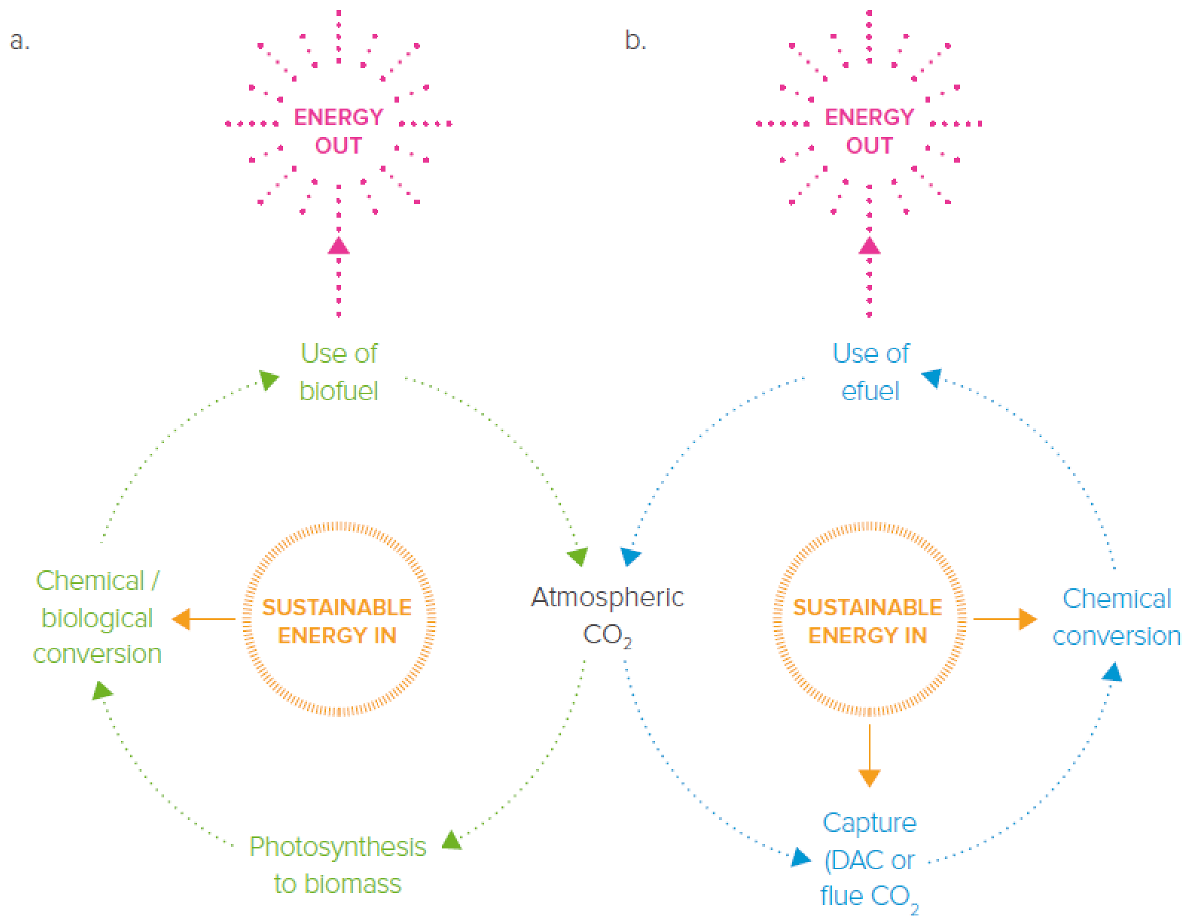


Figure 5.4 A sustainable carbon cycle utilising biomass and carbon dioxide.

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