ANALYSIS OF COST COMPARISON FOR THE PRODUCTION OF 1KW ENERGY FOR BOTH INTERNAL COMBUSTION ENGINE AND ELECTRIC VEHICLE

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A project report submitted in partial fulfilment of the requirements for the award of Master of Engineering in Electrical Engineering

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December 2017

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

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ABSTRACT

In this modern era, many industries operating Internal Combustion Engine (ICE) in their daily businesses. ICE been used to create rotation motion and can be implemented in many applications especially in transportation industry. However, source of energy in ICE is from fuel and most of fossil fuel well has been explored. Fossil fuel is a non-renewable energy that took millions of years to be produce. Furthermore, ICE emit gasses that contribute to the world pollution. Due to its challenges, researchers start to find alternative for ICE in transportation industry since it contributes the highest percentage of ICE usage. Electric Vehicles (EV) seem to be the possible candidate to replace ICE in transportation industry since it operates by using battery that could be charge and its working principle doesn't emit anything that could affect the environment. However, EV cost and efficiency need to be consider for it to replace ICE. This study will identify all stages involved in EV and ICE from generation side up to the operation of vehicles in term of cost and efficiency. The efficiency in all of the stages will contribute to the cost required for energy production. This study compared the cost in production of 1kW of energy between EV and ICE from well to wheel. Cost that has been consider in this study is the operational expenditure (OPEX) for any data above 2011. There are 4 stages for both EV and ICE is determined in this study which is the generation stage, intermediate stage, consumer station stage, and consumer stage. Each stage may have a number of method in its operation and this will be considered in cost data collection. Method of comparison in this study is by data collection from reliable sources and will be compared to determine cost for production of 1kW of energy. This data will also be used to determine which pathway is the most suitable in implementing EV as alternative for ICE.

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LIST OF SYMBOLS / ABBREVIATIONS

η	Efficiency
%	Percent
$	US Dollar (Currency)
USD	US Dollar (Currency)
AUD	Australian Dollar (Currency)
MYR	Malaysian Ringgit (Currency)
KD	Kuwaiti Dollar (Currency)
€	Euro (Currency)
V	Voltage
P	Power
I	Current
R	Resistance
GWh	Gigawatt Hour
kW	Kilowatt
kWh	Kilowatt Hour
km	Kilometre
kV	Kilo Volt
kVA	Kilo Volt Ampere
MW	Megawatt
GJ	Giga Joule
ICE	Internal Combustion Engine
EV	Electric Vehicle
HEV	Hybrid Electric Vehicle
BEV	Battery Electric Vehicle
FCV	Fuel Cell Vehicle
AC	Alternating Current
DC	Direct Current
VAC	Voltage Alternating Current
VDC	Voltage Direct Current
HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
HV	High Voltages

EHV	Extra High Voltages
T&D	Transmission and Distribution
TNB	Tenaga Nasional Berhad
IPP	Independent Power Producer
GT	Gas Turbine
ST	Steam Turbine
L-L	Line-to-Line
OPEX	Operational Expenditure
CAPEX	Capital Expenditure
Li-ion	Lithium-ion
CO_2	Carbon Dioxide
CO	Carbon Monoxide
HC	Hydrocarbon
NO	Nitrogen Oxide
PT	Particulates Matter
SI	Spark Ignition
NEP	Net Electric Power
CV	Calorific Value
CI	Compression Ignition
CARB	California Air Resource Board
ZEV	Zero-Emission Vehicle
IAEA	International Atomic Energy Agency
3-D	3 Dimension
EOR	Enhanced Oil Recovery
ETSAP	Energy Technology Systems Analysis Programme
PMC	Preventive Maintenance Cost
CMC	Corrective Maintenance Cost
TMC	Total Maintenance Cost

CHAPTER 1

INTRODUCTION

1.1 Background

The development of technology in the world keep on moving forward with the same goal of its invention which is to make life easier and better. One of industry that keep on developing and seem to be one of the most important industry in the world is the transportation industry. The effectiveness of the transportation industry today will have a huge impact to other industry as well. There are 3 medium of transportation which is by air, land or sea and most of all kind of transportation operate with the same fundamental which using the Internal Combustion Engine (ICE). Many transportation company keep on competing and developing their brand in term of efficiency and technology of their ICE.

Internal Combustion Engine are the most commonly used in producing rotating energy. It is applied in many such as for the mobile propulsion in vehicles, working equipment, and other portable machinery. By using ICE, it will gives advantages since it providing high-power to weight ratio with excellent fuel energy-density. However, ICE depending on the process of combustion where fuel is the source for combustion. As the development of the transportation industry where ICE is widely used, the need for fuel is highly demanding to support ICE operations. Fuel come from fossil where it is a non-renewable energy which created through natural processes for millions of years. Therefore, fuel will be very crucial in the future when every corner of these fossil in the world had been treasured.

The highly needs of these natural resources to support technology is worrying most of the government and country around the world as these resource productions keep on reducing over time. Therefore, to mitigate this problem and ensuring the continuity of life and technology, many researchers start to think of the replacement for these natural resources as source of energy. This is when the idea of using renewable energy as source of energy started. Researchers around the world start to invent energy sources using wind, thermal, solar and many other renewable energies to overcome the decreasing production of natural resources problem. Furthermore, the effect of fossil combustion were major contributor to the world pollution.

As for transportation industry, many companies started inventing Electric Vehicle (EV) as ICE alternative to overcome the fuel and pollution problem. The basic and obvious different between ICE and EV is that ICE is using fuel as source while EV using battery-cell as its source. However, the higher upfront cost in setup of electric vehicle as compared to the internal combustion engine (ICE) vehicles has become a major barrier for the widespread adoption. For future, the cost associated with EVs might be lower than that of ICE with the relatively lower electricity rates and potentially rising gasoline prices. However, its efficiency and its real effect to the world is still been discussed around the world

1.2 What is Electric Vehicle (EV)

Many people think that Electric Vehicles (EV) were considered as new in the market, and may even seem futuristic to some people. In fact, these so called "future technology" have actually been around for more than a century. They were popular mode of motorized transportation in the early 1900s until powerful Internal Combustion Engines fuelled by gas and diesel rendered them obsolete.

As mentioned, an electric car is powered by electric motor instead of a gasoline engine. Based on the use of accelerator pedal controlled by the driver, the controller is able to regulate the amount of power as well as energy to drive the propulsion. The electric car uses rechargeable batteries as the source of energy to drive the electric motor for propulsion. The used batteries can be recharged by common household electricity.

There are many type of EV to suit the customer requirement. Hybrid EV seems more practical currently since it can overcome the issues of limited driving range and long recharging time face by total EV that only depending on capacity of battery pack. Due to the limited driving range and long recharging times as well as the lack of commitment from automaker to manufacture it, EVs have not been widely adopted. This situation changed with the advance in battery technology. Hence, the increase in energy storage as well as the reducing cost had caused major automaker to start introducing new electric cars. (Brad Berman, 2014). The widely use of EVs will decrease the consumption of petroleum greatly since EVs do not need any fuel to operate.

Today EV once again emerging as alternative fuel burning vehicles for diminishing oil reserves, pollution from automobile emissions and government regulations aimed at protecting environment. Even in Malaysia, Ministry of Energy, Green Technology and Water planned for Malaysia to become a marketing hub for EV and targeting to build 125,000 charger station around Malaysia by the year 2030.

1.3 Problem Statement

More than 30% of our energy usage on earth is used for traffic and transportation. This area of traffic and transportation will emit CO_2 to the environment. Therefore to support the Green House Campaign where production will have to consider its effect to the environment, transportation area also participate in reducing CO_2 emission cause by the Internal Combustion Engine. Furthermore, the ICE were drive by the oil/gas and currently oil and gas resources around the world are very limited. Therefore, an alternative way to replace combustion engines on the long run need to be think of and the best developed system is at present is the electric engine solution for vehicles. It gives also the possibility to choose from different energy sources. Electric power can be generated by renewable energy such as wind energy, solar energy, bio energy or hydropower. So all renewable energy sources can be used as an energy source for Electrical Vehicles. EV could be consider as Green Technology as its characteristic in operation that emit less CO_2 and seem didn’t effect to the environment. However, the usage of energy by the EV required generation, transmission, distribution, and in-car charging efficiency to ensure its operations. All of this step may lead to a critical total losses and need to be analyse and identified before we make it into conclusion which technology either ICE or EV is more reliable and efficient to be moving towards in the future.

1.4 Objective

The objective of this paper is to study and compare the processes involved in each stages in ICE and EV to produce 1 kW of energy. This study is expected to educate and help the society to understand in bigger picture in term of cost and efficiency in each processes involved in production of 1kW of energy. To achieve objective stated, this report will identify and determine all aspects as below:

(i) To determine and identify all stages from harvesting sources of energy up until the production of 1kW of energy

(ii) To develop a model for comparison to between ICE and EV.

(iii) To identify the efficiency and losses in each stages involved.

(iv) To identify the cost including the setup model, operation and maintenance.

(v) To calculate and suggest which process is the most ideal way in producing 1kW of energy in term of cost, efficiency and the most environmental friendly.

The information and suggestion provided in this report is expected to be able to educate society and the government in determining the best technology to be implemented in the industry and in the future in Malaysia.

CHAPTER 2

LITERATURE REVIEW

2.1 Internal Combustion Engine (ICE)

Internal Combustion Engine is one of the popular type of engine for any kind of propulsion. This engine is widely use due to its simple arrangement and working operations compared to other engine in the early stage of technology development. ICE is also known as heat engine where combustion of fuel happen in the engine or to be specific known as combustion chamber in the engine that will push the connecting rod and thus make a force to the crankshaft. The repetition and correct sequence of this force in each combustion chamber will produce a continuous force for any propulsion. As we know, there is no ideal condition in any operation. There will be losses in any stage of operation thus making researchers to invent more advance technology base on this basic technology to close this losses gap to make it more efficient. Due to source of energy is by using fuel and the method of operation is by combustion that produce force, there will be many losses and bad effect to the environment. Since this research is to compare between ICE with EV which will be using car as a model, therefore for ICE in this topic will discuss and review more on ICE technology development and its efficiency especially related to car.

2.1.1 History and Technology development

Many scientist and engineer had put their efforts in developing the technology of ICE. The, Dutch physicist in the year of 1680. However, there a no effective engine was develop until 1859, when J. J. Étienne Lenoir built a gasoline-powered ICE with double acting process, spark and ignition by some certain sequence that made the engine can continuously running. Gasoline-powered ICE is an engine that using gas as its fuel for combustion. However this gasoline-powered ICE seems suffered a lot of fuel consumption and low power output. (Rochelle Forrester, 2006). Due to its drawback, Alphonse Beau de Rochas who is a French scientist invented and patented a design of four-stroke engine that compress the fuel and air mixture before ignition. The design was not been built until 1876 when Nikolaus A. Otto successfully built the very first four-stroke engine. His design was called “Otto Cycle”. In the same year Sir

Dougald Clerk invented successfully two-stroke engine which gives more mechanical efficiency. In 1886, Gottlier Daimler who worked with Otto design a four-stroke ICE that could run either by Gasoline-fuel or petrol-fuel and produce more power. Its design also use carburettor to pass air over the top of petrol to mix the petrol vapour and air which was ignited to force the piston down in the third stroke. Most engine are descended from Daimler's engine operation of ICE and further advance technology is more on material and controlling part to make it efficient.

As for car industry, the very first who successfully design car with ICE was Karl Benz. He inserted electrical coil for ignition of the fuel mixture at Daimler's ICE design and patented it. It was a three-wheeler and later he build his first four-wheeler in 1891. Karl Benz and owned a company Benz&Cie that become the largest manufacturer in the world in automobile industry. In term of technology development, Karl Benz was the first to invent the integration of ICE with the chassis-design together while Daimler was the first the practical and successful ICE. There are many names such as Henry Ford, Rene Panhard, Emile Levassor and many more who put efforts and automobile industry. Their invention is more on supporting the ICE by Daimler for propulsion such as pedal-operated clutch, chain transmission and others.

2.1.2 Working principle

There are two types of Internal Combustion Engine which is Spark Ignition (SI) and Compression Ignition (CI) or commonly known as four-stroke engine and two-stroke engine. Both of these engine work on the same principle which is ignition and combustion to create force to move the crankshaft. The detail of its working principle will be explain later in the topic. To understand better of how is the operation of ICE, it is better to understand the arrangement and the basic parts of the ICE as shown in Figure 2.1 and Figure 2.2.

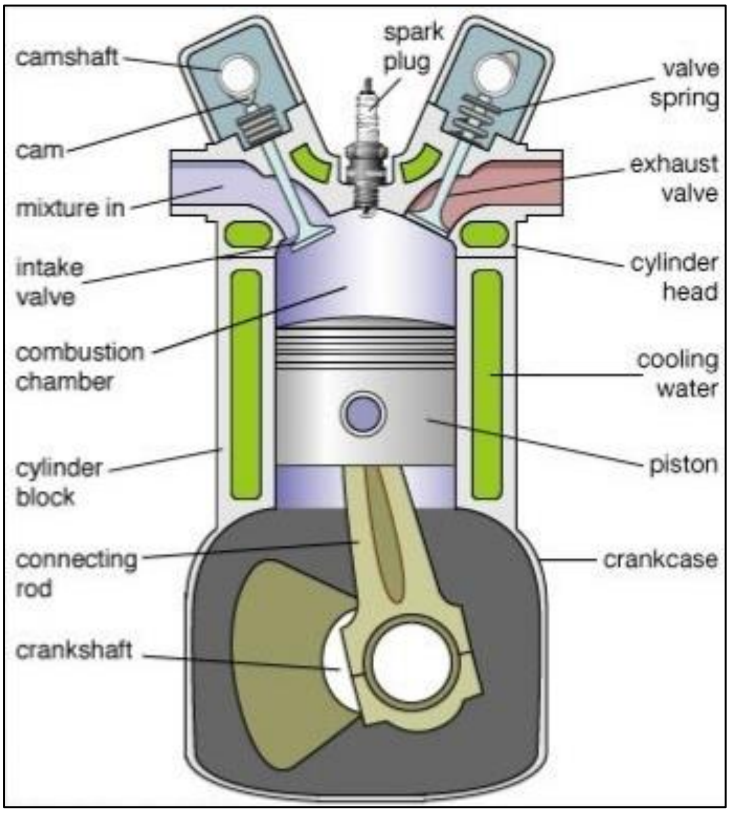


Figure 2.1 : Four-Stroke ICE parts

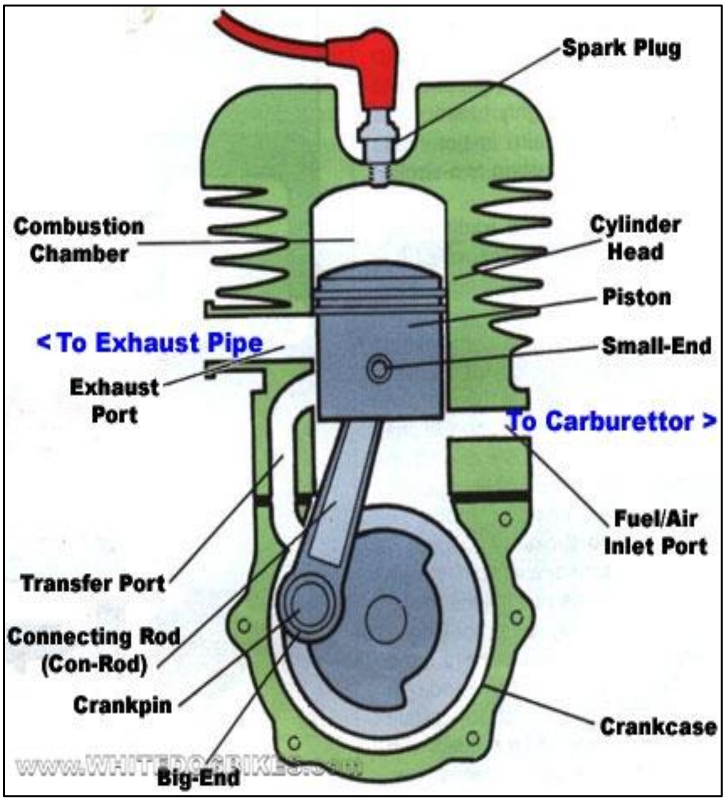


Figure 2.2 : Two-Stroke ICE parts

Each parts in the ICE plays significant functions to the performance of the engine. Thus, the function of each parts is mention as follow:

(i) Cylinder block – Main parts in ICE that was made by one piece cast iron with sustainability for combustion. This parts allow movement of piston for compression and high temperature combustion cycle.

(ii) Cylinder head – Also made by cast iron in one piece and have holes for intake and exhaust valve during operations.

(iii) Piston - A piston engage with the connection rod and works as suction of air intake and also transmit motion energy during combustion. Piston moves inside cylinder.

(iv) Connecting rod - Connecting rod or known as con-rod is a connector between the piston and crankshaft. It creates rotary motion to the crankshaft during movement of the piston. One end of con-rod which is larger are connected to the crankshaft and one end which is smaller are connected to the piston.

(v) Crankshaft - The crankshaft is a shaft which receives motion energy by each piston and create rotary motion. It is connected with con-rod through bearing so it can moves freely.

(vi) Crankcase - The main body of the engine to which the cylinder are attached and which contains the crankshaft. It’s also serves as the lubricating system where sump tank for lubricating oil is in it.

(vii) Valves – There are 2 valve which is the inlet of air-fuel mixture and exhaust of combustion gases for each cylinder for ICE. Some ICE even use 2 inlet valve and 2 exhaust valve to create more torque.

(viii) Spark plug – Ignition parts in the combustion chamber for petrol fuel ICE.

(ix) Injector - Injector is usually used in CI engine which operates by spraying fuel into chamber during compression cycle to create combustion.

(x) Camshaft - control both valve opening and closing at proper timing to let air-fuel mixture in and exhaust the combustion gasses.

(xi) Cooling water jacket – It is use to reduce heat transfer to ensure cylinder will not suffer expansion due to high temperature during combustion.

For the 4 stroke ICE, the process in generating propulsion power involve 4 step / stroke which is air intake stroke, compression stroke, combustion/power stroke and exhaust stroke. Repetition of all these 4 steps will produce a rotatory motion which can be converted into energy. During the first step or intake stroke, the piston were push downward and the inlet valve were open which allow air-fuel mixture to fill the combustion chamber. Then for second step or compression stroke, the inlet valve were closed and the piston will move upward hence compress the air-fuel mixture in the combustion chamber. At the maximum level of the piston during moving upward where the air-fuel mixture had been compressed, the spark plug ignite thus producing combustion energy that push the piston downward and this enter the third step or combustion stroke. As for last step in this cycle, the exhaust valve is open when the piston moved upwards again and allow the combustion gasses to be release before starting the new cycle of these 4 steps. Illustration of 4 cycle is provided in Figure 2.3.

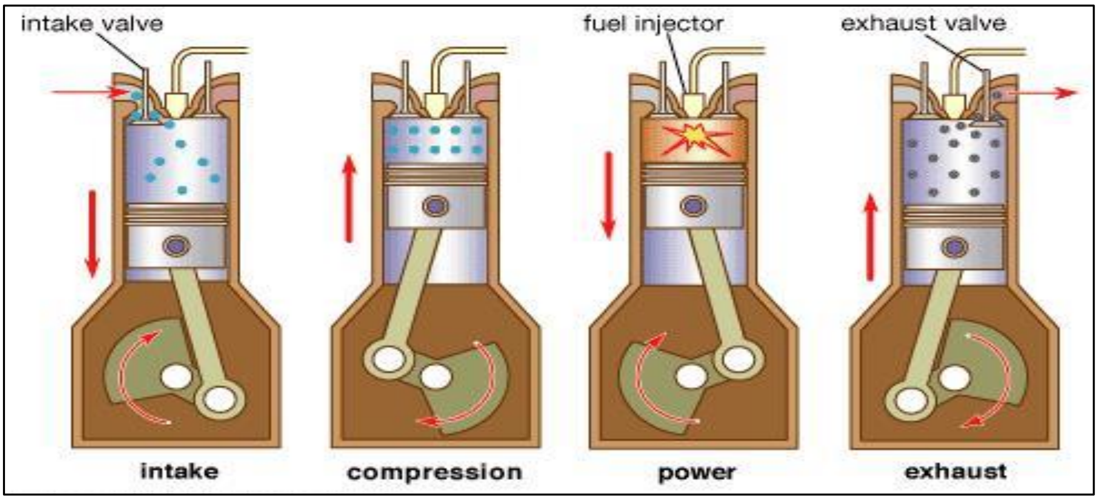


Figure 2.3: Four-stroke ICE steps in a cycle

As for two-stroke ICE it is much simpler working principle which only involve compression stroke and combustion/power stroke. During compression stroke, the piston moves upward and it covers two of the ports, the exhaust port and transfer port. This traps the charge of air- fuel mixture drawn already in to the cylinder. Further upward movement of the piston compresses the charge and also uncovers the suction port. Now fresh mixture is drawn through this port into the crankcase. Just before the end of this stroke, the compressed charge in the combustion chamber is ignited by a spark plug. During combustion/power stroke, the combustion pressure of the gases which forces the piston to move down the cylinder and closes the suction port, trapping the fresh charge drawn into the crankcase. Further downward movement of the piston uncovers the exhaust port and release the combustion gasses before open the transfer port and fresh charge in the crankcase moves in to the cylinder. This complete one cycle of two-stroke ICE and these steps will happen continuously to produce power through connected crankshaft. The illustration of the two-stroke step is provided in Figure 2.4.

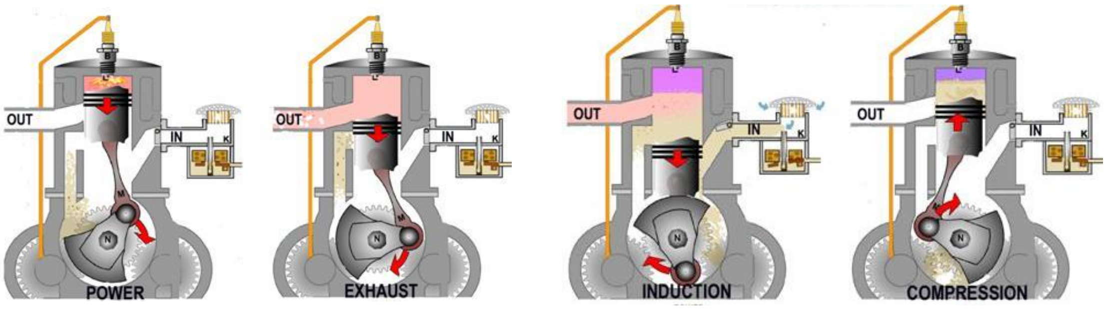


Figure 2.4 : Two-stroke ICE steps in a cycle

2.1.3 ICE emission

Due to its operation that require combustion using fuel as source and produce thermal effect afterwards. There are some parameter need to be monitor for ICE operation to ensure its operation wouldn’t affect the environment. ICE are one of the major source of urban air pollution. The exhaust gas from every combustion contain Nitric Oxide (NO_2), Carbon Monoxide (CO) and organic compounds which are unburned or partially burned Hydrocarbons (HC). The relative amount depend on the ICE design and operating conditions.

Referring to the Environmental Quality control of emission of ICE by Department of Environment Malaysia, the allowable of gaseous pollutant must not exceed the following standard as shown in Table 2.1.

Table 2.1 : Allowable Gaseous Pollutant by Department of Environment Malaysia

Mass of Carbon Monoxide(CO) Grammes per kWh	Mass of Hydrocarbons(HC) Grammes per kWh	Mass of Oxides of Nitrogen (NOx) Grammes per kWh	Mass of Particulates Matter (PM) Grammes per kWh
4.5g/kwH	1.1	8.0	0.36

2.2 Electric Vehicle (EV)

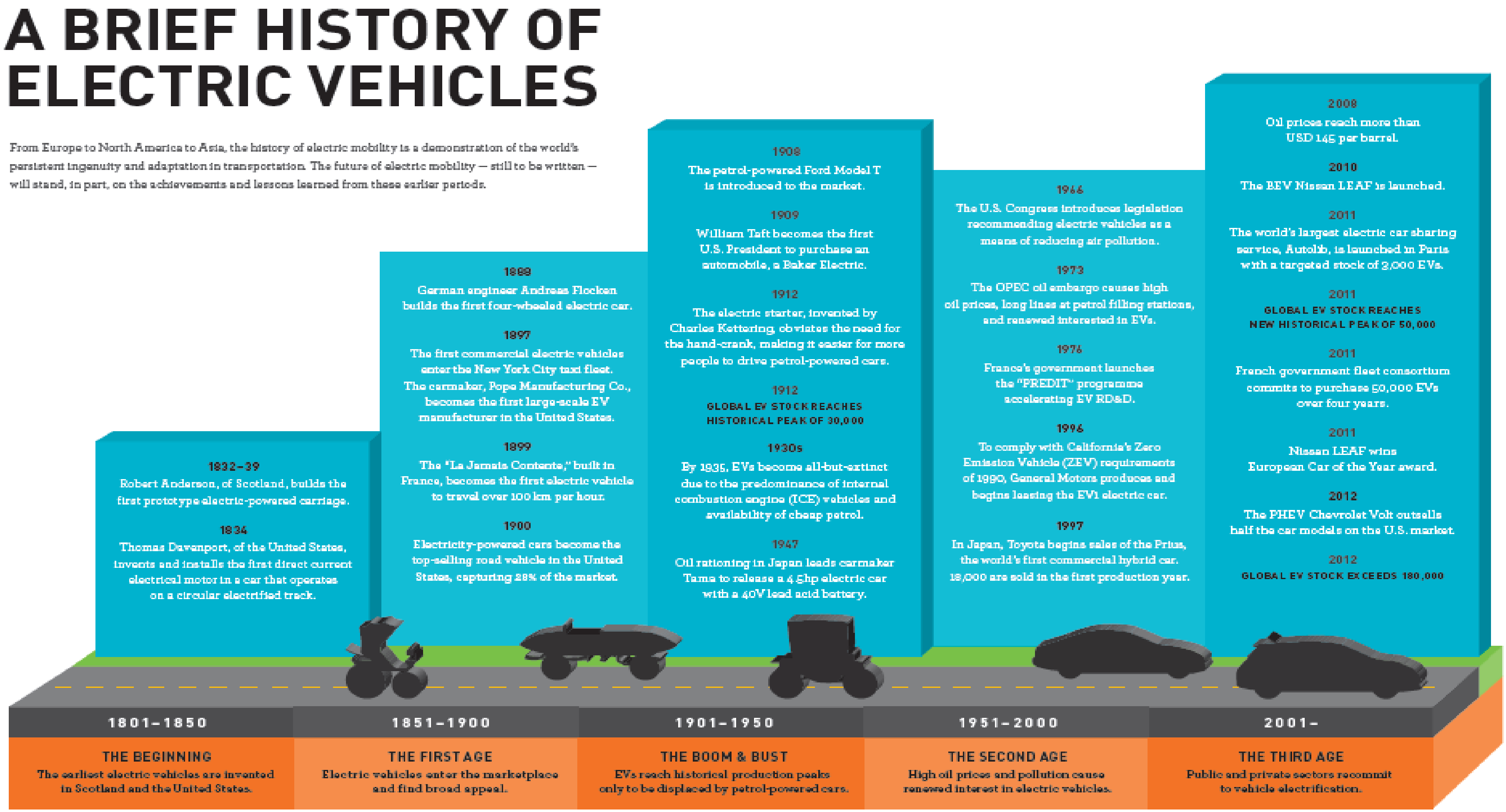
Electric Vehicle is not a new technology and it has been invented way before the invention of ICE vehicles. However, due to massive development in ICE and drawback in EV such as batteries capabilities and long period of charging time, ICE started to monopoly in the transportation industries afterwards. With this rapid development in ICE, researcher started to realize that there are also many challenges ICE will face in the near future. ICE which uses fossil fuel as its source and works with combustion when operated leads to a global warming and limited fossil fuel source. Therefore a replacement such as renewable energy and battery needed to be think of and to be develop to protect the world in the future.

2.2.1 History and Technology Development

EV technologies already started 150 years back since the invention of electric motor (Chun T. R and Chris M., 2017). It was one of the earliest automobile even before ICE become popular. There are some company that manufacture EV in Britain, America and France during the last decade of 18th century. There are also a company named Electric Cab Company that use EV as cab/taxis in London. EV is widely used in some area of the world until in 1930, EV were almost vanished in the transportation industries due to its problems associated with batteries and the development of ICE with availability of cheaper crude oil price during that time (C. C. Chan, 2007).

However, energy crisis that happened in early 1970’s make the world realize that energy from fossil fuel need to be control due to rising price of oil and massive growing environmental movement. Therefore America enforce a legislation of various acts such as Energy Policy and Conservation Act of 1975 and creation of Department of Energy in 1977 to control and mitigate this issue by reducing the dependencies on fossil fuel and work on alternative source of energy (History.com, 2010).

EV started to bounce back in the industries during 1990’s when California Air Resource Board (CARB) which is a government body that concern about pollution, enforce the Zero-Emission Vehicle (ZEV) mandate which requires 2% of vehicles for sale in California had to be ZEV in 1998 and the percentage increase until the latest that require 10% of vehicle for sale had to be ZEV in 2003. This mandate leads to production of first generation of modern EV such as Nissan Altra, Toyota EV RAV4, General Motor EV1 and Ford Electric Ranger. Most of this EV model are discontinued in production but due to ZEV mandate by CARB, variable type of alternative EV such as Hybrid EV (HEV), Battery EV (BEV), and Fuel Cell Vehicles are produced in the market with improved technologies. The history of EV can be explained in time line form in Figure 2.5.



A BRIEF HISTORY OF ELECTRIC VEHICLES

From Europe to North America to Asia, the history of electric mobility is a demonstration of the world's persistent ingenuity and adaptation in transportation. The future of electric mobility — still to be written — will stand, in part, on the achievements and lessons learned from these earlier periods.

1832–39
Robert Anderson, of Scotland, builds the first prototype electric-powered carriage.

1834
Thomas Davenport, of the United States, invents and installs the first direct current electrical motor in a car that operates on a circular electrified track.

1888
German engineer Andreas Flocken builds the first four-wheeled electric car.

1897
The first commercial electric vehicles enter the New York City taxi fleet. The carmaker, Pope Manufacturing Co., becomes the first large-scale EV manufacturer in the United States.

1899
The "La Jamais Contente," built in France, becomes the first electric vehicle to travel over 100 km per hour.

1900
Electricity-powered cars become the top-selling road vehicle in the United States, capturing 28% of the market.

1908
The petrol-powered Ford Model T is introduced to the market.

1909
William Taft becomes the first U.S. President to purchase an automobile, a Baker Electric.

1912
The electric starter, invented by Charles Kettering, obviates the need for the hand-crank, making it easier for more people to drive petrol-powered cars.

1912
GLOBAL EV STOCK REACHES HISTORICAL PEAK OF 30,000

1930s
By 1935, EVs become all-but-extinct due to the predominance of internal combustion engine (ICE) vehicles and availability of cheap petrol.

1947
Oil rationing in Japan leads carmaker Tama to release a 4.5hp electric car with a 40V lead acid battery.

1966
The U.S. Congress introduces legislation recommending electric vehicles as a means of reducing air pollution.

1973
The OPEC oil embargo causes high oil prices, long lines at petrol filling stations, and renewed interested in EVs.

1976
France's government launches the "PREDIT" programme accelerating EV RD&D.

1996
To comply with California's Zero Emission Vehicle (ZEV) requirements of 1990, General Motors produces and begins leasing the EV1 electric car.

1997
In Japan, Toyota begins sales of the Prius, the world's first commercial hybrid car. 18,000 are sold in the first production year.

2008
Oil prices reach more than USD 145 per barrel.

2010
The BEV Nissan LEAF is launched.

2011
The world's largest electric car sharing service, Autolib, is launched in Paris with a targeted stock of 3,000 EVs.

2011
GLOBAL EV STOCK REACHES NEW HISTORICAL PEAK OF 50,000

2011
French government fleet consortium commits to purchase 50,000 EVs over four years.

2011
Nissan LEAF wins European Car of the Year award.

2012
The PHEV Chevrolet Volt outsells half the car models on the U.S. market.

2012
GLOBAL EV STOCK EXCEEDS 180,000

1801–1850
THE BEGINNING
The earliest electric vehicles are invented in Scotland and the United States.

1851–1900
THE FIRST AGE
Electric vehicles enter the marketplace and find broad appeal.

1901–1950
THE BOOM & BUST
EVs reach historical production peaks only to be displaced by petrol-powered cars.

1951–2000
THE SECOND AGE
High oil prices and pollution cause renewed interest in electric vehicles.

2001–
THE THIRD AGE
Public and private sectors recommit to vehicle electrification.

Figure 2.5: Evolution of the Electric Vehicles

2.2.2 Types of EV

EV claims to be green technology that produce zero-emission which is good to the environment. However, there are many type of EV should be understand before jump into conclusion that EV is a very green technology. There are Hybrid EV (HEV) which can be break down into 4 type that is series hybrid, parallel hybrid, series-parallel hybrid, and complex hybrid (Chan , 2007). There are also Battery EV (BEV) and Fuel Cell Vehicles (FCV). Detail for each kind will be explained the section for better understanding.

2.2.2.1 Hybrid EV (HEV)

Hybrid EV are named hybrid due to its propulsion system that works using combination of ICE and battery powered electric motor. The idea of using HEV is to take advantages of each propulsion type and counter each disadvantages (Erjavex and Arias, 2006). As mention before that there are 4 type of HEV and the difference of each type is the arrangement of ICE and electric motor in the propulsion system.

Series-HEV used ICE as its prime mover for generator to charge the battery which work as the only energy source for the motor. In some literature, series-EV is also known as Extended Range Electric Vehicles (Tate et al,2008). This arrangement has the advantages of easier control and easy packaging but it widely used in heavy vehicles such military vehicles and truck and buses. (Ehsani et al, 2007).

Parallel-HEV allow the propulsion to works either using ICE or electric motor and even could operate with both at the same time. Parallel-HEV claims to be better that Series-HEV due to its smaller ICE and electric motor (Chan, 2007). However its construction is expensive, complicated control and complex vehicle space packaging (Çağatay Bayindir et al, 2011).

For Series-Parallel HEV, the construction of the propulsion system is by combination of both Series and Parallel EV with mechanical link between mechanical and electrical component. Series-parallel HEV takes the advantage of both series and parallel HEVs but at the expense of cost and complicated drive train (Chan, 2007).

Complex-HEV is similar to Series-Parallel EV but the electric generator not only functioning as generator but also could be used as a motor. The obvious drawback for this arrangement is the complexity of the system which also lead to a higher cost.

The differences in arrangement for all type of HEV could be understand in block diagram form in Figure 2.6.

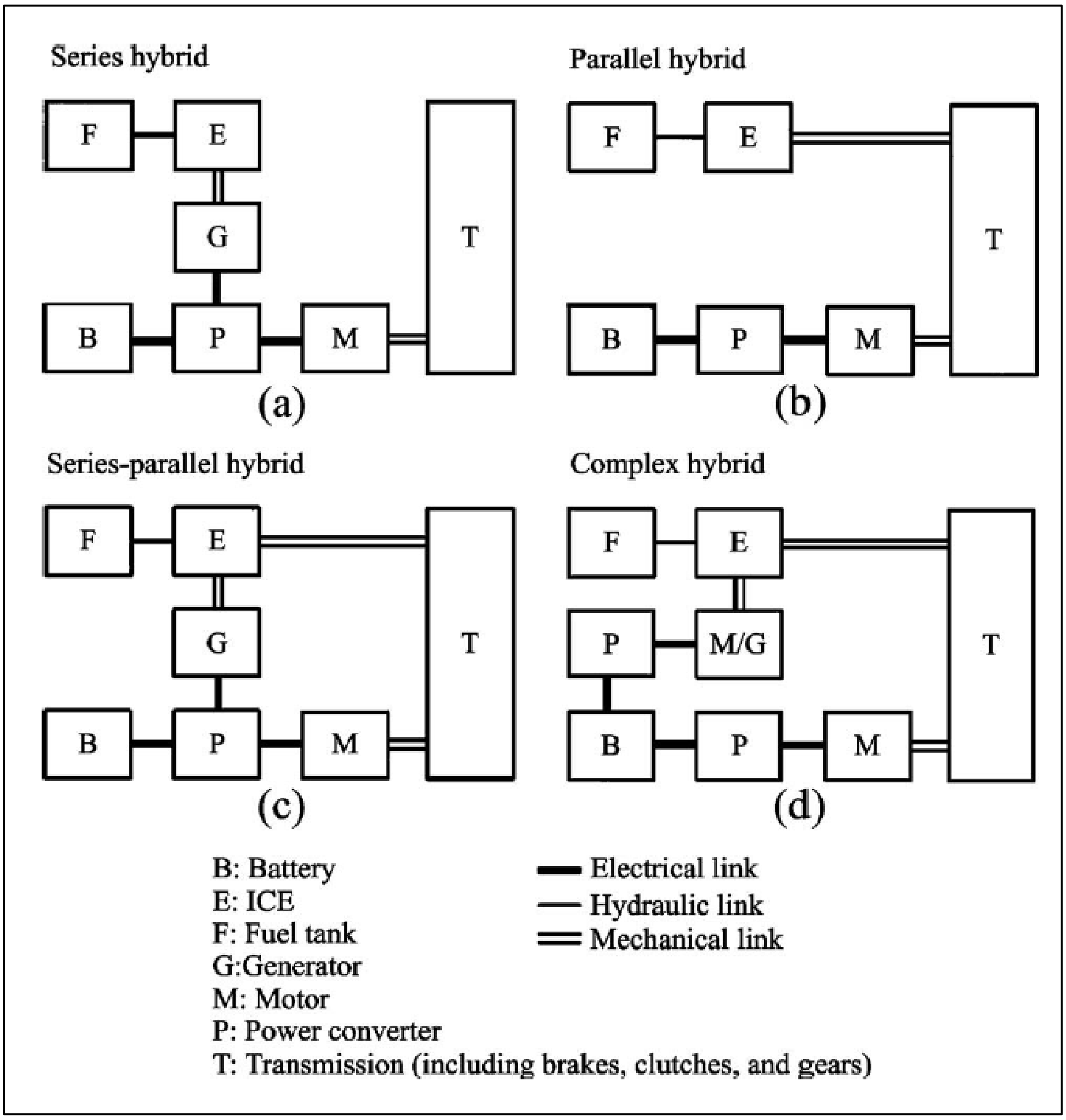


Figure 2.6: Four common arrangement of HEV

2.2.2.2 Battery EV

Battery EV (BEV) is a total depending on the batteries as it source of energy. BEV propulsion system could work one or more electric motor depending on the design efficiency needed. The arrangement of BEV propulsion is very straight-forward where only one source available which is the batteries and only one propulsion method which is the electric motor as shown in Figure 2.7. There are many advantages of using BEV that is (Guirong et al, 2011)

(i) Higher efficiency with 80% of electrical energy converted into propulsion motion while ICE only have 20% efficiency.

(ii) Zero-emission.

(iii) Operate more quietly due to lesser moving parts and vibration.

(iv) Less maintenance due to lesser moving mechanism.

(v) Could be charged from any sources such as renewable energy and hydro power plant and not depending only on fossil fuel power plant.

(vi) Have regenerative braking that absorb energy during braking which could increase the mileage by 10% to 15%.

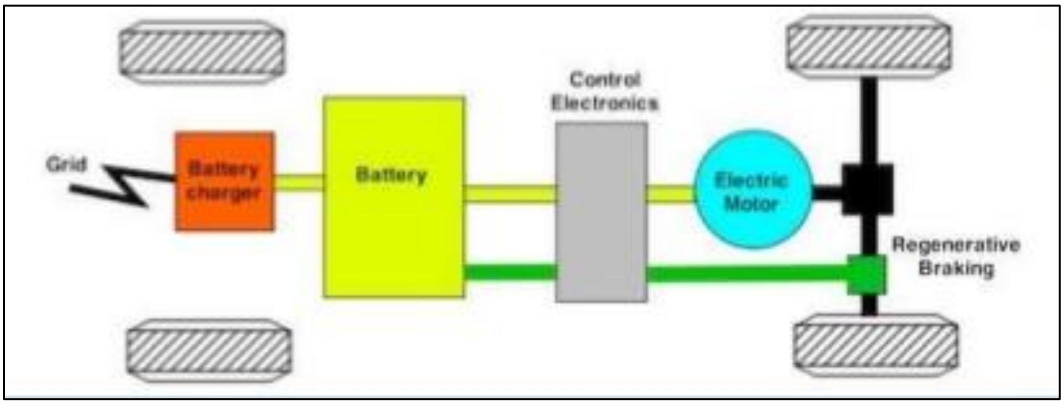


Figure 2.7: Main components of BEV

2.2.2.3 Fuel Cell Vehicles

Fuel Cell Vehicles (FCV) works similar to Series-HEV. The difference is that by FCV use fuel cell as replacement of ICE in its arrangement as shown in Figure 2.8. Fuel cell generates electricity by using oxygen from atmosphere and hydrogen from the fuel tank. FCV could be consider as green technology due to its tailback emission which only water, vapour and heat. FCV source to wheel efficiency also is higher than ICE. However, major drawback is lack of refuelling station, high cost, cold weather start problem and insufficient power density of the fuel cell (Halderman, 2013).

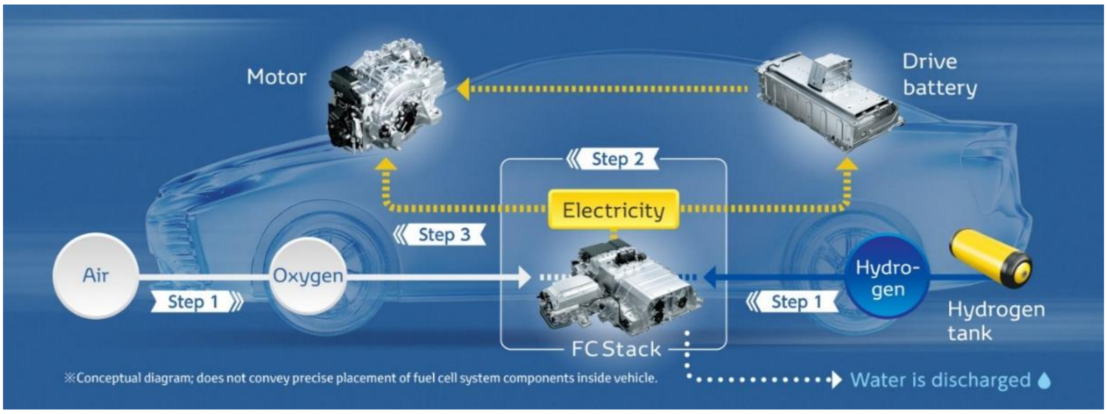


Figure 2.8: Main components of FCV

2.2.3 Working Principle and Charging Time

There are 3 basic parts in an EV which are battery as the source, electric motor as it propulsion medium and controller to control needed output. Obvious characteristic that make EV different from ICE is the propulsion part which using electric motor that derives power from the rechargeable battery packs rather that ICE that using combustion of fuel to move the crankshaft for vehicles motion.

EV operates on electric or current principle. The controller of EV used to control the power output of the electric motor and uses rechargeable batteries as its energy source (Holms and Argueta, 2010). The motor will rotate and transform the electrical energy into mechanical energy to move the wheels which will also move the vehicles. The motor can be choose either working on Alternating Current (AC) or Direct Current (DC) depending on designer or manufacturer. The vital parts that will effect EV efficiency is the controller part which manage the power needed to deliver to the motor. By stepping on the pedal which same as ICE, the controller need to manage the speed of the motor considering the load of the motor due facing uneven contour of road. The controller also will control the movement either moving forward or reverse.

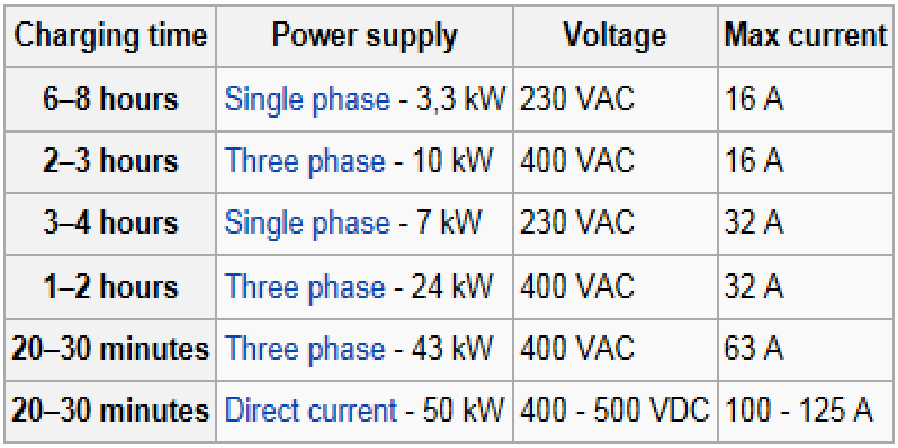
Another issues with EV is the capacity of the battery that suit the size of the vehicles. The higher the capacity the longer driving distance it can cover. Most of manufacturer are using lithium-ion (Li-ion) battery due to its higher power density and weight lighter which see that Li-ion battery is the best candidate to dominant in EV as source of energy. Even though the price is higher than other type of batteries, it seem that the price is rapidly decreasing for the decade. (Lowe et al., 2010). Table 2.2 show the battery capacity effect on mileage covered and price of the vehicle by 5 manufacturers:

Table 2.2: Specification of several BEV

OEM	**Model Name**	**Battery Capacity (kWh)**	**Mileage (km)**	**Price**
Nissan	Leaf	30	107	$34,200
Mitsubishi	iMiEV	16	150	$22,955
BYD	E6	61.4	300	$52,000
Tesla	Model S	100	540	$92,900

Charging time also play important part in expanding EV to support greenhouse campaign. Charging an EV currently can take from 20 minutes up to 2-3 hours depending on the advancement technologies of batteries. EV need to be charge at dedicated charging station for safety reason (Plug-in EV Handbook, 2012). The table 2.3 explain clearly on the charging time required depending on different types of power supply with different voltage and current ratings.

Table 2.3: EV charging time on different power supply



Charging time	Power supply	Voltage	Max current
6–8 hours	Single phase - 3,3 kW	230 VAC	16 A
2–3 hours	Three phase - 10 kW	400 VAC	16 A
3–4 hours	Single phase - 7 kW	230 VAC	32 A
1–2 hours	Three phase - 24 kW	400 VAC	32 A
20–30 minutes	Three phase - 43 kW	400 VAC	63 A
20–30 minutes	Direct current - 50 kW	400 - 500 VDC	100 - 125 A

2.3 Power Generation

In general, power generation source can be divided into two types which is from the renewable energy and from the non-renewable energy. The renewable energy sources means that the primary energy come from energy that can be reproduce naturally such as from the wind, tidal, run of river (hydro), biomass and solar. While for the non-renewable energy is the sources that can't be reproduce in a short period of time. Non-renewable energy might take a million of years to be produce such as fossil fuel which can be divided into many form such as coal, natural gasses and petroleum.

There are many types of power generation plants in the world such as the Coal-Fired Power Plant, Gas-Fired Power Plant, Oil-Fired Power Plant, Biomass Power Plant, Hydro Power Plant, Wind Power Plant, Marine (Tidal/Wave) Power Plant, Nuclear Power Plant and Solar Power Plant. Each plant is design depending on the available resources in each area which could produce optimum output of each plant. In Malaysia, Nuclear Power Plant never been built due to enough energy supply by other plant. However, Malaysia is in feasibility stage to build its own nuclear power plant by 2030 to support increasing energy demand even though the country has meet the requirement by the International Atomic Energy Agency (IAEA) (A. Naqib, 2017). While for Marine (tidal/wave) power plant and wind power plant is not very famous in the country due to limited resources for optimum output.

2.3.1 Working principle of power generation.

Most of the power plant is working based on the same principle which is by the rotation of alternator to produce electricity. The difference is from the primary energy to rotate the alternator that will determine the type of energy power plant. However, for photovoltaic or solar energy is a total different of principle where the photo energy produce Direct Current and been converted to Alternating Current before supplying energy to the transmission line. The whole parts from the prime mover up to the alternator is named as Generator. The current produced by the generator will be step-up by a transformer to give enough energy for transmission.

Most power plant except for solar rotate the alternator by using a turbine. The turbine is connected to the rotor of an alternator and provide rotation to the alternator and produce current. There are many type of sources to move the turbine either by air or liquid which come from the operation of the power plant such thermal by combustion or flow of water. Figure 2.9 to Figure 2.15 explain graphically on how each power generation plants operate that is popular in Malaysia.

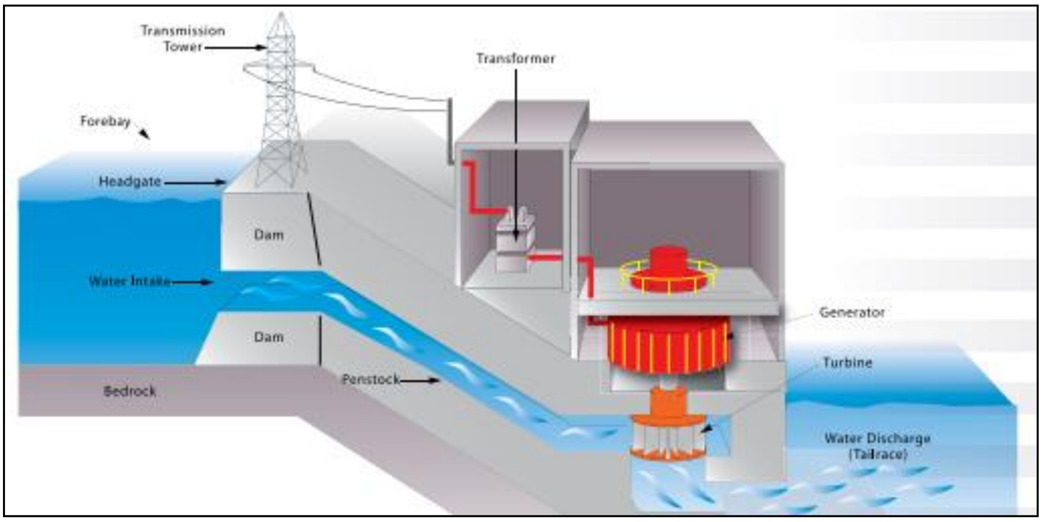


Figure 2.9: Hydro-power Plant

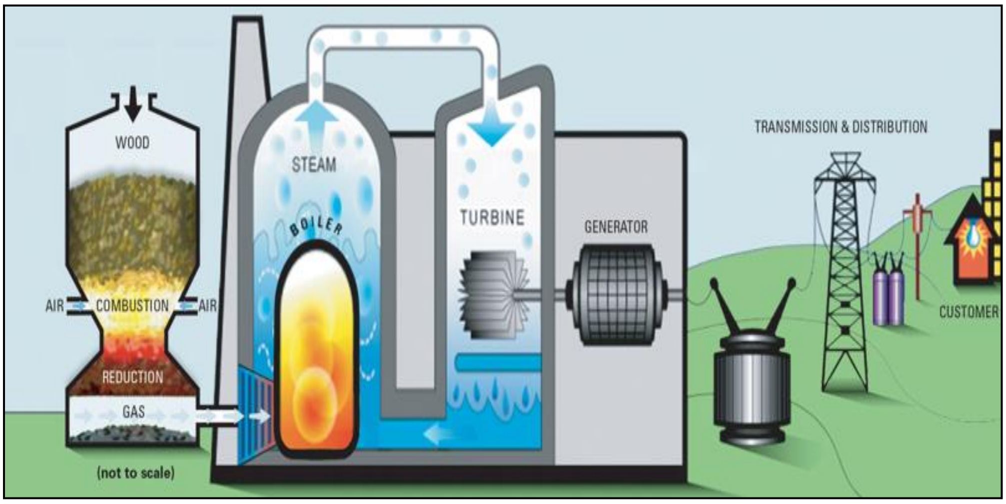


Figure 2.10: Biomass Power Plant

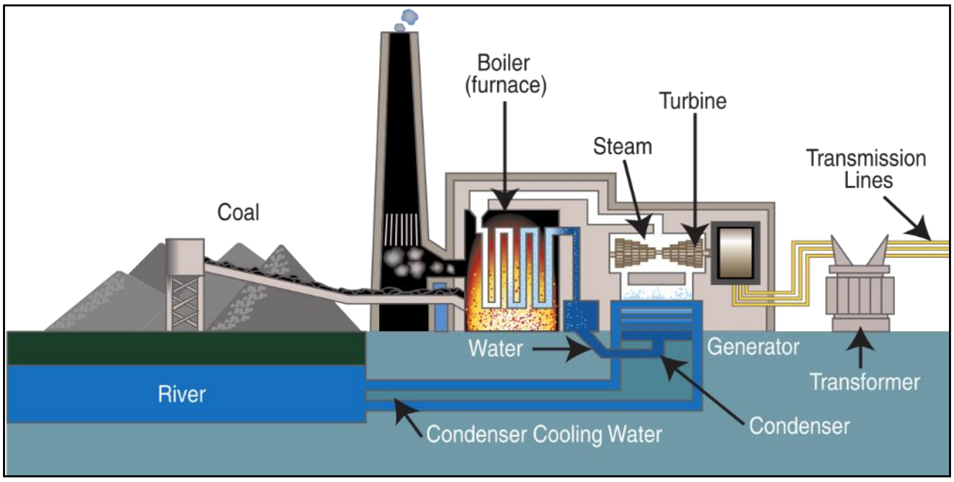


Figure 2.11: Coal Power Plant

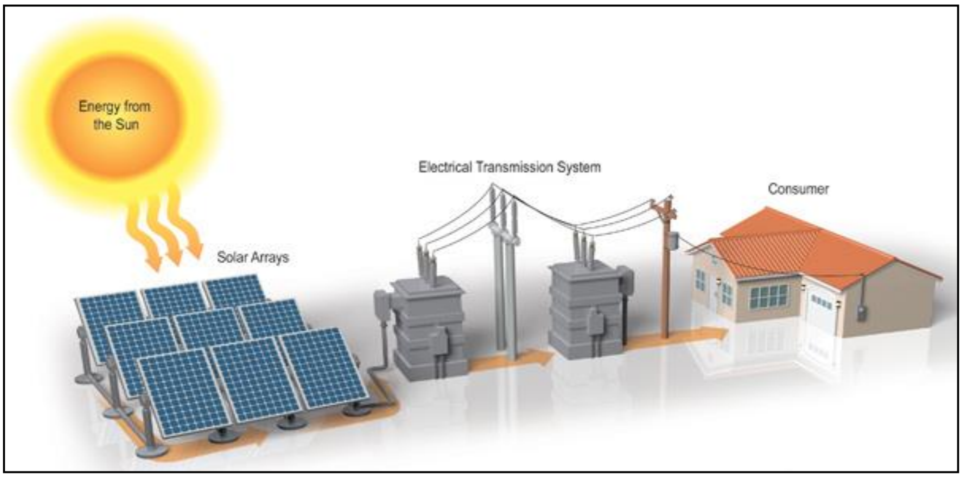


Figure 2.12: Solar Power Plant

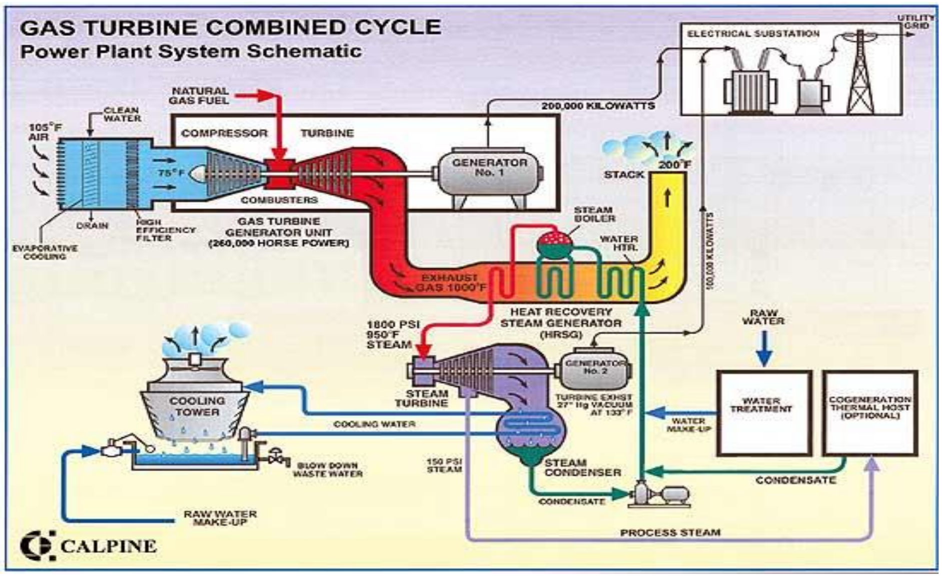


Figure 2.13: Gas Power Plant

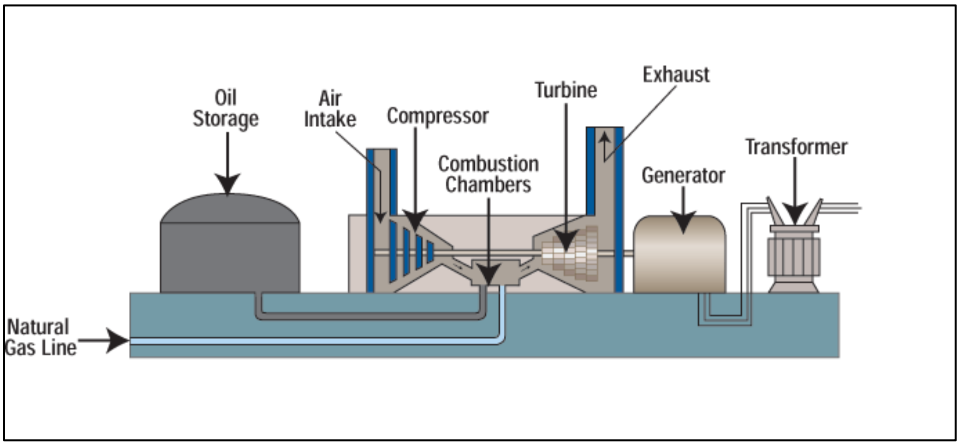


Figure 2.14: Oil Power Plant

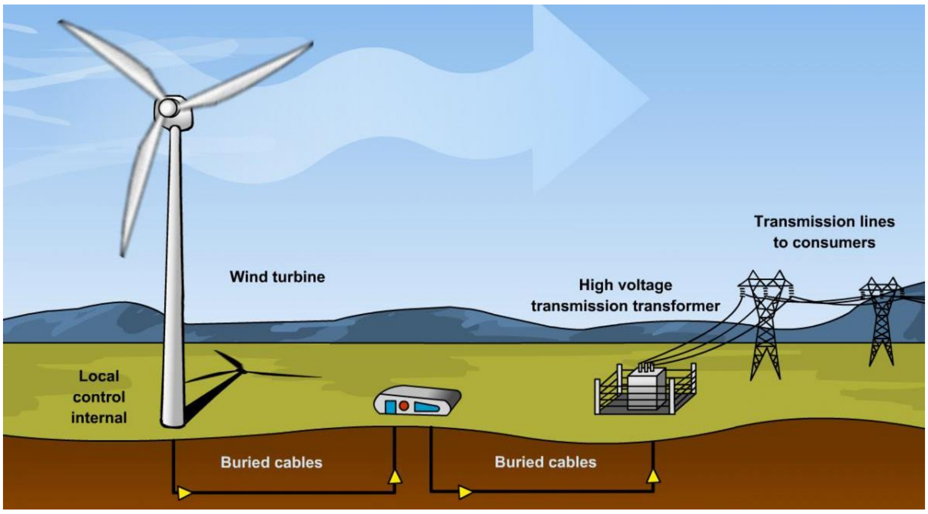


Figure 2.15: Wind Power Plant

2.3.1.1 Alternator operation

The alternator works based on Faraday’s Law of Electromagnetic Induction where current is induced due to motion between the conductor and a magnetic field. The mechanical which is from the turbine rotate the rotor which is inside a stator and a produce field cut across the conductors. The rotating magnetic field induced AC voltages in the stator winding and that is how current is produced. For a 3 phase current, 3 set of stator winding are built with physically offset so that the rotating magnetic field produces a current, displaced by one-third of a period for each phase. Figure 2.16 shows three-phase generated voltages displaced by one-third of a period and Figure 2.17 shows the structure of simplified electric generator.

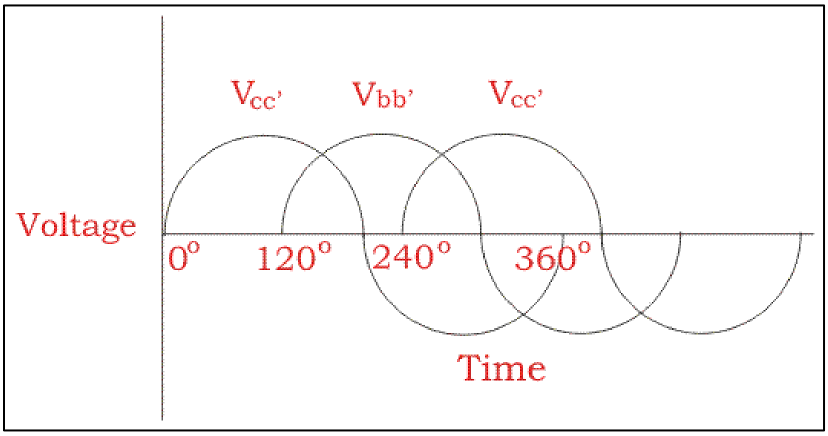


Figure 2.16: Three-phase Generated Voltage

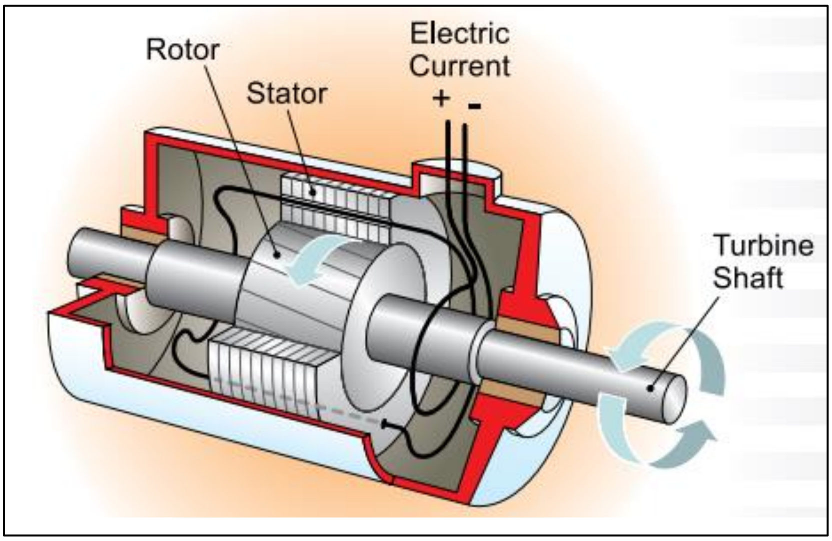


Figure 2.17: The Structure of a Simplified Electric Generator

2.3.2 Transmission and distribution

The power generates by the power generation plant need to be transfer and deliver to the consumer. Transmission line is the current conductor that carrying/transmit current from step-up transformer to the distribution network while distribution line is the current conductor that carrying/transmit current after the substation to the various power needs of consumer. This path can be briefly better in illustration as shown in Figure 2.18. Transmission network is form when the transmission line is interconnected with each other which also known as power grid.

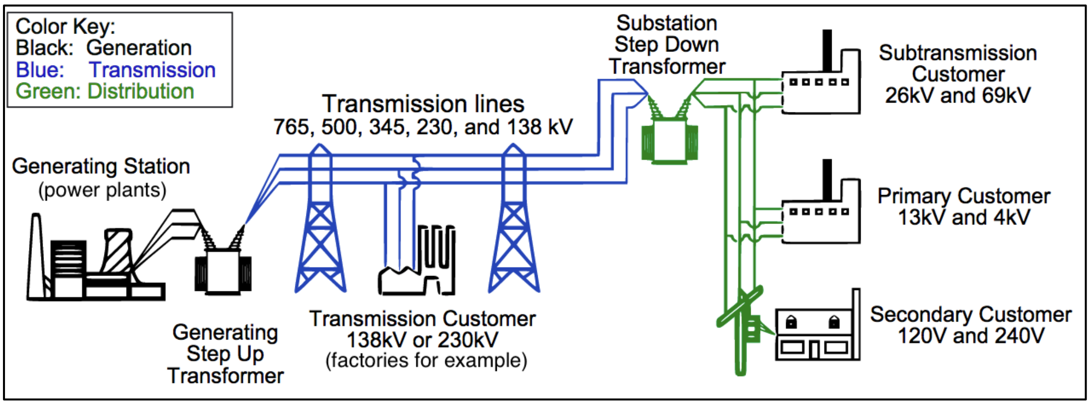
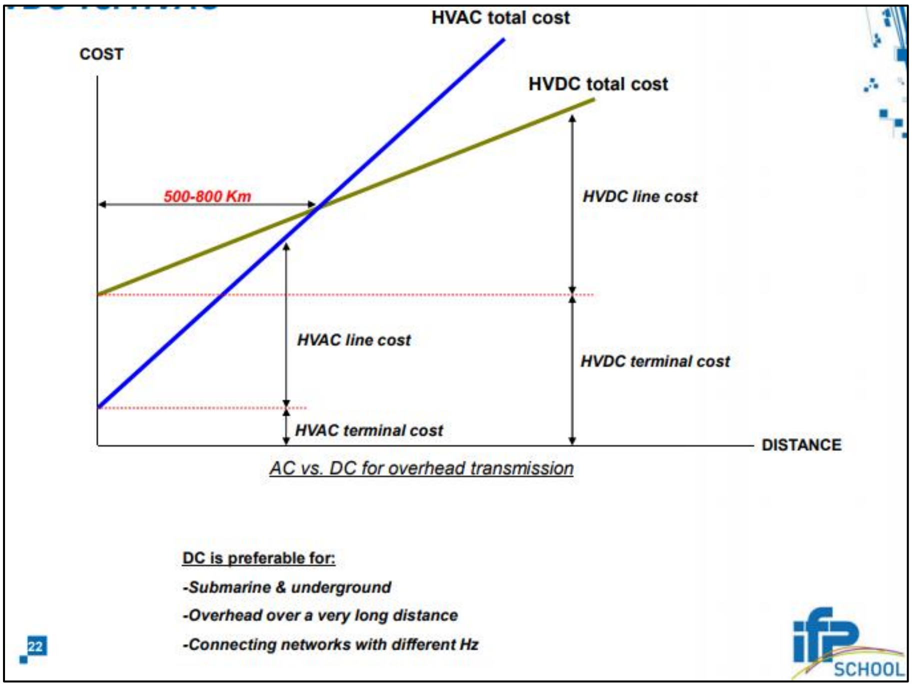


Figure 2.18: Transmission and Distribution

The fundamental of the transmission line can be divided into 2 major categories which are the High Voltages AC (HVAC) Transmission Lines and the High Voltages DC (HVDC) Transmission Lines. The comparison between HVAC and HVDC can be shown in Figure 2.19 in a graph form.



DC is preferable for:
- *Submarine & underground*
- *Overhead over a very long distance*
- *Connecting networks with different Hz*

Figure 2.19: Comparison for HVAC and HVDC (A. Farnoosh, 2015)

The High Voltages (HV) line can go up to maximum 200 miles length while Extra High Voltages (EHV) transmission line can generally supply energy up to 400 to 500 miles without intermediate switching and VAR support. There are also Ultra High Voltages in some area that can go maximum up to 1300 miles of length. The table for voltage level are shown in Table 2.4:

Table 2.4: Voltage Level in Transmission Line

Voltage Level	Value Level Mark	System	Valid Section
Low Voltage Level	Below 1000V	AC	Secondary distribution
Medium Voltage Level	1000V to 69kV	AC	Primary distribution
High voltage Level	Below 100kV	AC	Secondary transmission
Extra High Voltage level	230kV to 800kV	AC, DC both	Primary Transmission
Ultra High Voltage Level	800kV to 1000kV	AC, DC both	Primary transmission
	Over 1000kV	HVDC is preferable	Primary Transmission

Typically, transmission level are 400kV, 230 kV, 220kV, 132kV, 110kV and 66kV. For distribution line can be divided into two level which is the primary distribution level and secondary distribution level. Typical primary distribution level carry 33kV, 22kV 15kV, 11kV, 6.6kV, 3.3kV and 2.2kV while for secondary distribution level carry are 400V (L-L) and 230V (phase). Generally, in Malaysia, transmission line carry 500kV and 275kV, sub-transmission line carry 132kV while distribution line carry 33kV and 11kV. The economic voltage of transmission can be calculated by using these equation:

$$*\, E = 5.5\sqrt{\frac{L}{1.6} + \frac{KVA}{150}} \qquad (2.1)$$

E = Transmission voltage (KV) (L-L).
L = Distance of transmission line in KM
KVA=Power to be transferred

Transmission line are terminated at the bus of the substation. There are many types of transmission line as shown in Figure 2.21. The physical arrangement of most Transmission line consists of these major components and shown in Figure 2.20. Detail for each components is explained as follows:

(i) Tower: Made of steel and have many design..

(ii) Insulator: normally in vertical position or V arrangement to hold

(iii) Conductor: Each conductor is stranded, steel reinforced aluminium cable.

(iv) Foundation and Grounding: Steel reinforced concrete foundation and grounding electrodes placed in ground.

(v) Shield Conductor/ Overhead Grounding Cables: Use as protector of the phase conductor from lightning.

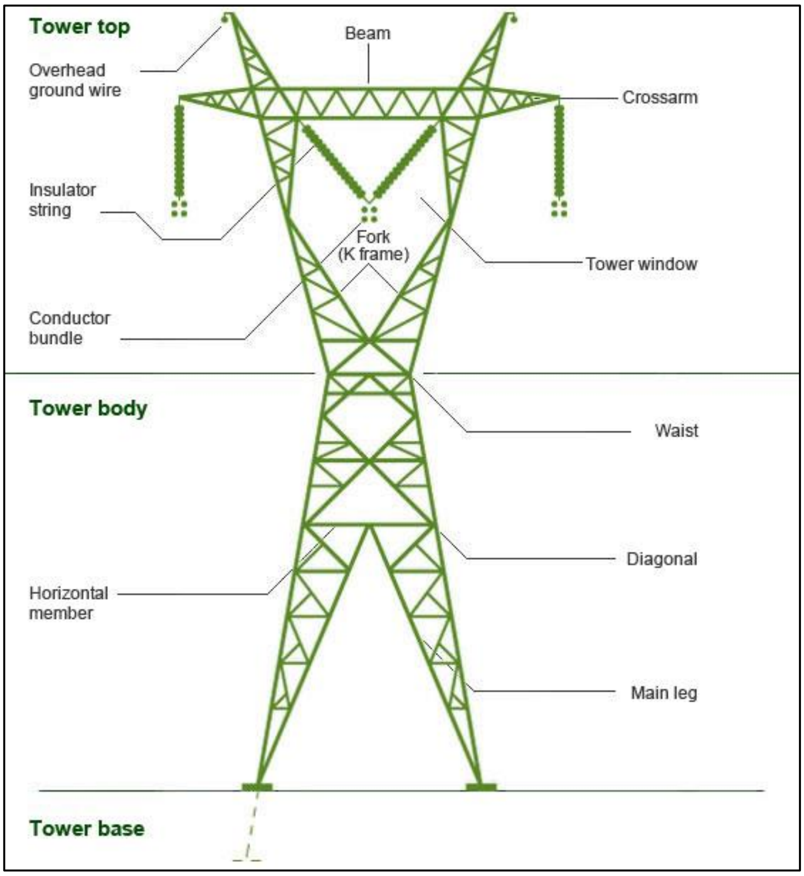


Figure 2.20: Arrangement of Transmission Tower

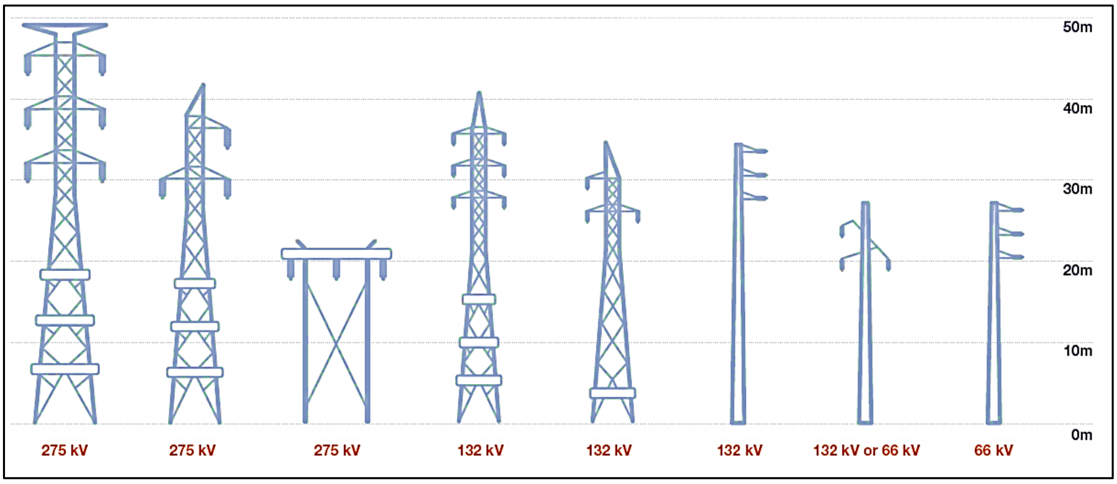


Figure 2.21: Type of Transmission Tower

HVDC transmission lines are used to transmit large amount of energy over long distances or through waterways. One of best known is the Pacific HVDC Intertie which interconnects southern California with Oregon. Another famous HVDC under water cables transmission is the interconnection between England and France. In HVDC system, the AC Voltage is rectified and DC lines transmit the energy. At the end of the line an inverter converts back the DC Voltages to AC. There are several of types faults in HVDC transmission system have been studied such as DC line faults, AC line faults and converter station Faults. The DC voltage is imbalance on DC side when the DC Line to Ground fault occurs and it is difficult to rebalance. The Line-to-Line fault in DC side of system leads to the fast discharging of DC capacitor and AC system is short-circuited by fault point. (A. K. Khairnar and P. J. Shah, 2016).

2.4 Fossil Fuel Energy

Internal Combustion Engine use the source either from natural gasses or petroleum product such as Fuel Oil, Diesel Fuel or Gasoline. All of these sources is a non-renewable energy where it is form by decayed component of living organism from million years ago. This eventually will form fossil fuels which currently explored by many as one of the most important energy. From exploration of the fossil fuel up to the petrol pump station to fill ICE tanks, there are many stages that need to be study to determine the cost and efficiency in every stages. All stages from well to petrol pump station can be explain in the Figure 2.22.

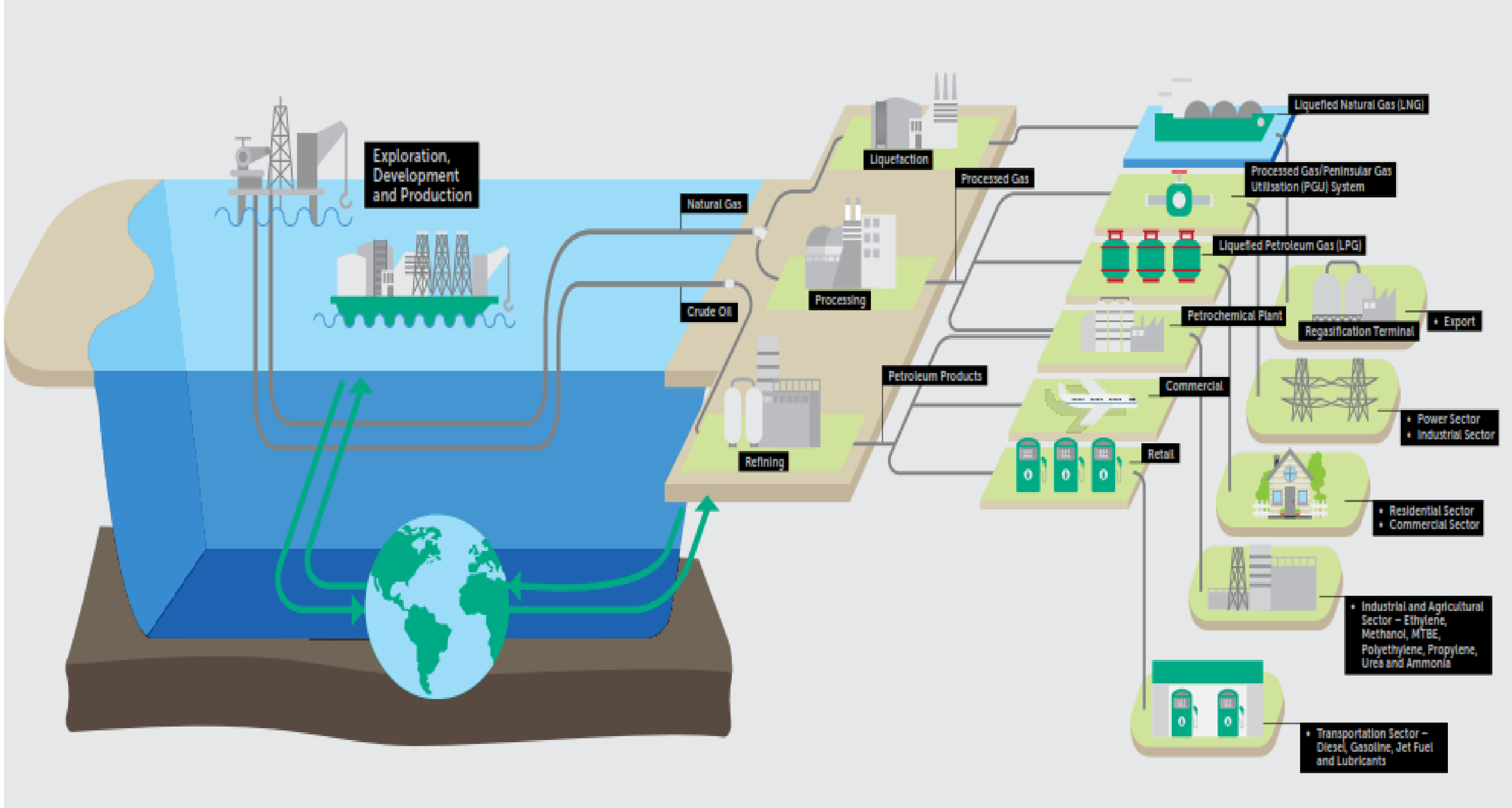


Figure 2.22 : Overview of Petroleum Industry

2.4.2 Petroleum Extraction

Fossil fuel exploration or known as Crude Oil Mining/Extraction is the primary stage in oil and gas industry. Crude oil is unrefined products which composed of hydrocarbon deposit and other organic materials. By mining or drilling crude oil, it is not only extracting crude oil but also other fossil fuel such as natural gas which is lighter than crude oil and also saline water which is denser than crude oil. These crude oil is trapped between the permeable rock and impermeable rock underneath the earth as shown in Figure 2.23 and need drilling process to be extracted.

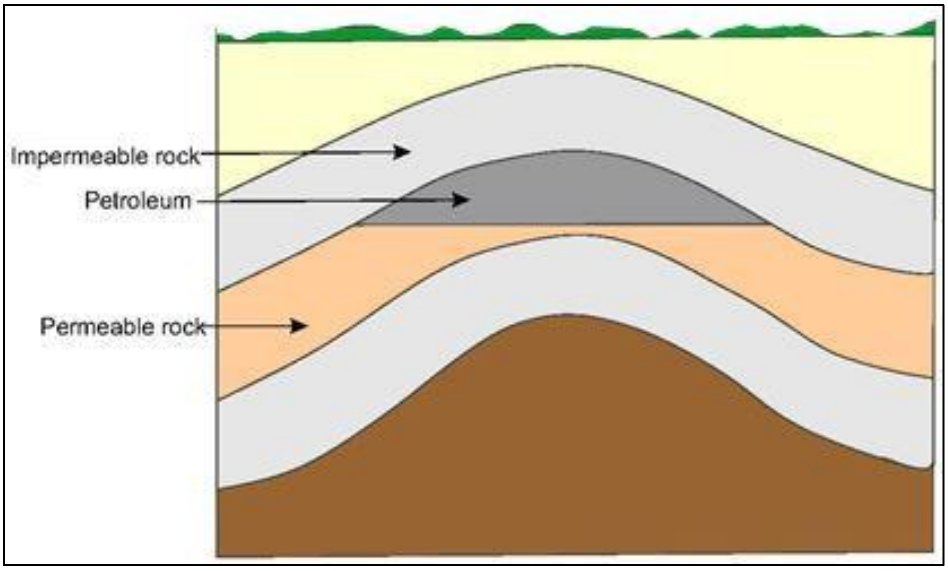


Figure 2.23: Location of Petroleum Source Trapped

The initial stage before mining process is to identify and determine the location of the crude oil well. This process will involve geologist and geophysicist or known as the ‘explorationist’ that will be using the 3-D Seismic survey system to determine the location of oil well. This Seismic Survey are done by sending transmitting high energy sound wave to the ground/seabed and measure the reflection back to the surface. The sound wave passed through different materials and could create a 3 dimension map of what lies beyond the surface. By this data, engineers can plan the most cost-effective well path for the reservoir. Then the exploration wells will be drilled and sample of the rock will be taken to analyse whether the site is likely to produce oil and natural gas and also the estimation quantity of oil/gas at the exploration wells.

There are many type of drilling rig been used for oil extraction depending on the location and requirement of each drill site. There are land base drilling rig, slim hole drilling rig, coiled tubing drilling rig, jackup drill rig, semi-submersible rig and drill ship. Figure 2.24 shows some of the drilling rig depending on the location of the wells.

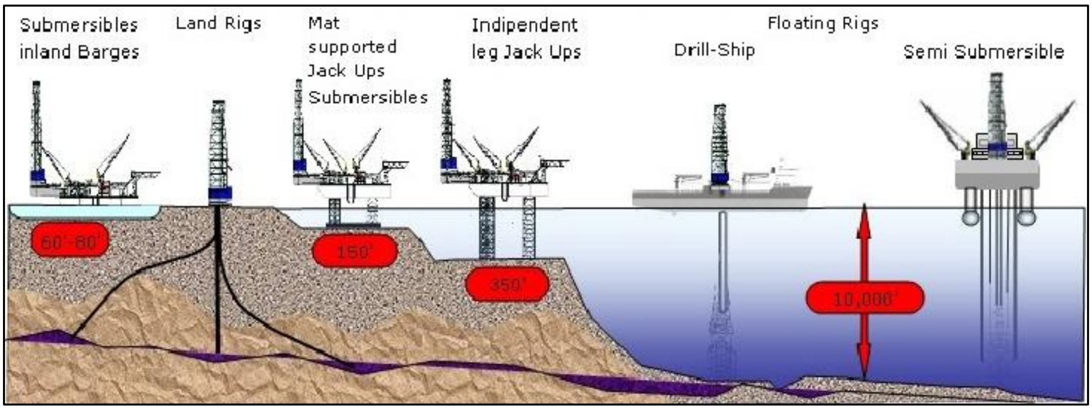


Figure 2.24: Types of Drill Rig

After drilling process, there are 3 stages involved in extracting the oil and gas from the well. At primary stages the oil gas is extracted by natural underground pressure that will drive the fluid to the surface. There are also artificial lift technologies such as pumps are used when the pressure falls. Primary recovery can only extract 5-15% of the total amount contain in the exploration area while secondary recovery is the enhanced process of the initial stage by injecting liquid or other material such as natural gas, carbon dioxide or air into the well to increase pressure and push oil to the surface. This secondary recovery technique can extract up to 30% with a total recovery for primary and secondary stages between 35%-45%. The final stages of oil extraction is the tertiary extraction stage which using the Enhanced Oil Recovery (EOR) technique. This technique used thermal, gas or chemical injection to increase pressure to the surface with a total recovery up to 60%. The reason why 100% of oil is not extracted is because the energy return on energy invested is not economical. In other words, the amount of energy that been used to extract the petroleum product exceed the amount of energy created and can be gain by the utilizing the petroleum, then the extraction efforts will be stop. Figure 2.25, Figure 2.26 and Figure 2.27 show graphical explanation on each stages mention.

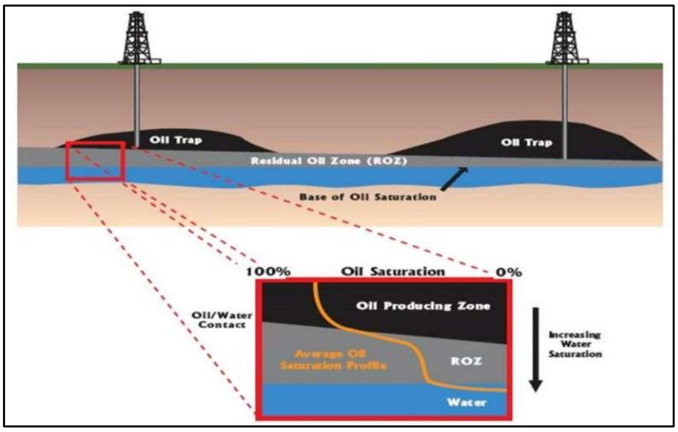


Figure 2.25: Primary Stage Recovery

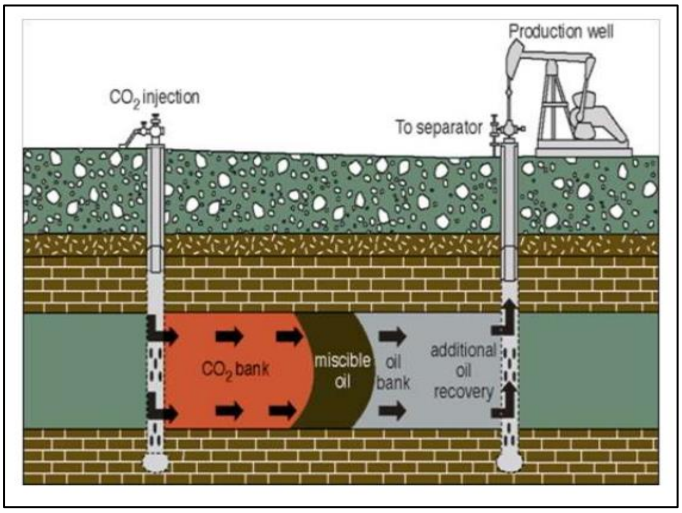


Figure 2.26: Secondary Recovery Stage (Gas Injection)

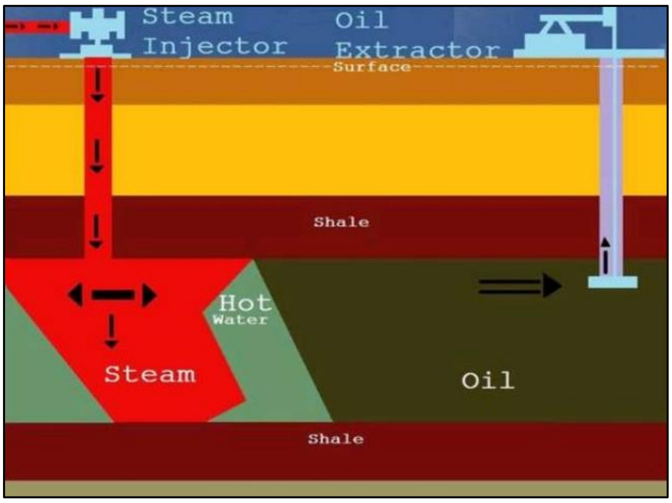


Figure 2.27: Tertiary Recovery Stage (Thermal)

2.4.3 Transportation

The petroleum product that has been extracted will be refine and transfer to the storage/distribution centre. The transfer processes need a transportation method which can be divided in to that is from the well to the refinery and also from the refinery to the storage/distribution centre. From well to refinery, the transportation method may vary depending on the location of the exploration area. Tanker ship and underwater pipelines can be used as method of transportation. However, installation of underwater pipeline is costlier over long distance which resulting usage of large oil tanker seem to be more practical and popular. Over land, petroleum product can be transferred through railroads, pipelines or road tanker. However using pipelines is the cheapest mean of transportation from well to refinery on land.

As for transportation from refinery to storage/distribution centre, Mean of transport is only pipelines. Its movement need usage of pump station along the pipelines to ensure the refined oil transferred to the storage/distribution centre. Figure 2.28 show the process of transportation in oil and gas industries.

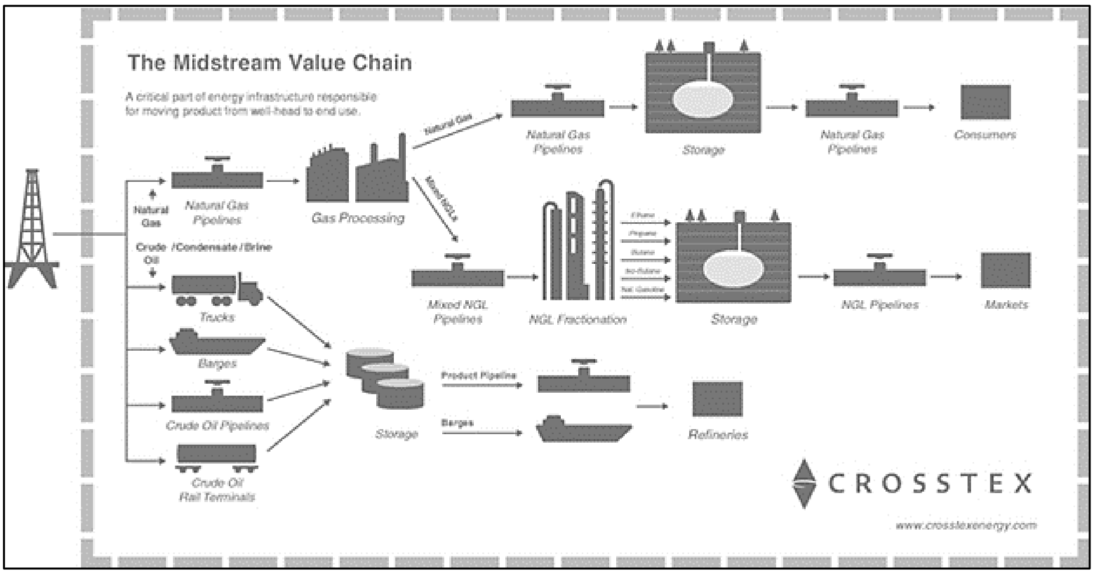


Figure 2.28: Means of Transportation for Petroleum Products

2.4.5 Refinery

In oil and gas industries, refinery stages is the most vital parts. Every petroleum product must undergo refinery process before obtaining the desire product. The main job of refinery is to improve the hydrocarbon within the crude oil and can be explain graphically in Figure 2.29. This process involved separation and reaction to some reactive process to produce various products. Refinery petroleum process could be categorized into seven basic operations as follows:

(i) Separation: Distillation and solvent refining
(ii) Conversion: Carbon removal and hydrogen addition
(iii) Reforming: Catalytic reforming and Steam/hydrocarbon reforming
(iv) Rearrangement: Isomerization
(v) Combination: Catalytic polymerization and alkylation
(vi) Treating, Finishing, Blending: End product of Gasoline, Kerosene, Diesel, Lubes, Waxes, and Asphalt.
(vii) Protecting the Environment: Water waste treatment, Disposal of solids and sulphur recovery.

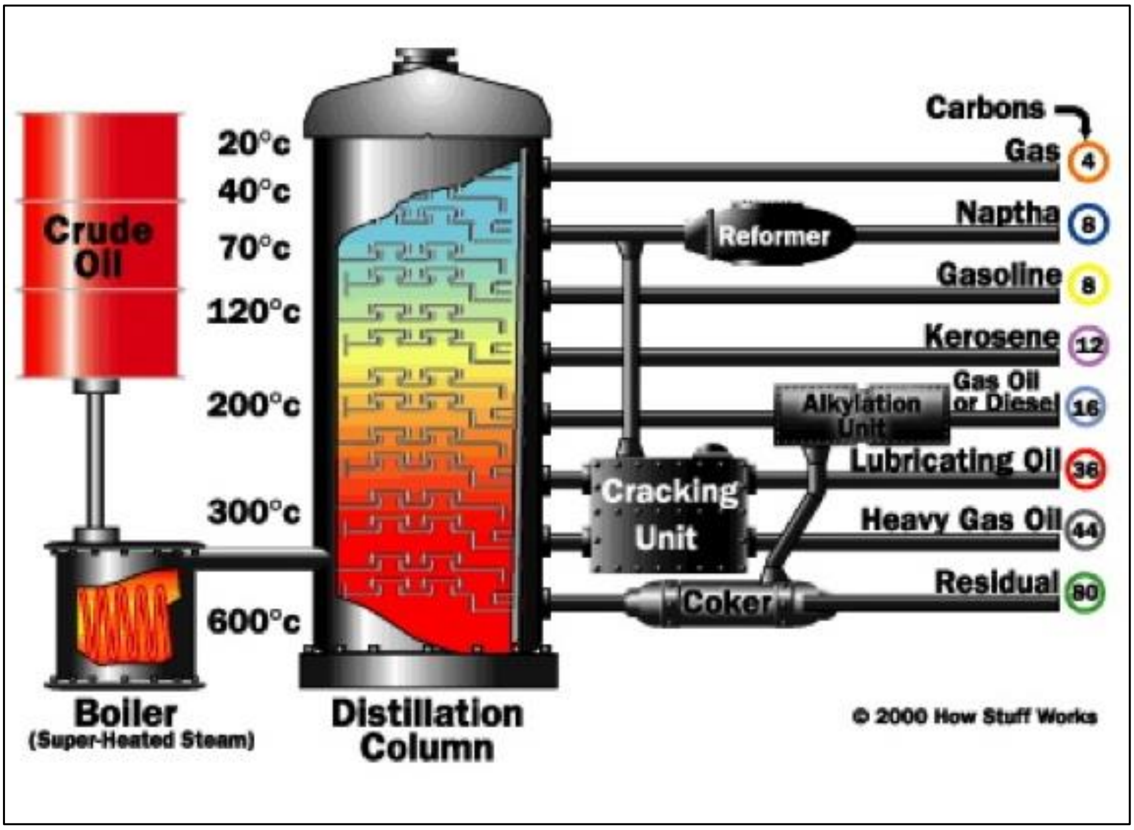


Figure 2.29: Refinery important process and its end products

2.4.6 Storage/Distribution Centre

After the refinery process, the petroleum product will be kept in storage tank/ distribution centre before the product been transfer to the consumer. This storage area typically has a tankage that could possibly located above ground or underground. Besides, a framework for discharge of the products from tankage to transport such as either road tanker, barge or pipelines. This area need to be kept well maintain to avoid spillage or leakage. The parameter of operation also need to be monitor closely to avoid accidents such as explosion and fire. Figure 2.3 shows type of petroleum storage tanks.

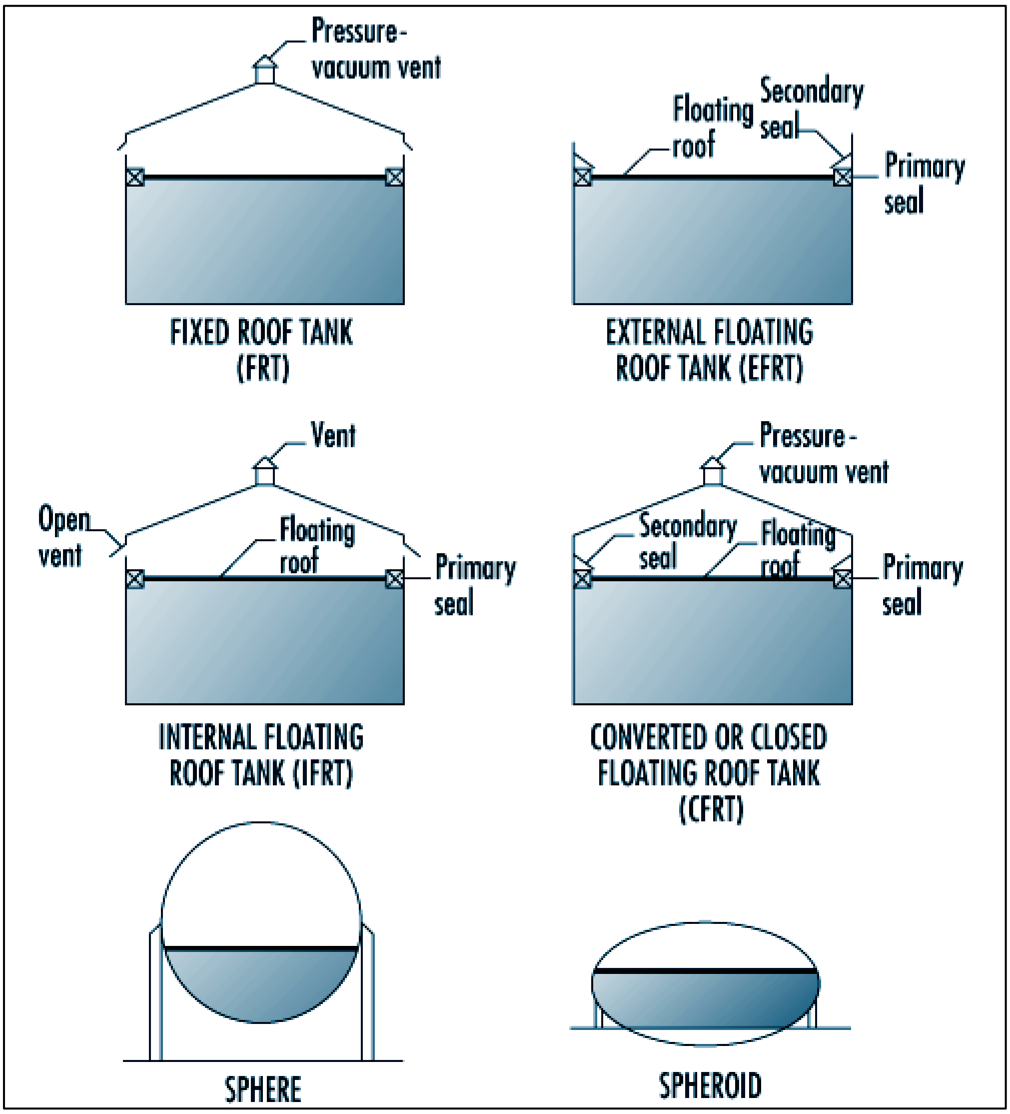


Figure 2.30: Type of Petroleum Storage Tanks

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this report, the scope of research need to be determine in order to achieve the objective. This report will be using method of data collection from any related report or study by others. This data will be collected in comparing the cost for 1 kW of energy between Internal Combustion Engine (ICE) Vehicles and Electric Vehicles.

Area of study for comparison that will be taken into account is all stages from well to wheel for both ICE and EV. To achieve the objective of this report, all data on efficiency and cost will be collected and analyse. This report will scope down the inventories from well to wheel which is implemented in Malaysia. As for costing data, only Operational Expenditure (OPEX) from the year 2011 and above will be considered in this study. Capital Expenditure (CAPEX) will not be accounted as it is a one-off expenditure which may vary depending many factor especially by the manufacturing year.

For EV study, the cost and efficiency data will consider from the many type of power generation to transmission and distribution and to ICE for its operations. While for ICE the data will consider from the exploration process up until the pump station and the EV operations.

For EV pathway, the type of EV that will be put in this area of study is the BEV type which is totally using battery as its source of operations. This will also correspond to the objective of study which is to identify and determine the future of EV as replacement for ICE.

Data collected may vary depending on its technology which will contribute to its cost and efficiency. Thus, this study will take average figures to of each process/stage to put in this comparison model. There are 12 stages that will be considered and focus on this study in term of cost and efficiency comparison. The processes flow is shown in Figure 3.1.

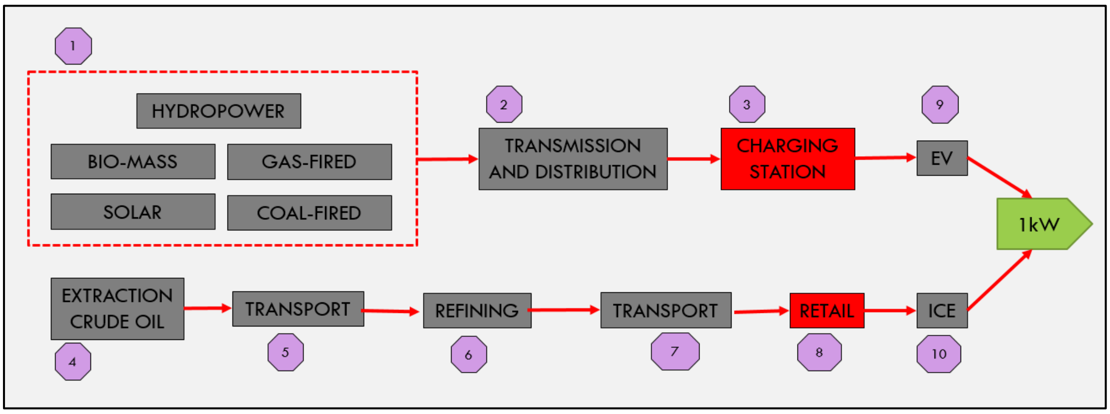


Figure 3.1: Energy Flow for EV and ICE in producing 1kW

3.2 Power Generation

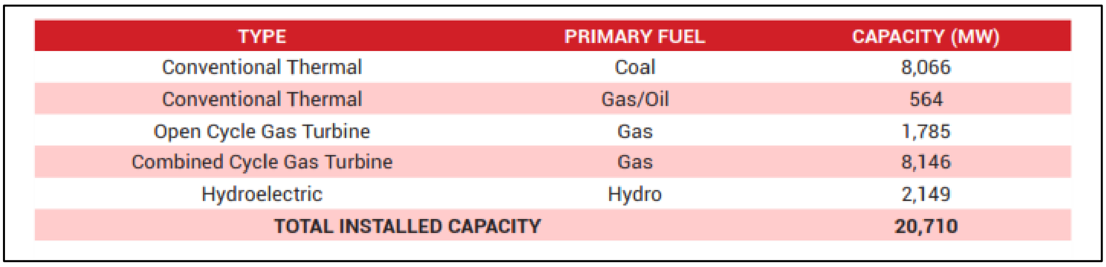
There are many types of Power Generation/Plant in this world. Its type is depending on its available sources in that certain area. Basic working principle of any power generation plant is by using a turbine that is attach to the rotor shaft which will rotate the rotor in the alternator to induce current. The type may vary depending on the sources to rotate the turbine. It is either from renewable sources or from non-renewable sources. Medium to rotate the turbine is either by flow of liquid such as run of river/tidal or movement of air such from steam, wind or exhaust by any combustion. However, there are some power generation plant which is not using rotation of alternator to induced current such as the solar power plant.

Power production and consumption in Malaysia is controlled by a government body “Energy Commission” who regulates all matters relating to electricity and gas supply industry. In Malaysia, Tenaga Nasional Berhad (TNB) is the largest electricity utility in Malaysia. TNB also is the only body who owned the transmission and distribution in Malaysia. Other than TNB, there is many other Independent Power Producer (IPP) such as Malakoff, YTL Power Generation Sdn Bhd, Tanjung Bin Power Sdn Bhd and many more which supply electricity to the grid. Each power plant electricity production may vary depending on its type and size.

In Malaysia, not all type power plant has been implemented or build due to lack of sources and costlier for return of energy production. In Malaysia, natural gas has become the main energy supplier. According to the National Energy Balance 2013, it is estimated that Malaysia gas reserve are expected to last for another 40 years.

Installed capacity in peninsular Malaysia based on its type of power station is list in Table 3.1 (Energy Commission Annual Report, 2016).

Table 3.1: Installed capacity in Peninsular Malaysia according to type of power station



TYPE	PRIMARY FUEL	CAPACITY (MW)
Conventional Thermal	Coal	8,066
Conventional Thermal	Gas/Oil	564
Open Cycle Gas Turbine	Gas	1,785
Combined Cycle Gas Turbine	Gas	8,146
Hydroelectric	Hydro	2,149
TOTAL INSTALLED CAPACITY		**20,710**

In this study each type of power station in Peninsular Malaysia with the highest capacity will be taken as a model for data collection. The energy capacity of each power station is used to determine the cost of operations while different of type of power station can be compared for their efficiency. The selected type of power station or this study with their capacity as shown in Table 3.2.

Table 3.2: Different Type of Power Station and its capacity in Peninsular Malaysia

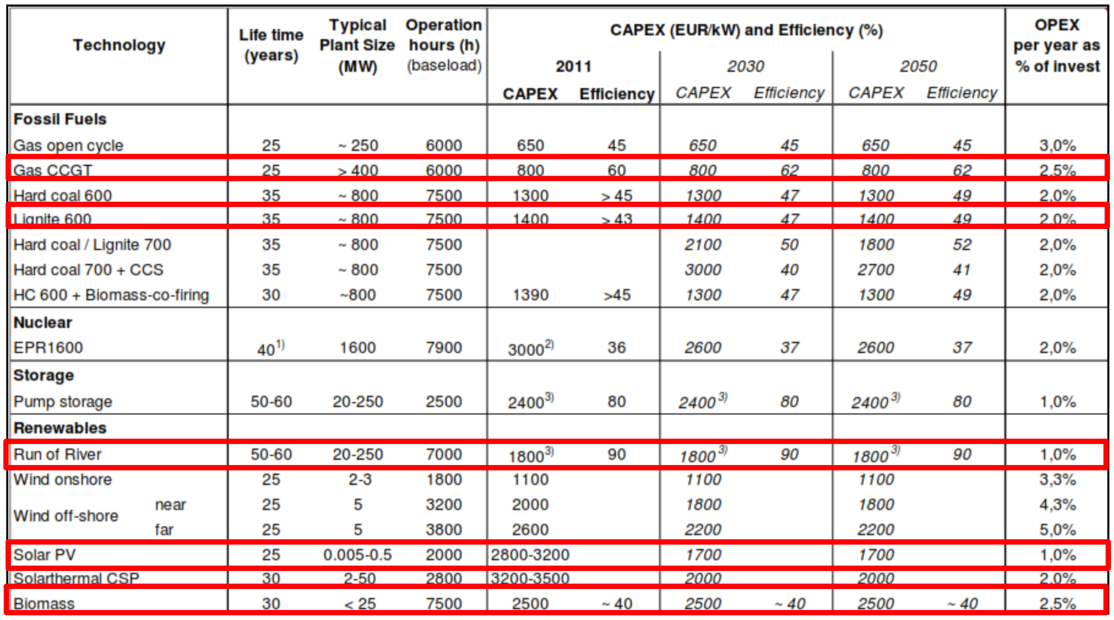
Type	**Name**	**Location**	**Generation Type**	**Capacity**
Hydropower	Sultan Idris II	Pahang	Turbine (Run of River)	150MW
Biomass	Recycle Energy Sdn Bhd	Selangor	Steam Turbine	8.9MW
Solar	Amcorp Gemas	Negeri Sembilan	-	10.25MW
Gas-Fired	Lumut Power Station	Perak	Combined Cycle (6 GT, 2 ST)	1,303MW
Coal-Fired	Manjung Power Station	Perak	Thermal (3 ST)	2,295MW

3.2.1 Cost of Power Generation

Based on the type of power station selected in this study, Operational Expenditure (OPEX) are gathered. However, expenses data for each plant from the

TNB and the IPP were private and confidential. Therefore, this study will find similar power station OPEX data from around the world and will be converted to a common base currency for comparison. Table 3.3 shows the survey by VGB Powertech on Investment and Operation Cost Figures – Generation Portfolio, 2011 in the percentage of OPEX cost for each power station in Europe.

Table 3.3: Expenditure based on type of power plant technology



Technology	Life time (years)	Typical Plant Size (MW)	Operation hours (h) (baseload)	CAPEX (EUR/kW) and Efficiency (%)						OPEX per year as % of invest
				2011		2030		2050		
				CAPEX	Efficiency	CAPEX	Efficiency	CAPEX	Efficiency	
Fossil Fuels										
Gas open cycle	25	~ 250	6000	650	45	650	45	650	45	3,0%
Gas CCGT	25	> 400	6000	800	60	800	62	800	62	2,5%
Hard coal 600	35	~ 800	7500	1300	> 45	1300	47	1300	49	2,0%
Lignite 600	35	~ 800	7500	1400	> 43	1400	47	1400	49	2,0%
Hard coal / Lignite 700	35	~ 800	7500			2100	50	1800	52	2,0%
Hard coal 700 + CCS	35	~ 800	7500			3000	40	2700	41	2,0%
HC 600 + Biomass-co-firing	30	~800	7500	1390	>45	1300	47	1300	49	2,0%
Nuclear										
EPR1600	$40^{1)}$	1600	7900	$3000^{2)}$	36	2600	37	2600	37	2,0%
Storage										
Pump storage	50-60	20-250	2500	$2400^{3)}$	80	$2400^{3)}$	80	$2400^{3)}$	80	1,0%
Renewables										
Run of River	50-60	20-250	7000	$1800^{3)}$	90	$1800^{3)}$	90	$1800^{3)}$	90	1,0%
Wind onshore	25	2-3	1800	1100		1100		1100		3,3%
Wind off-shore near	25	5	3200	2000		1800		1800		4,3%
far	25	5	3800	2600		2200		2200		5,0%
Solar PV	25	0.005-0.5	2000	2800-3200		1700		1700		1,0%
Solarthermal CSP	30	2-50	2800	3200-3500		2000		2000		2,0%
Biomass	30	< 25	7500	2500	~ 40	2500	~ 40	2500	~ 40	2,5%

Based on Table 3.3, the OPEX is by percentage of investment or Capital Expenditure (CAPEX). The OPEX could be simplified for better understanding for this study is shown in Table 3.4.

Table 3.4: OPEX based on type of power plant technology 2011

Type	Generation Type	Plant Size (MW)	OPEX(EUR/kW)
Hydropower	Turbine (Run of River)	20-250	€18
Biomass	Steam Turbine	<25	€62.5
Solar	-	0.005-0.5	€28-32
Gas-Fired	Combined Cycle	>400	€20
Coal-Fired	Thermal	~800	€28

3.2.2 Efficiency of Power Generation

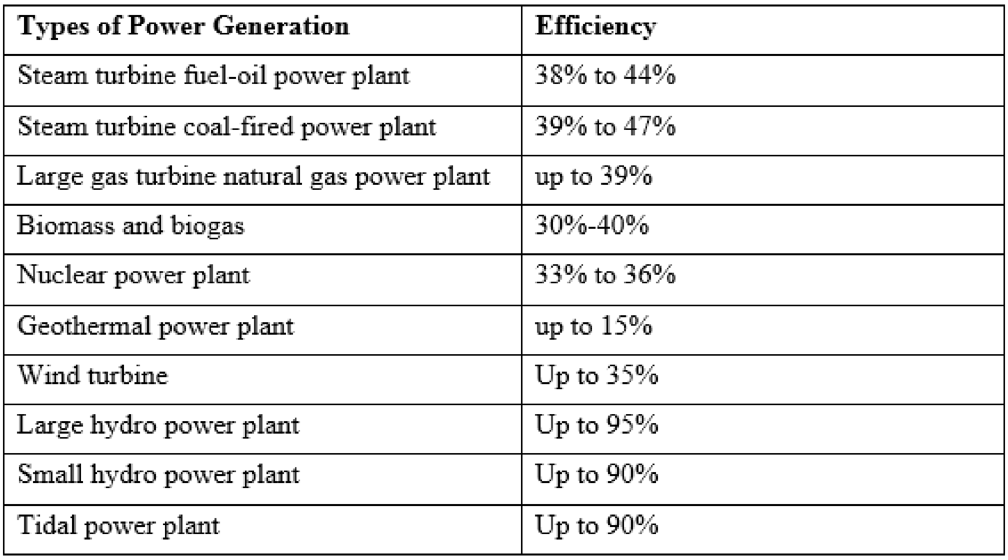
Efficiency of each power plant may vary depending on its working principle as explained in literature review. The medium and technology of moving the turbine will determine the efficiency of each power plant. There are many losses that need to be consider in this study such as the thermal losses, mechanical losses, pumping losses, fraction losses and many more. This losses will contribute to the efficiency of each plant energy. Power plant efficiency can be calculated by formula below where NEP is the Net Electric Power supplied to the grid and CV is the Calorific Value or can be define as energy contained in the source.

$$\text{Power plant efficiency, } \eta = \frac{NEP}{CV} \times 100\% \tag{3.1}$$

$$\text{Losses} = CV - NEP$$

Based on report on energy in electricity generation by Eurelectric, the efficiency of power plant which use thermal to move the turbine has a great losses compared to power plant that use flow of liquid method such as hydropower plant. Tube leak problems were the primary reason for the decline in dependability of conventional coal-powered plants while vibrations, turning gear overload and generator rotor winding open circuit were the problems encountered by gas-powered plants. The efficiencies for various type of power plant is shown in table 3.5:

Table 3.5: Efficiencies for various type of power generation



Types of Power Generation	**Efficiency**
Steam turbine fuel-oil power plant	38% to 44%
Steam turbine coal-fired power plant	39% to 47%
Large gas turbine natural gas power plant	up to 39%
Biomass and biogas	30%-40%
Nuclear power plant	33% to 36%
Geothermal power plant	up to 15%
Wind turbine	Up to 35%
Large hydro power plant	Up to 95%
Small hydro power plant	Up to 90%
Tidal power plant	Up to 90%

As for solar power plant, most solar panels convert around 15% of the sun's energy into electricity. More experimental photovoltaic panels, like concentrating solar panels, can convert 40% of incident solar energy into electricity.

3.3 Transmission and Distribution

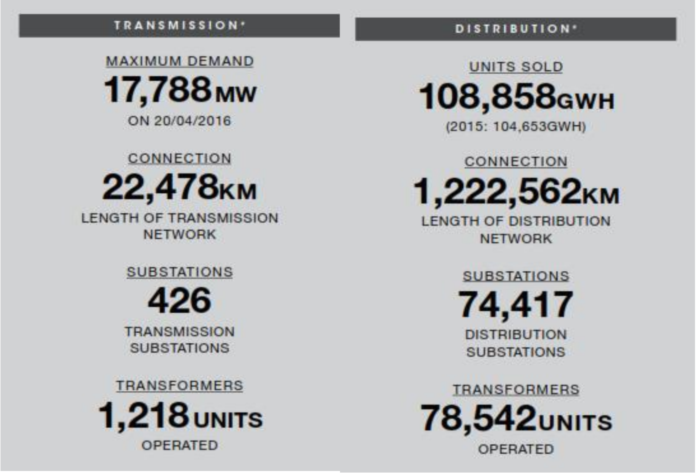
Electricity network or grid in Malaysia is owned and maintained by TNB. Transmission and distribution system involved stepped-up and down voltages along the line to ensure the correct amount of energy delivered to the consumer. Therefore, the efficiencies of transformers play big part in the percentage of energy efficiencies. Ohm’s Law explained in how the amount of power which involved Voltage, Current and Resistance are related and affecting each other.

$$V = IR \; ; \quad P = VI = I^2R \qquad (3.2)$$

It shows that the power losses will increase greatly with the small increase in current. Therefore, by keeping the voltages high during transmission could keep to current low and avoid mass power losses. By keeping the current low will also reduce the heat loss during power transmission.

3.3.1 Cost of Transmission and Distribution

In order to determine the cost for Transmission and Distribution (T&D), the amount of energy and the connection length need to be identified at both T&D. The connection length is the vital factor in this study because the connection length will reflect on the figures of T&D tower and also the power station. Figure 3.2 presented the TNB T&D in Peninsular Malaysia.



TRANSMISSION*

MAXIMUM DEMAND
17,788MW
ON 20/04/2016

CONNECTION
22,478KM
LENGTH OF TRANSMISSION NETWORK

SUBSTATIONS
426
TRANSMISSION SUBSTATIONS

TRANSFORMERS
1,218UNITS
OPERATED

DISTRIBUTION*

UNITS SOLD
108,858GWH
(2015: 104,653GWH)

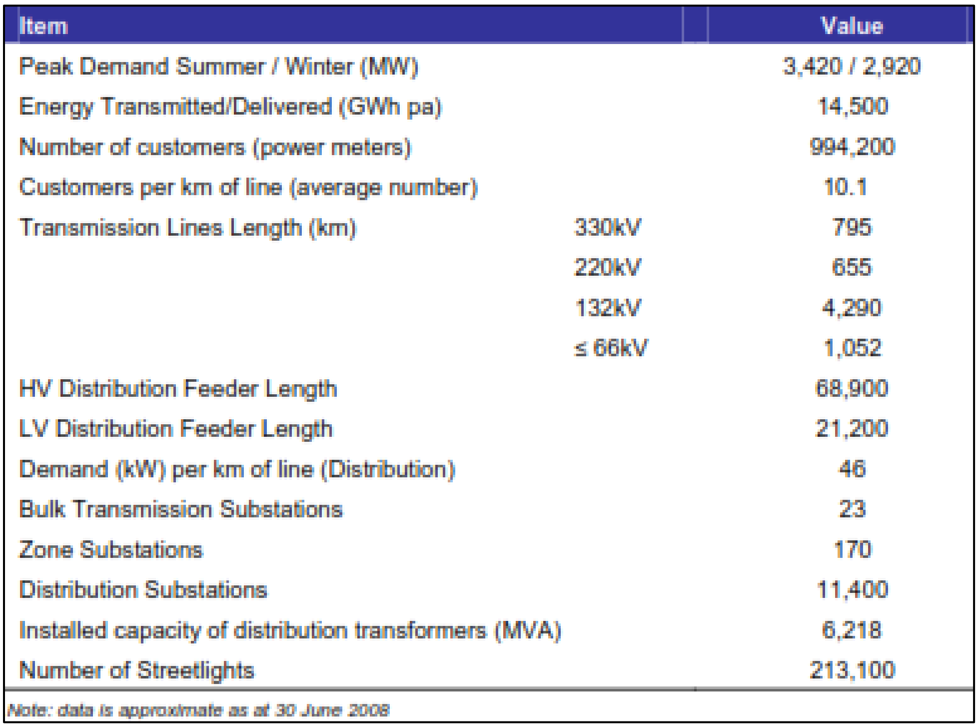
CONNECTION
1,222,562KM
LENGTH OF DISTRIBUTION NETWORK

SUBSTATIONS
74,417
DISTRIBUTION SUBSTATIONS

TRANSFORMERS
78,542UNITS
OPERATED

Figure 3.2: Transmission and distribution network in Peninsular Malaysia (TNB Annual Report, 2016)

This study will compare with data available and will scale to fit the parameter. Western Australia power network will be used and the information is detailed in Westernpower Capital and Operating Expenditure 2009/10 to 2011/12 Report. Based on the report the OPEX for transmission cost is AUD 28.7 million per year while OPEX for distribution network is AUD 80.80 million per year. Detail parameter of the length of T&D for Western Australia is shown in Figures 3.3.



Item		Value
Peak Demand Summer / Winter (MW)		3,420 / 2,920
Energy Transmitted/Delivered (GWh pa)		14,500
Number of customers (power meters)		994,200
Customers per km of line (average number)		10.1
Transmission Lines Length (km)	330kV	795
	220kV	655
	132kV	4,290
	≤ 66kV	1,052
HV Distribution Feeder Length		68,900
LV Distribution Feeder Length		21,200
Demand (kW) per km of line (Distribution)		46
Bulk Transmission Substations		23
Zone Substations		170
Distribution Substations		11,400
Installed capacity of distribution transformers (MVA)		6,218
Number of Streetlights		213,100

Note: data is approximate as at 30 June 2008

Figure 3.3: Western Australia power network

Based on the data above, table of equivalent has been developed to determine the cost of OPEX in Malaysia. The value is determined base on the scale of length for T&D network and from it the cost per energy could be determined. Table of equivalent is shown in Table 3.6.

Table 3.6: Table of equivalent for transmission and distribution cost

	Western Capital (AUSTRALIA)	**Energy Commission (MALAYSIA)**	**Ratio**
Energy	14,500GWh	108,858GWh	1 : 75
TRANSMISSION			
Transmission Length	6,792km	22,478km	1 : 3.3
Transmission Cost	AUD 28.7 million	AUD 94.71 million	
Transmission Cost/KM	**AUD 4,213.45/km** AUD 1 = MYR3.09 (2011)		
Transmission Cost/Energy	**AUD 870/GWh @ MYR 2,688.30/GWh**		
DISTRIBUTION			
Distribution Length	90,100km	1,222,562km	1 : 13.57
Distribution Cost	AUD 80.80 million	AUD 1,096.45 million	
Distribution Cost/KM	**AUD 896.85/km** AUD 1 = MYR3.09 (2011)		
Distribution Cost/Energy	**AUD 10,072.29 /GWh @ RM31,123.38/GWh**		

3.3.2 Efficiencies of Transmission and Distribution

Efficiencies of Transmission and Distribution Network can be divided into 4 major parts as follows:

(i) Step-up transformer losses from generator to transmission line : 1 -2 %

(ii) Transmission Line : 2 – 4 %

(iii) Step-down transformer from transmission line to distribution network : 1 – 2%

(iv) Distribution network transformers and cables : 4 – 6%

Most of the losses is due to heat losses in the network. The overall power losses along the transmission and distribution line are around 8-15% with efficiencies of 85 – 92%. In this study, we could use the value of 89% as the means value of efficiencies.

3.4 Electric Vehicles (EV) Charging Station

In Malaysia, there were already 212 Charging Station across Malaysia with maximum power supply up to 22kW until July 2017. Malaysia plan to deploy 100,000 EVs in the next five years. There are 3 types of charging station that where each type affect its cost and efficiencies in term of charging time. The development of semi-conductor and control system of charging station will determine the future of EV.

Efficiency of Charging Station really depending on the advancement of technology. Recently, Charging Station Level 2 could have the efficiency up to 94%. While for the OPEX cost of EV's charging station depending on its type is shown in Table 3.7. This data is collected from Charging Infrastructure for Electric Vehicles in Germany Progress Report and Recommendations, 2015.

Table 3.7: Operation Cost for Electric Vehicle Charging Station

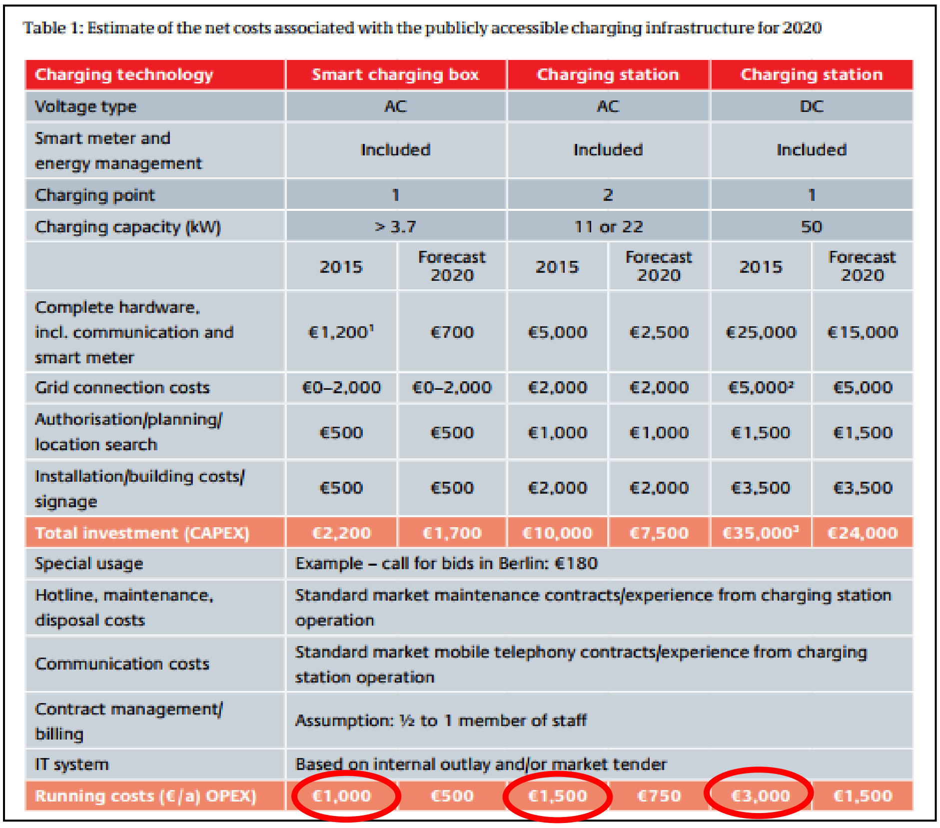


Table 1: Estimate of the net costs associated with the publicly accessible charging infrastructure for 2020

Charging technology	Smart charging box		Charging station		Charging station	
Voltage type	AC		AC		DC	
Smart meter and energy management	Included		Included		Included	
Charging point	1		2		1	
Charging capacity (kW)	> 3.7		11 or 22		50	
	2015	Forecast 2020	2015	Forecast 2020	2015	Forecast 2020
Complete hardware, incl. communication and smart meter	€1,200[1]	€700	€5,000	€2,500	€25,000	€15,000
Grid connection costs	€0–2,000	€0–2,000	€2,000	€2,000	€5,000[2]	€5,000
Authorisation/planning/ location search	€500	€500	€1,000	€1,000	€1,500	€1,500
Installation/building costs/ signage	€500	€500	€2,000	€2,000	€3,500	€3,500
Total investment (CAPEX)	€2,200	€1,700	€10,000	€7,500	€35,000[3]	€24,000
Special usage	Example – call for bids in Berlin: €180					
Hotline, maintenance, disposal costs	Standard market maintenance contracts/experience from charging station operation					
Communication costs	Standard market mobile telephony contracts/experience from charging station operation					
Contract management/ billing	Assumption: ½ to 1 member of staff					
IT system	Based on internal outlay and/or market tender					
Running costs (€/a) OPEX)	€1,000	€500	€1,500	€750	€3,000	€1,500

In 2015, average currency conversion for €1 is equal to MYR 4.208. Therefore, OPEX cost for charging station yearly may vary from MYR2,104.00 (equal to €1000) to MYR12,624.00 (equal to €3,000) depending on its type of operations.

3.5 Petroleum Extraction

In petroleum extraction or known as the upstream sector of Oil and Gas Industry, the major operation and expenses is more on maintaining the oil rig. There are many type of oil rig depending on the petroleum reservoir but their basic operation is about the same where they do the drilling and pumping works as explained in the literature review. Therefore, the drill mechanism operation and the pumping line is the vital component in the oil rig.

In term of efficiency, petroleum extraction can only pump out the fossil fuel up to 60% of efficiency because of energy return on energy invested if more than 60% is not economical. The efficiency of the oil rig can be assumed as more than 95% efficiency because its inefficiency can be measured by the oil spill during its operations and can be monitored visually and by sensors by its operator.

As for the operating expenditures, the cost will depending on the production of the crude oil and natural gasses. The higher the cost the higher the operating expenditure. However, OPEX cost can be measured by cost of barrel. This cost per barrel then can be converted into energy for comparison purposes of this study. Based on operating cost of oil production in Malaysia during 2014, OPEX cost for 1 barrel of crude oil is $16.40. Barrel of crude oil can be converted into litre which equal to 159 litre per barrel. The Operating Cost and Oil Production for some country around the world in 2014 is shown in Figure 3.4.

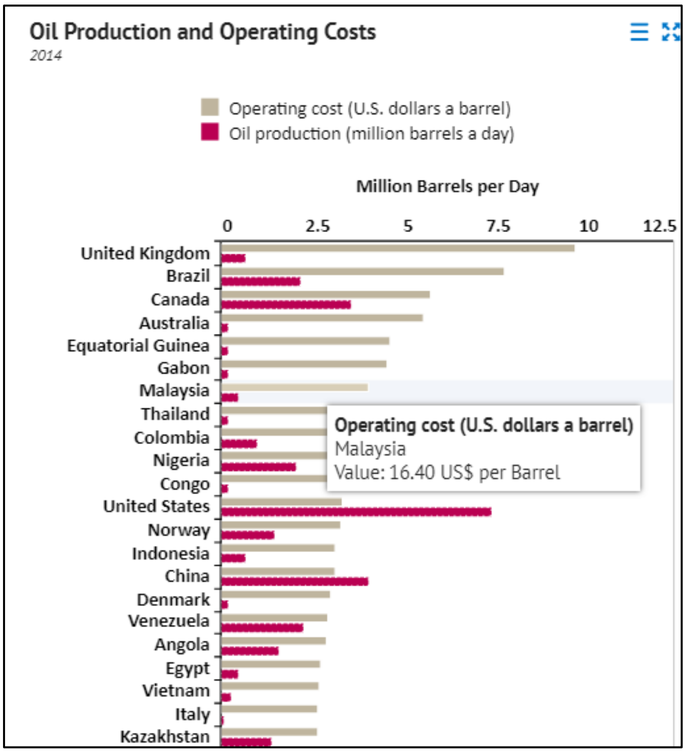


Figure 3.4: Operating Cost and Oil Production 2014

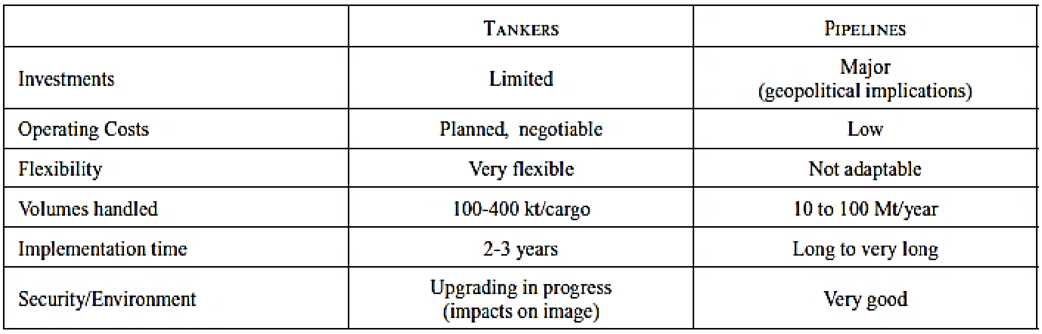
3.6 Petroleum Transportation

In general, there are many kind of transportation method involved in oil and gas industry depending on the requirement of operations. All of this method either by vehicles or by pipelines will require a lot of cost in maintaining and its operations.

As for transportation by vehicles either by road tanker, rail roads or ship tanker, the operations of each vehicles will require another source of energy. It might be using ICE as its prime mover which will also require petroleum product as its fuel source. Therefore, its efficiency can be divided into two which is the efficiency in transporting the product that can be measured by volume and also the efficiency of its operations of each vehicle. In term of transfer volume of product efficiencies, it can be said that by either pipeline or vehicles the percentage is more than 95% where the 5% losses is due to vaporization.

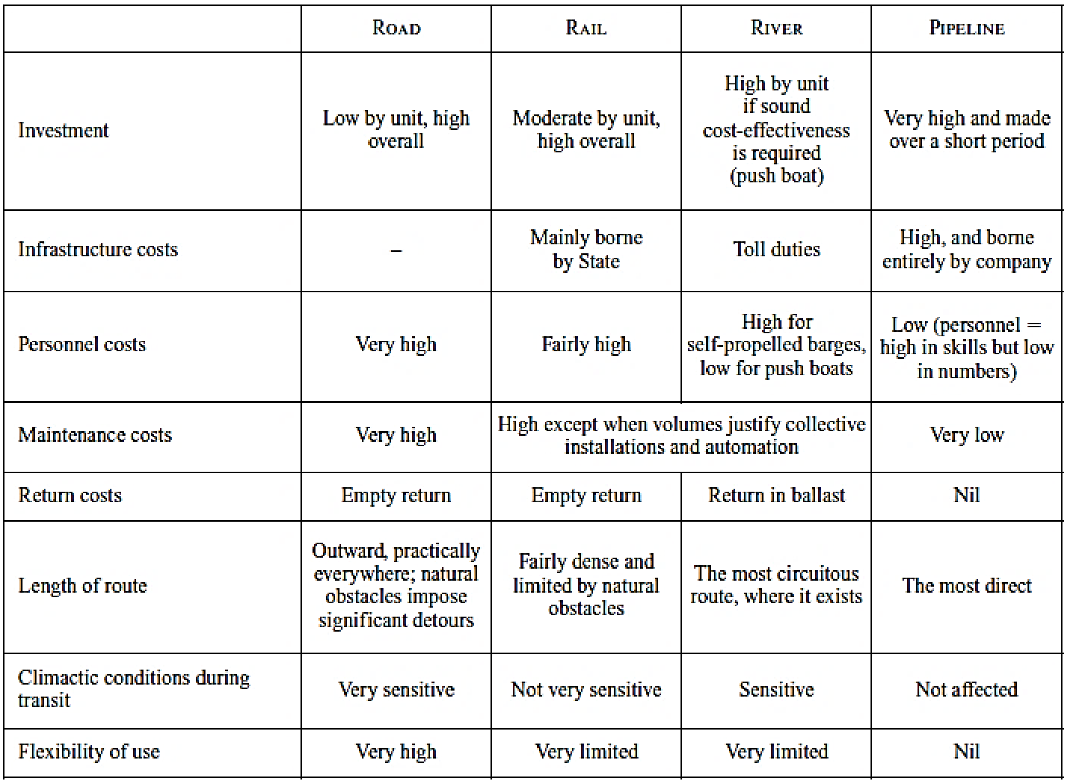
While for transportation by pipelines, its method requires good material and installation of the pipelines. The maintenance is less afterwards where it only need maintenance for the wear and tear parts over time. However, every pipeline requires pumps station where the number of pumps station depending on the length of the pipelines. The pump is a mechanical operation which its power source come from electricity. The maintenance of the pumps also is very less where technology nowadays could make the pump last longer. The methods of transportation were compared and the results were listed in the Table 3.8 and 3.9.

Table 3.8: Comparisons between Tankers and Pipelines



	TANKERS	PIPELINES
Investments	Limited	Major (geopolitical implications)
Operating Costs	Planned, negotiable	Low
Flexibility	Very flexible	Not adaptable
Volumes handled	100-400 kt/cargo	10 to 100 Mt/year
Implementation time	2-3 years	Long to very long
Security/Environment	Upgrading in progress (impacts on image)	Very good

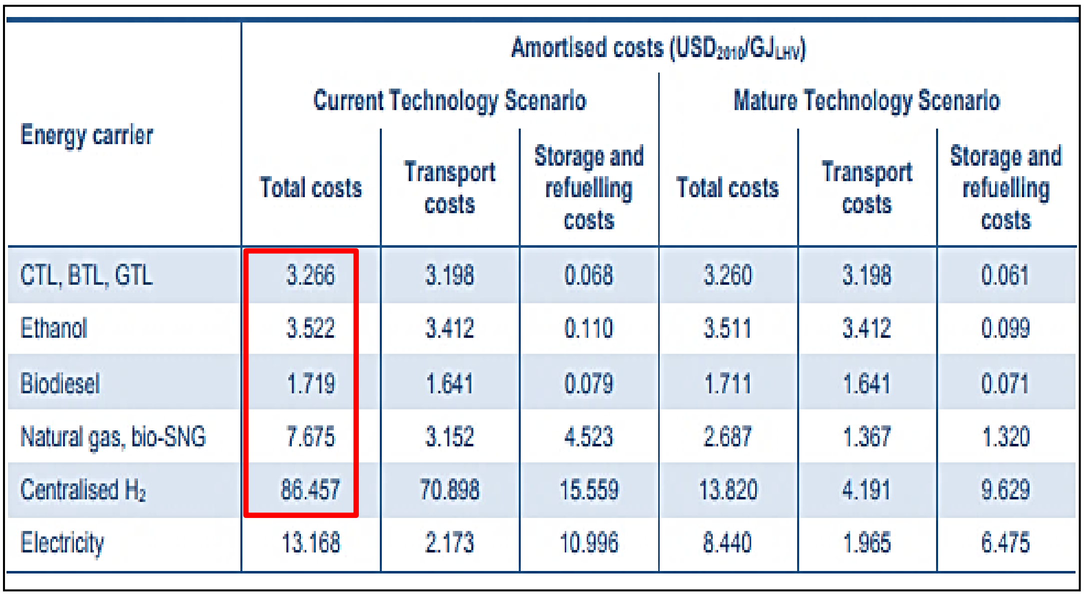
Table 3.9: Comparison of Methods of Transport



	ROAD	RAIL	RIVER	PIPELINE
Investment	Low by unit, high overall	Moderate by unit, high overall	High by unit if sound cost-effectiveness is required (push boat)	Very high and made over a short period
Infrastructure costs	–	Mainly borne by State	Toll duties	High, and borne entirely by company
Personnel costs	Very high	Fairly high	High for self-propelled barges, low for push boats	Low (personnel = high in skills but low in numbers)
Maintenance costs	Very high	High except when volumes justify collective installations and automation		Very low
Return costs	Empty return	Empty return	Return in ballast	Nil
Length of route	Outward, practically everywhere; natural obstacles impose significant detours	Fairly dense and limited by natural obstacles	The most circuitous route, where it exists	The most direct
Climactic conditions during transit	Very sensitive	Not very sensitive	Sensitive	Not affected
Flexibility of use	Very high	Very limited	Very limited	Nil

The cost for energy transport by petroleum product is shown in the Table 3.10. The table is the data for United States cost of transportation. The total cost for petroleum product is USD102.639 / GJ where it can be converted as USD0.3695/kWh.

Table 3.10: Cost for Transportation by Energy Carrier



Energy carrier	Amortised costs (USD_{2010}/GJ_{LHV})					
	Current Technology Scenario			Mature Technology Scenario		
	Total costs	Transport costs	Storage and refuelling costs	Total costs	Transport costs	Storage and refuelling costs
CTL, BTL, GTL	3.266	3.198	0.068	3.260	3.198	0.061
Ethanol	3.522	3.412	0.110	3.511	3.412	0.099
Biodiesel	1.719	1.641	0.079	1.711	1.641	0.071
Natural gas, bio-SNG	7.675	3.152	4.523	2.687	1.367	1.320
Centralised H_2	86.457	70.898	15.559	13.820	4.191	9.629
Electricity	13.168	2.173	10.996	8.440	1.965	6.475

3.7 Petroleum Refinery

Refinery is one of the vital processes in oil and gas industry where the type of end product for the consumer is determined. Refinery plant will require many sensors and control equipment for its operation because its process involved temperature and viscosity control. The boiler itself required energy to produce the heat up to 600°C before it goes to distillation column.

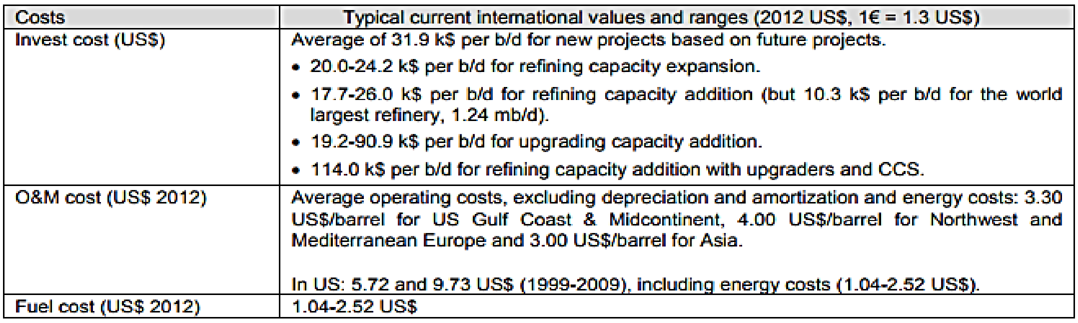
I.P. Rivera et al (2011) have study from well to wheel where determining the petroleum refineries efficiencies has become a necessary step for life cycle analysis. This report determine the amount of energy used for refinery operations. Table 3.11 below shows that the efficiency of refinery process is 91.4% with all product included.

Table 3.11: Refinery Energy Efficiencies

	Allocated % of Total Refining Fuel Use	% of Total Refinery Products Energy Content	Relative Energy Intensity	Overall Petroleum Refinery Efficiency	
				91.4% (with all products included)	**88.3%** (with less desirable products excluded)
LPG Gasoline Distillate	93.9%	85.2%	1.10	**90.6%**	**87.3%**
Other (residue, naphtha)	6.1%	14.8%	0.41	**96.3%**	**94.9%**

Based on Energy Technology Systems Analysis Programme (ETSAP), 2014, the cost for OPEX cost in refinery process is USD3.00 per barrel of crude oil. Major factor that decreases efficiency in refinery process is corrosion of the metallic components. Corrosion will cause failure of equipment items as well as increasing the maintenance schedule of the refinery which will also lead shut down of the refinery plant. Table 3.12 shows the cost involved in refinery process.

Table 3.12: Cost in Refinery Process



Costs	Typical current international values and ranges (2012 US$, 1€ = 1.3 US$)
Invest cost (US$)	Average of 31.9 k$ per b/d for new projects based on future projects. • 20.0-24.2 k$ per b/d for refining capacity expansion. • 17.7-26.0 k$ per b/d for refining capacity addition (but 10.3 k$ per b/d for the world largest refinery, 1.24 mb/d). • 19.2-90.9 k$ per b/d for upgrading capacity addition. • 114.0 k$ per b/d for refining capacity addition with upgraders and CCS.
O&M cost (US$ 2012)	Average operating costs, excluding depreciation and amortization and energy costs: 3.30 US$/barrel for US Gulf Coast & Midcontinent, 4.00 US$/barrel for Northwest and Mediterranean Europe and 3.00 US$/barrel for Asia. In US: 5.72 and 9.73 US$ (1999-2009), including energy costs (1.04-2.52 US$).
Fuel cost (US$ 2012)	1.04-2.52 US$

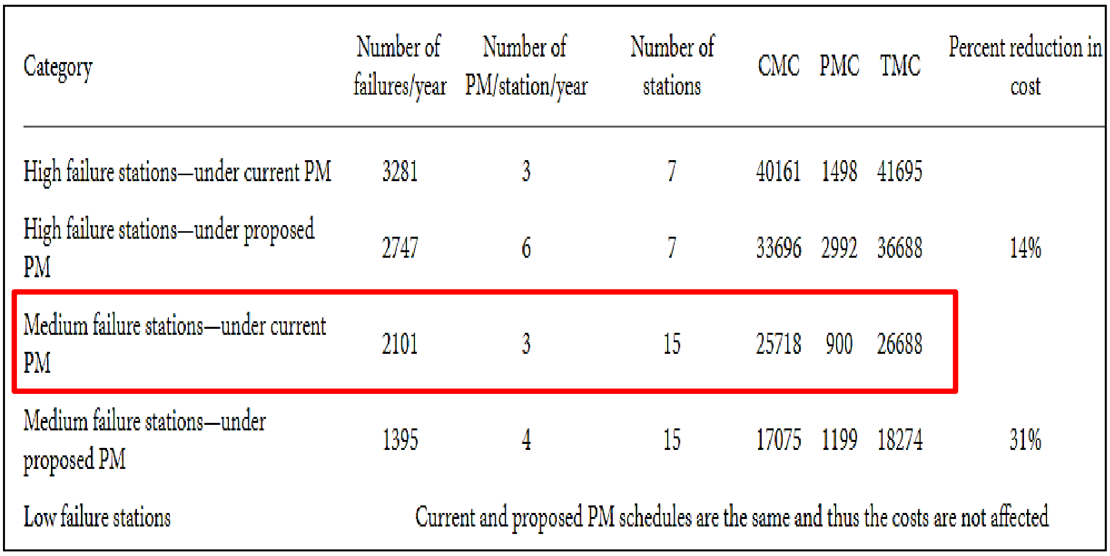
3.8 Retail Pump Station

A construction of a retail pump requires large amount of cost and need to be built at a specific area where safety requirement has to be met. Since the purpose of pump station is to deliver fuel to the consumer, the vital parts in this station is the pump and also the storage. The storage requirement is similar to the Storage Plant where it need to be kept at a specific parameter of temperature to avoid any accident.

In term of efficiencies, a better fuel transferred is reflected by the efficiency of the oil pump. Study has shown that any pump will have an average of 3% losses during operations. Therefore, it can be said that retail pump station has 97% efficiency.

Its maintenance is more on the pump its self and also the feedback sensors. Retail pump station will require electrical energy for it to operate. Based on Kuwait retail pump station, the operation and maintenance cost is shown in Table 3.13 where it consider the cost for Corrective Maintenance Cost (CMC) and Preventive Maintenance Cost (PMC) in a year. It shows that in 2013, the Total Maintenance Cost (TMC) for medium failure station or average station is around Kuwaiti Dollar (KD) 26,688.00 per year. It can be converted to MYR 24,855.42 per year with average currency exchange 2013 of 13.97 (Mehmet, 2013)

Table 3.13: Maintenance Cost for Petrol Station



Category	Number of failures/year	Number of PM/station/year	Number of stations	CMC	PMC	TMC	Percent reduction in cost
High failure stations—under current PM	3281	3	7	40161	1498	41695	
High failure stations—under proposed PM	2747	6	7	33696	2992	36688	14%
Medium failure stations—under current PM	2101	3	15	25718	900	26688	
Medium failure stations—under proposed PM	1395	4	15	17075	1199	18274	31%
Low failure stations	Current and proposed PM schedules are the same and thus the costs are not affected						

3.9 Tank to Wheel Comparison

In order to determine the efficiency and cost of EV and ICE, this study will consider both vehicles travel for the same distance over the same period of time. In this study, both EV will be consider to travel 75,000 miles over 5 years and then the efficiency and cost per year will be determine. As for maintenance cost, this study will not consider maintenance where both EV and ICE need to spend such as the wear and tear or the wheel and cosmetic of the car. According to CALSTART, the advanced transportation consortium in California, 70% of an electric vehicles component parts may be different from a gasoline-powered vehicle where its component function equivalence is explained in Table 3.14 while Figure 3.5 shows the difference of both car component which will reflect to the cost and efficiency.

Table 3.14: Function equivalence in EV and ICE

GASOLINE VEHICLE	FUNCTION	ELECTRIC VEHICLE
Gasoline Tank	Stores the energy to run the vehicle	Battery
Gasoline Pump	Replaces the energy to run the vehicle	Charger
Gasoline Engine	Provides the force to move the vehicle	Electric Motor
Carburetor	Controls Acceleration and speed	Controller
Alternator	Provides Power to accessories	DC/DC converter
	Converts DC to AC to power AC motor	DC/AC converter
Smog Controls	Lowers the toxicity of exhaust gasses	

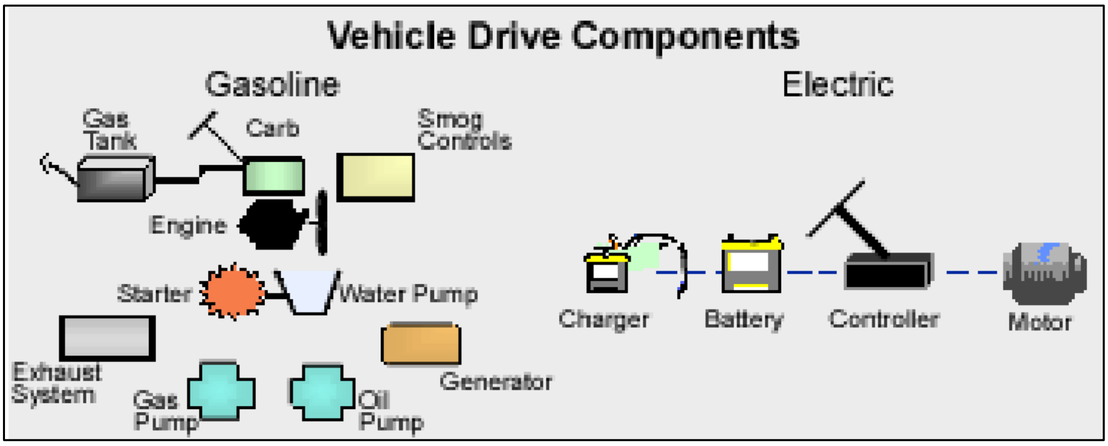
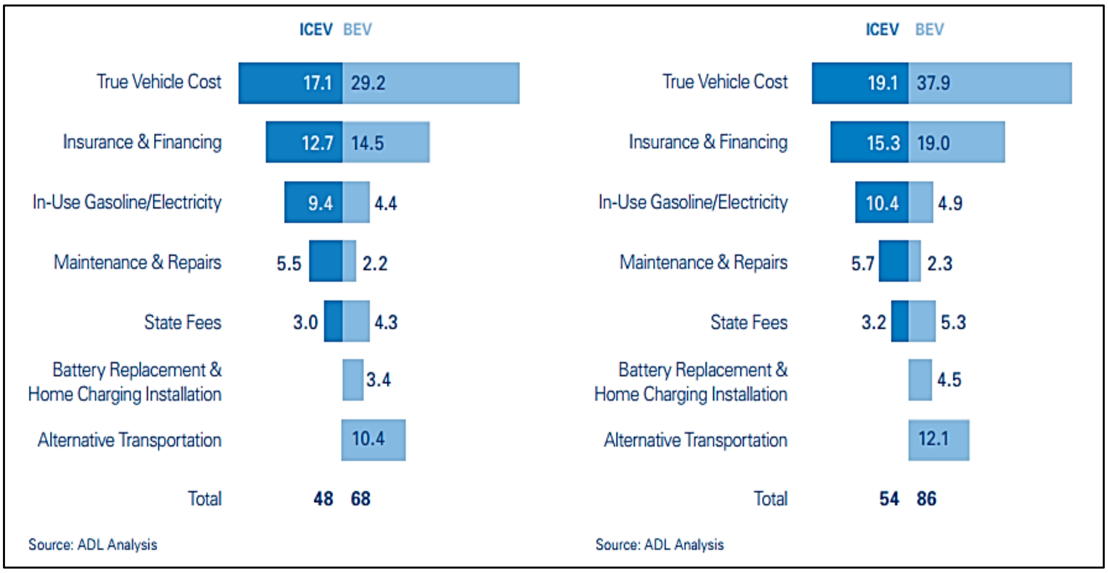


Figure 3.5: EV and ICE vehicles drive component

Total cost of ownership which include maintenance and repair cost between EV and ICE as shown in figure 3.6. This data is develop 20 years of time and there for the cost for maintenance and repair is USD285 per year ICE and USD115 per year for BEV.



Source: ADL Analysis

Source: ADL Analysis

Figure 3.6: Total cost of ownership comparison between ICE and EV

3.9.1 Electric Vehicles Efficiencies

In term of well to wheels efficiency, we could consider that the electric motor itself is very efficient in term of delivering it from batteries. Efficiency from around 95% due to losses in power drivetrain. However, the batteries provide DC power while the motor works on AC. This will require inverter and inverters efficiency is about 95%.

To charge the batteries also requires another converter from AC (Charging station) to DC (batteries). This parts also is about 95% efficient. During charging, not all of the power end up stored, there are some losses during the operations with 85% - 90% efficiency (S. S.Williamson, 2005). Therefore, the total tank to wheels efficiency is just 73% considering all the losses as shown in Figure 3.7.

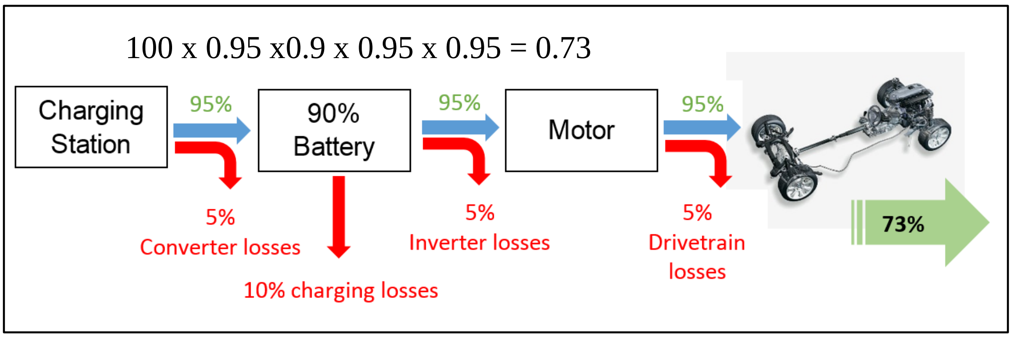


Figure 3.7: Efficiency in EV

3.9.2 Efficiency of ICE

There are some aspects that will be consider in determining the ICE efficiency which is the fuel combustion to energy ratio, internal friction, thermal losses and emission to the environment. In a car, the function of ICE is to provide power to the driven wheels. In order for this purpose to be achieve efficiently, ICE need to be installed with lubrication system and a coolant system. This is due to metal to metal contact between moving component that will creates heat and fraction. Lubrication system will prevent friction and wear during continuous movement of piston while coolant system is to keep the lubricant and other component material remains in acceptable temperature to perform well. The properties of lubricants depending on temperature effect where its most efficient steady state operating temperature is between 100^0C to 110^0C. High lubricant viscosity at lower temperature resulting to high frictional losses. (Will F., 2011) estimated that if ICE started in a cold start at early stage (around 20^0C), the frictional losses is 2.5 times higher than if the lubricant is at their steady state. (Samhaber C, 2001) predicted the fuel consumption will increase by 13.5%. Therefore the efficiency of ICE is highly dependent to temperature during its operations.

Combustion efficiency of a modern ICE engine is well optimised with approximately 98% of energy contained within the fuel is being released during combustion in the diesel engine and 95% to 98% in gasoline engine. (A. Roberts, 2013).

This percentage is referring only to its mechanical energy efficiency. However the energy that leaving the engine is typically only 40% of the fuel energy due to thermal losses. This energy is called as “brake work” and it is even lesser in drive train since fraction happened in drive ancillaries such as water pump and alternator. Fuel conversion efficiency formula can be define as follow:

Fuel Conversion Efficiency = Combustion Efficiency X Gross Indicated Thermal Efficiency (3.3)

This prove that ICE efficiency is depending on temperature. This fuel conversion efficiency can be define in illustration flow as Figure 3.8:

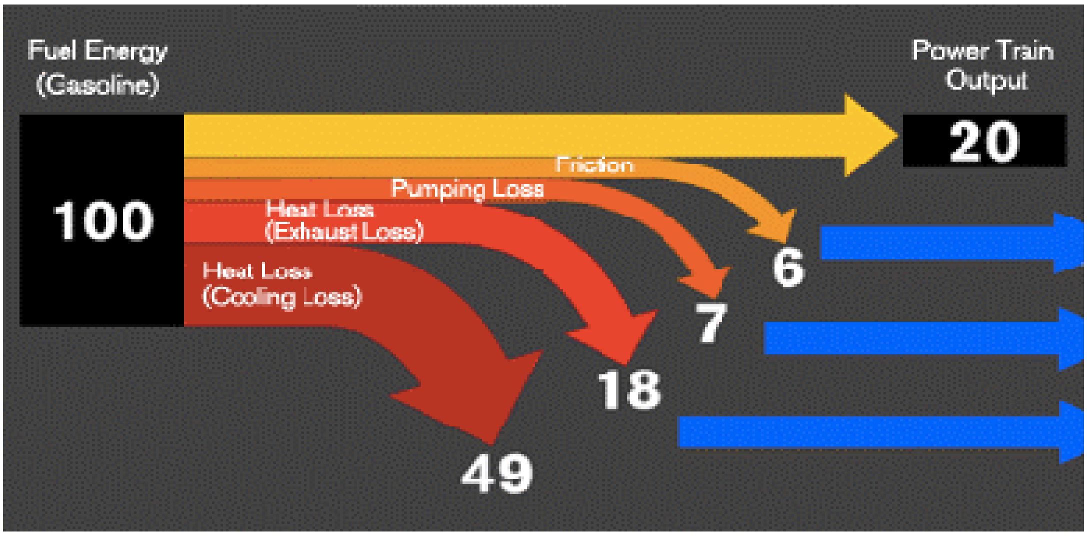


Figure 3.8: Fuel conversion efficiency to power train output

3.10 Conversion

As information are gathered in this study, there are many form or unit of measurement in each stages. Therefore, a conversion method for a common base need to be determine. In this study, the energy that we are considering is in production of 1kW of energy. All form of units will be convert to achieve production 1kW of energy. As for currency, all will be converted to a reference currency Malaysia Ringgit (MYR) as a base. The conversion process will consider the currency exchange from the year data collected. Table 3.15 shows conversion that been used in this study.

Table 3.15: Conversion Table

Energy	**Base**	**Conversion**
Electricity	1kWh	1kWh
Gas	$1m^3$	11 kWh
Petrol	1 litre	9.7 kWh
Diesel	1 litre	10.7 kWh
Biodiesel	1 litre	9.9 kWh
Kerosene	1 litre	10.5 kWh
Coal	1 kg	6.64 kWh
Crude Oil	1 barrel	159 litre

Base unit in production of 1kW of energy along the process referring to the information gathered can be shown in Figure 3.9.

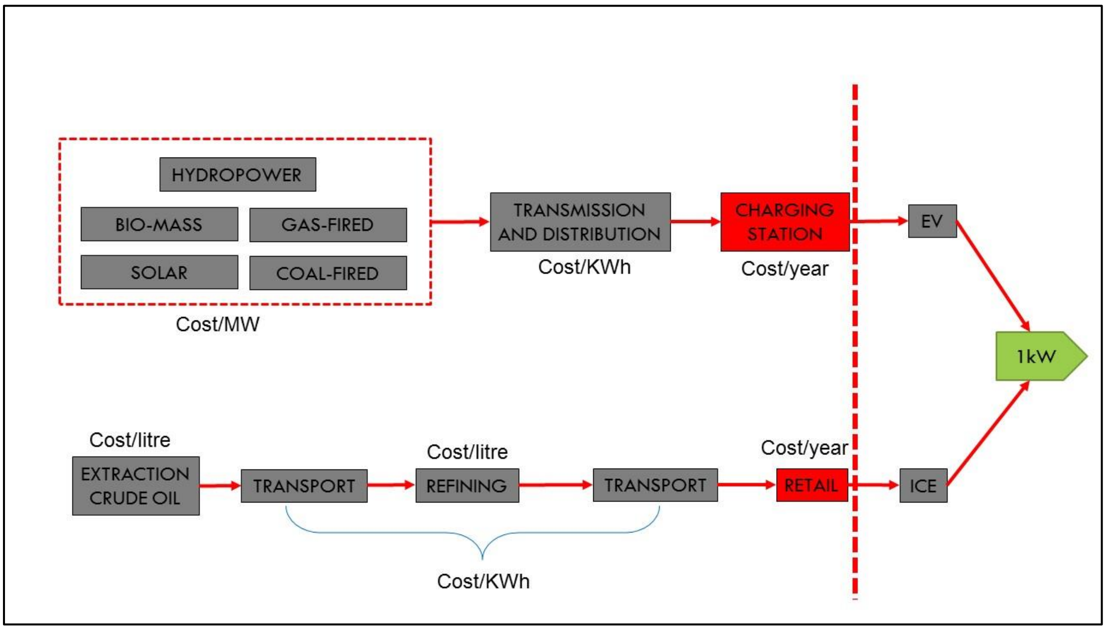


Figure 3.9: Overview of base measurement unit in all stages

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Energy Efficiency

In order to achieve the objective of the study to calculate the production cost of 1kW of energy between ICE and EV, a comparison flow or table need to be determined. Figure 4.1 shows the overview of energy efficiency to calculate the required amount of energy for each stages.

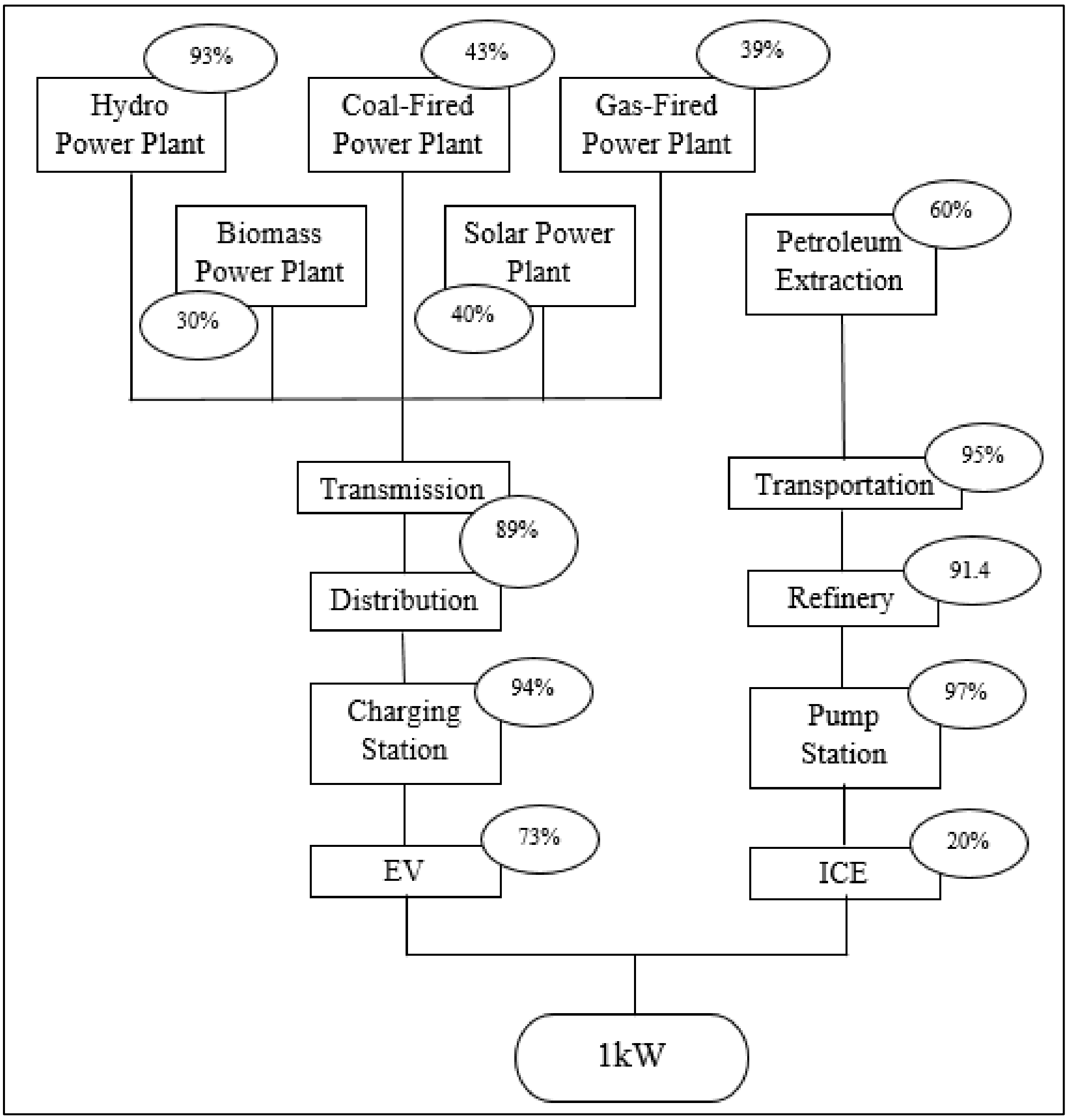


Figure 4.1: Overview Energy Efficiencies for all stages

Based on efficiency in figure 4.1, the energy required for each path from well to wheel may vary and is shown in Figure 4.2.

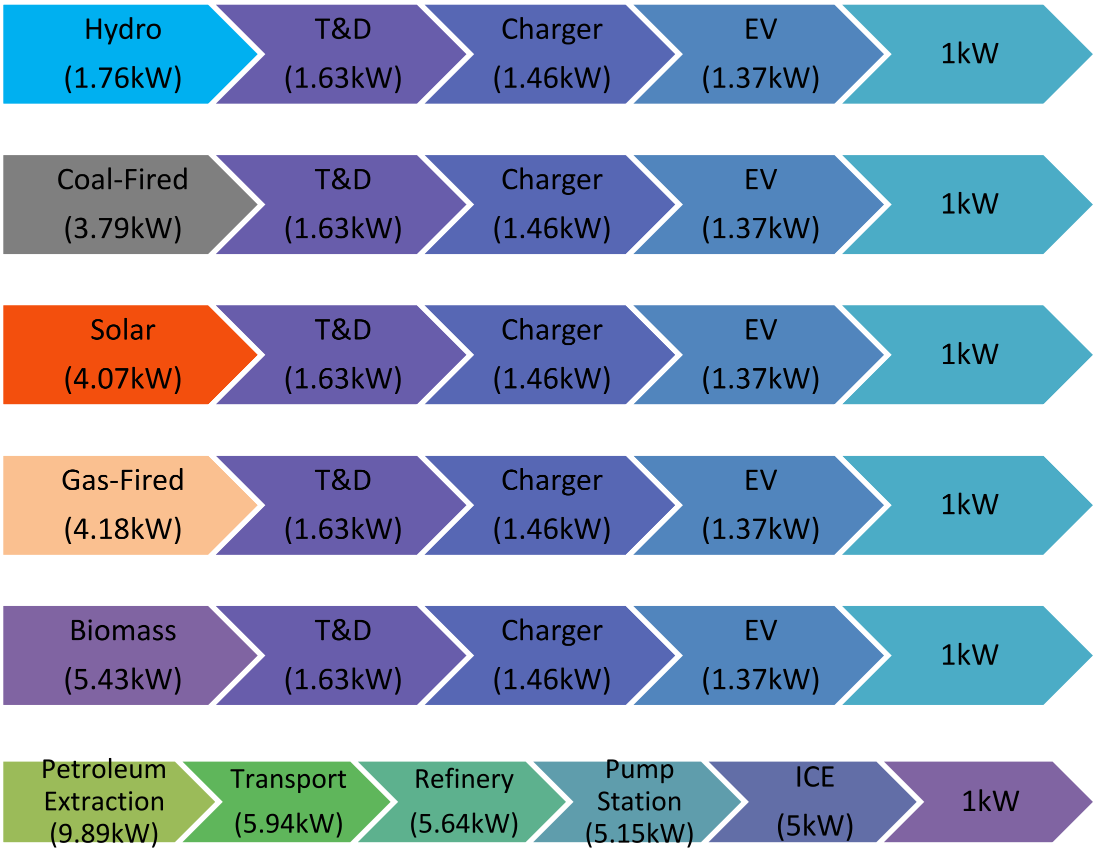


Figure 4.2: Energy required for each path

It is obviously shows that energy required for EV is better that ICE. Even the highest energy required for EV path which is by the source from biomass is nearly half the energy required in ICE in producing the same amount of energy. However, every energy path has its own requirement in order it can operate at its optimum efficiencies.

For EV energy path, the difference is from the source of power generation. Even though hydro power plant is the most efficient source of generation, it capital expenditure in building it is very high. Hydropower plant also require easy access to river source where the plant is built, for economical operations outcome.

As for coal and gas fired power plant, the source is from a non-renewable energy and its efficiency need to consider the exploration / extraction of the fuel source. Therefore, it is not a best method to operate EV by using the source from this kind of generation. It might even inefficient if compared to ICE.

Based on the source of generation list in this study, the renewable energy sources are from the solar and biomass power plant. Solar energy seems to be a better solution in implementing EV as alternative for ICE since the availability of solar source even though its efficiency is not its very best. As for biomass, its availability source is renewable but its operation require combustion which emit chemical that is not good for environment.

In transmission and distribution line, the main factor that will determine the efficiency is the length of the connection. Therefore, the distance between the power plant and the network grid will reflect to its efficiency. However, efficiency percentage of 89% is consider as good in the energy transferred.

In ICE pathway, the stages that has less efficiency percentage is the ICE operations itself and the petroleum extraction process. The percentage of 60% in petroleum extraction process seems higher than most of power generation. However, higher initial cost and its source from a non-renewable makes its efficiency percentage is important for its operations. ICE technology is considered as mature enough in development yet its efficiency is still a great loss to the world.

4.2 Cost of Energy

Conversion table 3.15 will be the guidance in determining the cost for each process. Based on the conversion table and data gathered in the methodology part, the cost for each stages is shown in table 4.1 and can be segregate into 4 parts that is generation, intermediate, consumer station and vehicles. Generation part will include OPEX cost for all type of power generation in EV pathway and Petroleum Extraction as power generation source in ICE pathway. As for intermediate level will consider all process from the generation to the station which will involve OPEX cost for transmission and distribution in EV pathway and refining and transportation cost in ICE pathway. In consumer station level, this study will compare the OPEX cost for Charging Station and Retail Pump Station. Lastly at the consumer level, this study will compare the cost for operating the EV and ICE. This table will show clearly in term of OPEX cost for comparison between EV and ICE.

Table 4.1: Overview Operational Expenditure cost in each stages

EV pathway			**ICE pathway**		
Process	**Cost**	**Conv. Cost**	**Process**	**Cost**	**Conv. Cost**
Generation					
Hydro	€18/kW	MYR76.86	Petroleum Extraction	MYR0.44/ltr	MYR4.27/kW
Coal-fired	€28/kW	MYR119.56			
Gas-Fired	€20/kW	MYR85.4			
Biomass	€62.5/kW	MYR266.88			
Solar	€30/kW	MYR128.1			
Intermediate					
Transmission	MYR2,668.3 /GWh	~MYR 0/ kW	Refining	$3.00/barrel	MYR0.64/kW
Distribution	MYR31,123.38/GWh	~MYR 0/ kW	Transport	MYR1.15/ kWh	MYR1.15/ kWh
Consumer Station					
Charging Station	MYR12624/ year	same	Pump Station	MYR24855.4/ year	same
Consumer					
EV	$115/year	MYR495/ year	ICE	$285/year	MYR1,225/ year

Cost comparison in this study can be divided into 4 parts which is the generation part, intermediate part, consumer station part and the vehicle part. Each parts unit of measurement for both EV and ICE need to be equivalent in order to make a fair comparison.

4.2.1 Generation Level Cost Comparison

In power generation parts, the cost for EV pathway shows that biomass plant is the highest operational expenditure per kW followed by coal-fired plant, solar plant, gas-fired plant and the lowest operational expenditure is the hydropower plant. However, if it is compared to generations parts for EV pathway which is by petroleum extraction, the operational cost shows a big difference where hydropower plant is 18 times costly than petroleum extraction in term of OPEX. It shows that, in term of generation parts, ICE will be considered as relevant to be operated if we look into cost saving factor.

Lifespan of equipment or plant for each generation plant need to be consider in this study. Most of EV generation plant is a fixed position where its lifespan is longer than any kind oil rig in petroleum extraction. Average lifespan for most oil rig is around 20 to 30 years old while in EV power generation plant, coal and gas fired power plant has the lowest lifespan of 40 years old and hydropower plant has the highest lifespan of than 100 years. This need to be consider due to high capital expenditure in all generation plant.

4.2.2 Intermediate Level Cost Comparison

Intermediate level is the process between the generation level to the consumer station level. In EV pathway, it is clearly shown that if compared in scale of 1kW, the transmission and distribution OPEX cost is very low. It can only be measured in term of cost when transmitting energy in Gigawatt scale. As for ICE pathway, in refining process the cost per kW of energy is MYR0.64 while for transportation will cost MYR1.15 per kW. Most of cost in EV pathway OPEX depending on the inspection and changing parts schedule. T&D CAPEX cost is very high and could last long with a lesser operation and maintenance cost compared to ICE pathway. In refining, as its working principle involved heat, the maintenance cost is more on its heating element and its material that deteriorate.

It shows that for intermediate level EV pathway OPEX cost is better if compared to ICE pathway OPEX cost. Some transporting fuel in ICE pathway will use vehicles as medium and as we know, most of the vehicles use ICE that will emit gasses that will affect the environment. Furthermore, the efficiency of ICE is low and it shows that if looking at intermediate level, EV pathway is more efficient and cost effective.

4.2.3 Consumer Station Level Cost Comparison

EV charging station can be installed at any location with a proper power supply. It can be outside of a building or even could be installed at home. It doesn’t need a special dedicated area as Retail Pump Station required. In term of OPEX cost in this study, data shown that cost for Retail Pump Station is double if compared to Charging Station. Charing Station shows a great advantages over Retail Pump Station in many aspects such as cost of installation, operation, maintenance, risk and requirement and it prove that EV is a better choice for future implementation.

4.2.4 Consumer Level Cost Comparison

As the world is moving toward EV as alternative for ICE, the price in owning an EV start to reduce and affordable to many. The development of technology especially in its control unit and also the capacity of battery increase in numbers of EV buyers. It is obviously shown that EV win in many aspect except for its charging time and mileage, In term of OPEX cost, simple arrangement of EV shows a great advantage with only average if MYR495 while ICE require MYR1,225 per year.

EV could eliminate the need of ICE if its drawbacks in charging period can be improved. As for now, people only require less than 3 minutes to fill a full tank for any normal car while the best charging station require 20-30 minutes to fully charged EV battery. However, EV win in many more aspect especially if looking into cost efficiency.

CHAPTER 5

CONCLUSION AND RECOMENDATION

Hence, it can be concluded that in implementing EV as alternative for ICE, many factor need to be put into consideration. This study has proved that EV efficiency of 70% show a great advantages over ICE with 20% efficiency. However, charging period of the battery need to be improve so that EV could be charged in a shorter time to compete with time taken to fill in fuel for ICE. This would take a lot of efforts in developing the charger itself but this aspect can be overcome if the battery capacity and EV consumption could be enhanced so that the battery could sustain for at least 12 hours where average of human driving period in a day. It is similar to a telecommunication industry where capability of any hand phone could sustain for daytime and can be charged during night time.

This study also proved that cost and efficiency of process involved from generation to the battery lead to a bright future of EV as alternative. The mobility, less maintenance and cost effective in any charging station contribute huge impact in replacing retail pump station. Lifespan and low operational expenditure in transmission and distribution added the beneficial factor in implementing EV. Power Grid in Malaysia has already works in very efficient with a low possibility of disruption or power outage.

However for generation side, the most efficient in term of pollution reduction due to exhaust gasses and resources availability is by Hydropower plant. Power generated by hydro power plant can be claimed as clean energy sources with optimum efficiency. It is more advantageous if most of generation plant in Malaysia is from hydropower since Malaysia has a lot of river to build a power generation dam. However, power capacity produced by hydropower plant is small as explained in literature review and require a lot of plant to meet power demand. The other alternative is by using solar energy due to its availability of solar sources. Implementing solar energy as source for charging station seem to be the best solution in implementing EV as alternative for ICE and it only require power from the grid only for backup. This suggestion pathway will reduce the stages required from well to wheel which will also reduce losses along the pathway. As for generation plant which uses combustion as its medium of operation, this generation source should be avoided to prevent the tailback effect of the exhaust. This study shows that any combustion method will contribute to pollution and high heat losses.

It can be concluded that EV is more cost effective in production of 1kW of energy if compared to any ICE.

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