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Common Types of Fuels in Steam Power Plant: A Review

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Abstract – *Steam power plant plays essential roles in the generation of electrical energy. Steam power plant divided into two types which are conventional steam power plant and non-conventional steam power plant. The common type of conventional steam power plant are thermal power plant, nuclear power plant and natural gas power plant while common type of non-conventional steam power plant are geothermal power plant, biogas power plant and biomass power plant. This paper reviews the common type of fuels used in the steam power plant in order to produce steam and indirectly generating electricity. Fuel candidates encompass the entire spectrum from gases to solids. Gaseous fuels include natural gas, process gas, low-Btu coal gas and vaporized fuel oil gas. Liquid fuels can vary from light volatile naphtha through kerosene to the heavy viscous residuals. A final fuel group contains high-ash crudes and residuals. The basic fundamental of steam power plant operation and its essential equipment is also considered. The major type of steam power plant used is thermal power plant or coal power plant which account for almost 41% of the world electric generation with efficiency ranges from 32% to 42%. Besides, this paper reviews the features and characteristic of the common fuels used, the waste products from the fuels, advantages and disadvantages of the fuels and cost of the fuels. It is marked that several common type of fuels used in steam power plant are identified as fossil fuels, waste heats, waste fuels, and nuclear fuels.*

Keywords: Steam power plant, classification of power plants, types of fuels, plant efficiency

1.0 INTRODUCTION

The world energy consumption in the last thirty years has doubled and keeps increasing with about 1.5 % per year. Fifty percent of the electrical power produced in Finland is produced in steam power plants [1]. Majority of the electricity used in the United States also is generated in steam power plants [2]. Steam power plant is a power plant which comprises pressurized feed water tank, high-pressure steam turbine, high-pressure steam boiler, water-cooled steam condenser, and low-pressure steam turbine that connected in series in a closed circuit [3]. Steam power plant consists combustion chamber, compressor, gas turbine, steam generator and steam turbine [4]. Besides, steam turbine comprises steam engine and operator-controlled throttle for regulating the flow of the steam, supplying heat, prime mover operable and simultaneously regulation [5]. Steam power plant also has feed water heater, circulating pump, evaporator, reheater, combine jet, air condenser, and pressurized boiler[3]. Figure 1 shows the essential of steam power plant equipment.

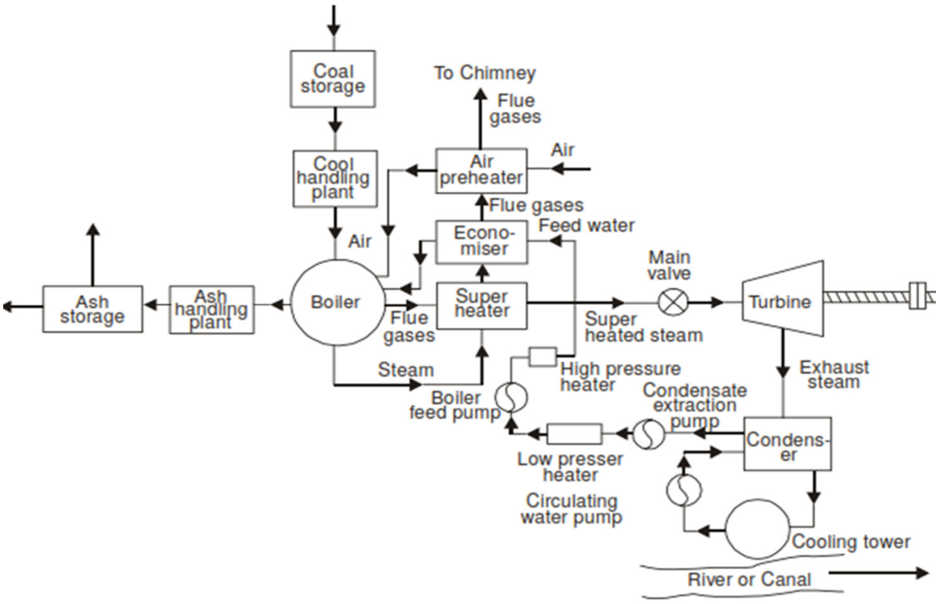

Figure 1: Steam Power Plant Equipment

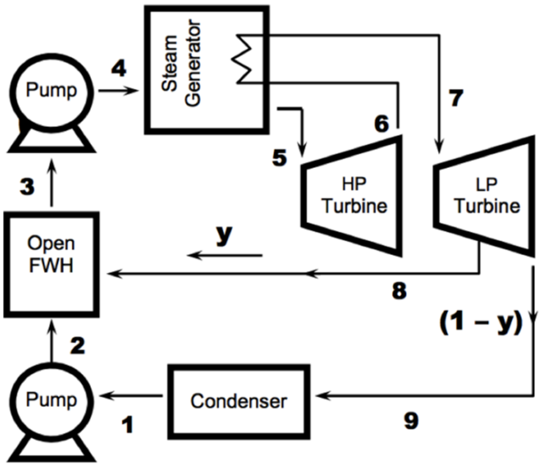

Figure 2: Rankine cycle flow

Steam power plants have been in use for about two hundred years for generating electricity mostly in the 20th century[3]. Steam power plant are generally operating by using Rankine cycle process. Rankine cycle process is the cycle of boiling of water to steam, expansion of steam from high pressure to low pressure, condensation of steam and feed water pump to return the water into the boiler[6]. In the simple Rankine cycle process, steam flow to a turbine, where some of its energy is converted to mechanical energy that is transmitted by rotating shaft to drive an electrical generator. The reduced energy steam is then condenses to liquid water in the condenser. Next, the pump returns the condensed liquid to the steam generator or boiler[2]. Figure 2 and Figure 3 shows the Rankine cycle flow and T-s diagram respectively.

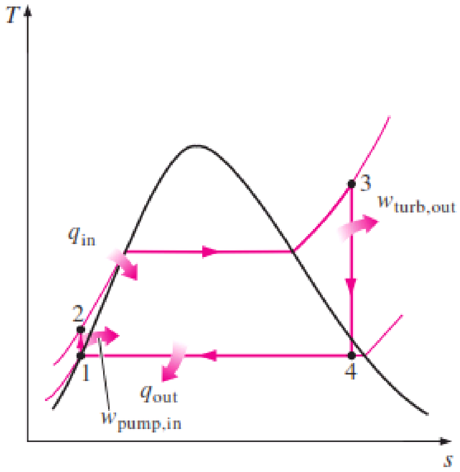

Figure 2: T-s Diagram

Several types of steam power plants are thermal power plant, gas turbine power plant and nuclear power plant. Thermal power plant or coal fired thermal power plant is the most conventional plant of generating electric power with high efficiency. In thermal power plant, the fuel is burnt into the furnace of steam boiler to produced high pressure steam. The steam is then passed through super heater and entered into turbine at high speed. The steam force rotates the turbine blades which caused the conversion of potential energy to mechanical energy and generation of electricity[7]. Nuclear power plant generates electrical power by nuclear reaction. In nuclear power plant, the heat generated by nuclear fission is used to produce steam from water in the boiler. The steam is then used to drive a steam turbine which then generate electrical energy by alternator[8]. Gas turbine can be used in several different modes such as power generation, aviation, and smaller related industries. A gas turbine essentially brings together compressed air and fuel that are then ignited. The resulting gases are expanded through a turbine which caused rotation of turbine's shaft and drive the compressor continuously. The electrical energy is then generated[9].

Next, there are several types of fuel used in different type of steam power plants which are fossil fuel, waste heat, waste fuel and nuclear fuel. Fossil fuel consist of coal, oil, and natural gas while waste heat consist of gas turbine exhaust and diesel. Besides, waste fuel consist of biomass while nuclear fuel consist of uranium, MOX, and thorium. In thermal power plant, the common fuel used to boil the water to superheated steam is coal. Generally in India, bituminous coal or brown coal are used as fuel of boiler as the volatile content ranging from 8% to 33% and ash content from 5% to 16%[7]. In nuclear power plant, the availability of nuclear fuel is not plenty but very less amount of nuclear fuel can generate high amount of electrical energy. As example, one kg of uranium can produce as much heat as can be produced by complete combustion of 4500 metric tons high grade coal[8]. In geothermal power plant, the fuel used to extract steam is the hot underground rocks while in renewable energy plant and biomass fuelled power plant, the common fuel used are the waste from sugar cane, landfill methane, municipal solid waste and others[10].

2.0 FOSSIL FUEL

A fossil-fuel power station is a power station which burns fossil fuel such as coal, natural gas or petroleum to produce electricity. Central station fossil-fuel power plants are designed on a large scale for continuous operation. In many countries, such plants provide most of the electrical energy used. Fossil-fuel power stations have machinery to convert the heat energy of combustion into mechanical energy, which then operates an electrical generator. The prime mover may be a steam turbine, a gas turbine or, in small plants, a reciprocating internal combustion engine. All plants use the energy extracted from expanding gas, either steam or combustion gases.

By products of thermal power plant operation must be considered in their design and operation. Waste heat energy, which remains due to the finite efficiency of the Carnot, Rankine, or Diesel power cycle, is released directly to the atmosphere or using a cooling tower. The flue gas from combustion of the fossil fuels is discharged to the air. This gas contains carbon dioxide and water vapor, as well as other substances such as nitrogen oxides (NO), sulfur oxides (SO), and, for coal-fired plants, fly ash. Solid waste ash from coal-fired boilers must also be removed.

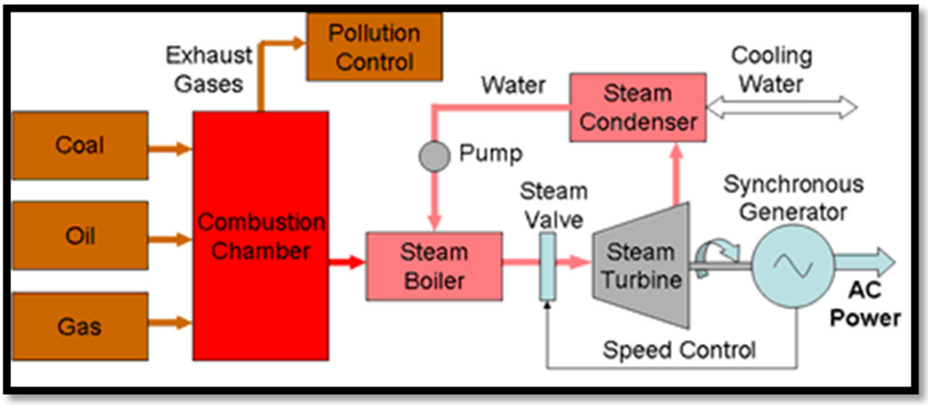

Figure 3: Fossil Fuel Powered Steam Turbine Electricity Generation [11]

Basically, fossil fuel steam power plant work such as in Figure 4. From Figure 4, can be seen clearly Fossil fuelled plants use combination either coal (60%), oil (10%) or gas (30%) in purpose designed combustion chambers to raise steam. These are all non-renewable resources whose supply will ultimately be exhausted.

Oil is probably the most convenient fuel but it has mostly been replaced by coal as oil prices have risen faster than the price of coal due to insecurities of supply. At the same time, the premium value of oil for transportation and chemical uses, rather than for just burning it to extract its calorific value, has also been recognised.

Coal is the least convenient. Its calorific content, on average, is less than half that of the other two fuels. Handling and transporting it is more difficult and it produces large quantities of residues, ash and greenhouse gases, some of which are toxic, depending on the quality of the coal.

Besides, taking into consideration the three conversion processes, thermal, mechanical and electrical, used to extract the energy from fossil fuels the overall efficiency of a modern fossil fuelled electrical power generating plant will be about 40%. This means that 60% of the energy input to the system is wasted. Efficiencies may be as low as 30% in some older plants[11]. Not all plants are typical however and the actual efficiencies obtained depend on the fuels used and the technical sophistication of the generating plant and processes.

The development of carbon capture from gases produced in thermal process like combustion in the form of CO2 and its storage in appropriate geological formations is one of the most promising options for greenhouse gas (GHG) effect reduction. The greatest interest for carbon capture and storage (CCS) implementation is found on the power production sector, and more specifically, on coal-fired thermal plants which account for most of the anthro-pogenic CO2 emitted worldwide[12]. Post-combustion capture options are considered the most mature of the options for CO_2 separation, i.e. its separation and capture from flue gases. The other important technology is oxy-combustion, i.e. the replacement of air with pure oxygen stream as the oxidizing medium.

Although that a gas stream with high CO2 concentration is pro-duced in all the capture processes, a gas purification step is required before transfer and storage, especially when the CO2 comes from an oxy-fired reactor (combustor or calciner). The use of CO2purifi-cation unit for the oxygen and other inert gases removal is essential for both safety and technical reasons[13].

Calcium looping (CaL) process was proven the best option for CO2 capture among the others, in terms of overall energy and exergy efficiency. In other words, it seems that the answer to the question raised in the introduction is high quality heat through fuel combustion[14].

2.1 Coal-Fired Power Plant

The power potentials depend on the fact that coal can be readily oxidized, with the production of a high temperature and energy of about 0.0000001 megawatt days per gram. That is, of course, very little, but large amounts of coal (perhaps millions of tons) appear to be available.

The chief advantage is that the critical amount is very much smaller for coal than for any fissile material. Fission plants become, as is well known, uneconomical below 50 megawatts, and a coal-driven plant may be competitive for small communities with small power requirements.

2.2 Design of Coal Reactor

The main problem is to achieve free, yet controlled, access of oxygen to the fuel elements. The kinetics of the coal-oxygen reaction are much more complicated than fission kinetics, and not yet completely understood. A differential equation which approximates the behaviour of the reaction has been set up, but its solution is possible only in the simplest cases.

It is therefore proposed to make the reaction vessel in the form of a cylinder, with perforated walls to allow the combustion gases to escape. A concentric inner cylinder, also perforated, serves to introduce the oxygen while the fuel elements are placed between the two cylinders. The necessary presence of end plates poses a difficult but not insoluble mathematical problem.

2.3 Fuel Elements

Canning is unnecessary and indeed undesirable since it would make it impossible for the oxygen to gain access to the fuel. Various lattices have been calculated and it appears that the simplest of all, a close packing of equal spheres, is likely to be satisfactory. Computations are in progress to determine the optimum size of the spheres and the required tolerances. Coal is soft and easy to machine, so the manufacture of the spheres should present no major problem.

2.3.1 Coal-Fired Plant Operation

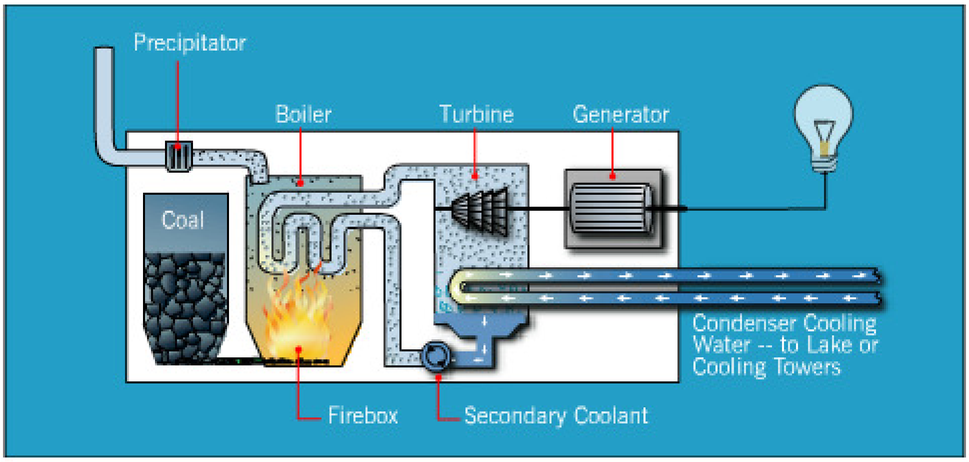

Figure 5: Coal-Fired Plant Work

Firstly, coal is pulverized to the fineness of talcum powder before burn. Coal then mixed with hot air and blown into the firebox of the boiler. Burning in suspension, the coal/air mixture provides the most complete combustion and maximum heat possible. Then, highly purified water pumped through pipes inside the boiler, is turned into steam by the heat. The steam reaches temperatures of up to 1,000 degrees Fahrenheit and pressures up to 3,500 pounds per square inch, and is piped to the turbine. Next, the pressure of the steam pushing against a series of giant turbine blades turns the turbine shaft. The turbine shaft is connected to the shaft of the generator, where magnets spin within wire coils to produce electricity.

Then, the steam is drawn into a condenser, a large chamber in the basement of the power plant. In this important step, millions of gallons of cool water from a nearby source (such as a river or lake) are pumped through a network of tubes running through the condenser. The cool water in the tubes converts the steam back into water that can be used over and over again in the plant. The cooling water is returned to its source without any contamination, and the steam water is returned to the boiler to repeat the cycle. Once the reaction is started its rate can be controlled by adjusting the rate at which oxygen is admitted. This is almost as simple as the use of control rods in a conventional fission reactor.

2.3.2 Health Hazards

The main health hazard is attached to the gaseous waste products. They contain not only carbon monoxide and sulphur dioxide (both highly toxic). To discharge these into the air is impossible. It would cause the tolerance level to be exceeded for several miles around the reactor.

It is therefore necessary to collect the gaseous waste in suitable containers, pending chemical detoxification. Alternatively, the waste might be mixed with hydrogen and filled into large balloons which are subsequently released.

2.4 Natural Gas

Natural gas is a naturally occurring hydrocarbon gas mixture consisting primarily of methane, but commonly including varying amounts of other higher alkanes, and sometimes a small percentage of carbon dioxide, nitrogen, hydrogen sulfide, or helium. Natural gas (NG) is an extremely important source of energy to assist in creating a healthy environment as it reduces environmental pollution and has a great advantage over the use of other fossil fuels[15].

Natural gas gains growing positions in the global energy sector due to its obvious advantages, including availability, accessibility, versatility, and smaller impact on the environment as compared with other fossil fuels[16]. Importance of natural gas in the global energy balance rises constantly, and between 2020 and 2030 it could become a leading fossil fuel[17]. According to the Energy International Agency (EIA) forecast, in 2010-2040 the fraction of natural gas in the world electricity generation will growfrom 22 to 24%[18].

For the centralized energy supply, large power generating plants based on gas-turbines with more than 20 MW power and 33-35% efficiency are used. At present the combined steam-gas-turbine installations with the efficiency close to 60% are employed. However, for local distributed power generation within the power range <10MW, gas-piston engines (GPEs) are clearly preferential because of their high reliability, considerable economy in electric networks, and, as a result, better fuel saving. Their efficiency exceeds 40% (up to 46-47%)[19].

Natural gas is a fossil fuel used as a source of energy for heating, cooking, and electricity generation. It is also used as fuel for vehicles and as a chemical feedstock in the manufacture of plastics and other commercially important organic chemicals. It is a non-renewable resource. Natural gas is found in deep underground rock formations or associated with other hydrocarbon reservoirs in coal beds and as methane clathrates. Petroleum is another resource and fossil fuel found in close proximity to, and with natural gas.

2.4.1 Gas Turbine LM6000 System

The General Electric LM6000 gas turbine is a stationary gas turbine that is derived from the CF6 jet engines family. The GE LM6000 PC is rated to provide more than 43 MW at ISO conditions. More than 1000 LM6000 gas turbine engine have been produced that they had over 21 million hours of operation. They're used in marine application and power plants to produce electricity and heat. The aircraft version of the engine is called the CF6-80C2 turbofan engine and is used to drive several types of "wide body" commercial aircraft, including the Boeing 747- 400 (LM6000 GEK 105059, 2003, LM6000, 2012). The illustrated diagram, station numbering and main component of LM6000 is shown in Fig. 6.

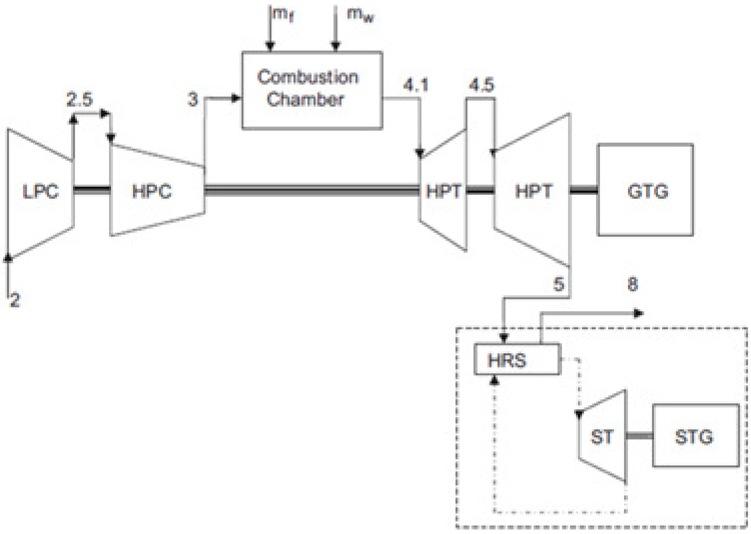

Figure 6: Schematic illustration of the LM6000 GTE based power plant with steam turbine cycle[22]

The LM6000 gas turbine is a dual-rotor, concentric drive-shaft, gas turbine capable of driving a load from the front and/or rear of the low-pressure (LP) rotor. It has a 5-stage low-pressure compressor (LPC), a 14-stage variable-geometry high-pressure compressor (HPC), an annular combustor, a 2-stage high-pressure turbine (HPT), a 5-stage low-pressure turbine (LPT), an accessory gearbox (AGB) assembly, and accessories[20].

The air is compressed in LPC and HPC compressors by the ratios of approximately 2.4 and 12, resulting in a total compression ratio of 30 relative to ambient. From the HPC, the air is directed into the signal annular combustor section, where it mixes with the fuel from fuel nozzles. The hot gas that results from combustion is directed into the HPT that drives the HPC. This gas further expands through the LPT, which drives the LPC and the output load.

2.5 Oil-Fired Steam Power Plant

Electricity generation using fossil fuels has destructive effects on environment. Emission of pollutants such asSO2 produced by burning fuel oil and coal in power plants has damaged public health, water and forest ecosystem, due to the acidification of soil and lakes[23]. The example country using oil-fired steam power plant to generate electricity is Iran. Heavy oil consumption in steam power plants achieved to the highest amount of it in this year. This increasing trend is still continuing; the consumption of this energy carrier in 2008 was equal to 19,592 TJ[24].

SO_2 emissions from oil-fired steam power plants SO2 concentration isdirectly measured in terms of ppm by Testo 350XL flue gas analyzer.Using temperature and static pressure of the stack,this concentration turns into mass concentration interms of mg/m3 (Testo Instruments,2003). Velocityof flue gas(interms of m/s) is measured by Pitot tube using the flue gas analyzer. Afterwards, flowrate of combustion gases in determined regarding surface area specifications of the stack (Testo Instruments,2003). Emission rate of SO2 (in terms of g/s) is then calculated by multiplying flow rate based on m3/s inSO2 mass concentration. The SO2 emissions of heavy oil-fired steam power plants (ESO2) in terms of g are calculated using emission factor method by[25].

$$ESO_2 = \sum A \times EFSO2 \times (1\text{-}\eta) \qquad (1)$$

where A is the activity rate (electricity generation in terms of kWh), EFSO2 is the experimental emission factor of SO2 in terms of g/kWh and η is the total emission reduction percentage which is equal to zero if pollution reduction systems are not used.

2.6 Strategies for Reducing SO_2

The strategies for reducing SO2 emissions from heavy oil-fired steam power plants can be classified into three groups[26]:

- Fuel switching from heavy oil to natural gas.
- Sulfur content reduction of heavy oil fuel.
- Installation of Flue Gas Desulfurization (FGD) systems.

One of the simplest ways to reduce the amount of SO2 emissions can be achieved by switching to a fuel, which has lower sulfur content. Considering Iran’s position as the second reservoir of natural gas in the world (992 Trillion cubicfeet (15.9% of the world total), the cost of this method is relatively low[27] . Fuel switching from heavy oil to natural gas is considered to be the best strategy for following reasons:

2.6.1 Environmental Well Being

Using natural gas in substitution to heavy oil, results in the reduction of SO2 and other pollutants. Heavy oil contains large amounts of sulfur (about 3% mass) while this is insignificant in natural gas. Therefore fuel switching from heavyoil to natural gas will decrease the SO2 emissions considerably[28].

Technical well being In contrast with a heavy oil-fired steam power plant the total energy consumption in a natural gas-fired power plant is lower. This is because gas firing requires less excess air and no steam for atomizing the fuel, and the flue gas is discharged at a lower temperature. With natural gas firing, higher efficiency and higher heat transfer rates can be maintained due to lower deposits on the boiler tubes. Fuel ash corrosion and sticky ash deposition on the tubes of the superheater and economizer do not occur in natural gas firing. In contrast with a heavy oil-fired steam power plant the maintenance cost f or a natural gas-fired power plant is less. Typically 28.6–37.5%[26].

2.7 Waste Fuel

Based on the thesaurus or dictionary, waste fuels are directly referred to the biomass. Biomass can be explained as fuel that is developed from organic materials, a renewable and sustainable source of energy used to create electricity or other forms of power[29]. Biomass can make up from scrap lumber, forest debris, certain crops, manure and some types of waste residues.

Biomass is classified as renewable source because waste residues will always exist which is in terms of scrap wood, mill residuals and forest resources; and also properly managed forests will always have more trees, and we will always have crops and the residual biological matter from those crops[30].

Biomass power is carbon neutral electricity generated from renewable organic waste that would otherwise be dumped in landfills, openly burned, or left as fodder for forest fires. When burned, the energy in biomass is released as heat. If you have a fireplace, you already are participating in the use of biomass as the wood you burn in it is a biomass fuel. In biomass power plants, wood waste or other waste is burned to produce steam that runs a turbine to make electricity, or that provides heat to industries and homes. Fortunately, new technologies including pollution controls and combustion engineering have advanced to the point that any emissions from burning biomass in industrial facilities are generally less than emissions produced when using fossil fuel[31].

2.7.1 Positive Aspect of Biomass

A comparison between biomass with the fossil fuel has been made, it shows that biomass have lower carbon emission. Biomass is not entirely clean, some greenhouse gas (GHG) emission are still produced. But the GHG emission production by biomass is far less compared to fossil fuel[31].

Table 1: Greenhouse Gas Emission Reductions is 981.68 kg CO2 Equiv. per year[32]

Greenhouse gas emission reductions.					
	Greenhouse Gas Emission Reductions (kg CO2equiv)				
Fuel	CO_2	CH_4	N_2O	CO	TNMOC
Fuel wood	0	243.75	150.17	216.39	152.78
Charcoal	0	43.36	10.54	53.48	68.65
LPG	22.21	0.01	0.73	0.22	1.35
Kerosene	16.69	0.04	0.3	0.19	0.82
Total	38.9	287.16	161.74	270.28	223.6

It shows that the green house reductions by the combustion of fuel wood are higher than the other types of fuels such as charcoal, liquid petroleum gas and kerosene. The total reduction of GHG emission was 981.68 kg CO2 equiv. per year. The 100 kWe biomass generating system in the United Kingdom (UK) will lead to a CO2 emission reduction of around 600 t per unit each year; this is compared with emissions from fossil fuel fired heat and electricity production. This is a significant saving which will greatly benefit the environment by reducing the release of CO2 and GHGs, into the atmosphere. The total GHG mitigation by implementing the Dan Chang bio-energy (bagasse-fired) project in Thailand by combustion process is expected around 278,610 t of CO2 equivalent per year[32].

Case Kaunas et al. compared the energy and material recovery of Household Waste Management (HWM) from the environmental point of view. The results suggest that the energy recovery from bio-waste could be a better recommendable HWM than the material recovery from households waste[33]. Recycling helps to reduces energy usages, consumption of fresh raw materials, air pollution, water pollution and GHG emissions. It helps in protecting the environment in the most balanced manner. It also helps in conserving the important natural resources such as wood, and ensures its optimum use[34].

The conversion of biomass into alternative fuels such as ethanol, biodiesel, biogas, biomethonal and methane can be described: Ethanol is produced from the biomass crops which reduce the GHG emission. The CO2 produced during production of ethanol is being supplied into the plant for the purpose of fermentation. This would reduce air pollution. The blended ethanol with gasoline burns clearly and releases less emission into the environment than pure gasoline[35]. Demirbas presented environmental impacts of bio-fuels. Ethanol, biodiesel is an environmentally friendly alternative liquid fuel that has the potential to reduce GHG emissions into the atmosphere. Most traditional bio-fuels, such as ethanol, a biodiesel from biomass reduce the consumption of crude oil and environmental pollution. Ethanol addition to gasoline has reduced CO_2 and hydrocarbon emissions. Biodiesel increases NO_x emissions when used as fuel in diesel engine. Oxygenated diesel fuel blends have a potential to reduce the emission of particulate matter[36].

The advantages of electricity generation from biomass also can be described as: The people of Bhalupani hamlet near Bhubhaneswar were living in darkness without grid electricity and using kerosene for lighting and cooking purposes. In 2006, biomass-gasifier-based electricity generation plant has been installed to provide electricity in Bhubhaneswar. The smile on the faces of the villagers during the biogas plant inauguration speaks volumes of their happiness[30]. Suntana et al. studied the benefits of forest biomass as a source of bio-energy that reduces carbon emissions in Indonesia. In Indonesia methanol produced from forest biomass could provide electricity to more than 42 million households annually. The use of biomethanol for electricity generation and as substitute for gasoline can avoid 9–38% and 8–35% of total annual carbon emission respectively. The number of rural and urban households received benefits from biomass[37]

2.7.2 Negative Aspect of Biomass

The negative impact of biomass energy can describes as: The occupational injuries and illness associated with agriculture and forest biomass energy production systems are several times more than underground coal mining and oil mining operations[30]. In terms of a million kilocalories of output, forest biomass has 14 times more occupational injuries and illnesses than underground coal mining and 28 times more than oil and gas extraction[38]. A wood-fired steam plant requires 4 times more construction workers and 3–7 times more plant maintenance and operation workers than a coal-fired plant. Including the labor required to produce corn, about 18 times more labor is required to produce a million kcal of ethanol than an equivalent amount of gasoline[30]. The safe harvesting practices and equipment should be developed to reduce the occupational injuries while harvesting and agricultural production for energy[38]. The high rank of burden of disease is attributed to Bangladesh, India, Myanmar and Pakistan with percentage ranging from 3.2 to 4.6. The international commitment was built from the EU member countries to work and tackle these issues together. The urgent need of improving access of the poor to cleaner energy sources was agreed by the international community[39].

Gumartini studied the emission from biomass energy in Asia Pacific region. About 22% of the world total CO_2 was emitted by developing countries in the Asia-Pacific region with 4.9%

annual increases of CO_2 emissions since 1990. In this region, the top ten ranks of CO_2 emitting countries are China, India and Japan[39]. The production of biofuels from large scale industries waste large amounts of emissions, cause heavy soil erosion and emit small scale water pollution[40].

The biomass waste might be used as fuel for power generation and cogeneration (heat and electricity). Singhal et al. analyzed the status and future directions of solid waste management in India. The generation of municipal solid waste has been estimated to exceed 260 million tons in the year 2047[41]. Kumar et al. estimated the methane emission from waste landfills for the period of 1980–1999 in India The atmospheric methane concentration has been increasing in the range of 1–2% per year. The estimation of the national level methane emission from solid waste disposal areas using the default methodology and using triangular pattern of gas generation methodology varies from 263.02 Gg to 502.46 Gg and 119.01 Gg to 400.66 Gg respectively in year 1980 to in year 1999[42]. Using animal and human waste to power engines may save carbon dioxide emissions, but it increases methane gases, which are also harmful to the earth's ozone layer. Using trees and tree products to produce power results in major topological changes and destroys the homes of countless animals and plants[30].

2.8 Waster Heat

Heat recovery is the collection and re-use of heat arising from any process that would otherwise be lost. The process might be inherent to a building, such as space heating, ventilation and so on, or could be something carried out as part of business activity, such as the use of ovens, furnaces and the like. Heat recovery can help to reduce the overall energy consumption of the process itself, or provide useful heat for other purposes. Ventilation systems bring cool fresh air into a building using fans in Air Handling Units (AHUs). The AHUs also contain heating coils to allow the fresh air to be raised to the required temperature by the buildings boiler. The air continues to be heated by the occupants and equipment in the room and all this heat energy is lost when the air is extracted and dumped into the environment. The addition of heat recovery means that some of the heat contained within the extract air can be recovered. The heat energy is passed into the incoming fresh air effectively pre-heating it and meaning the boiler needs to add less heat. The two air streams need not mix directly to allow the transfer of heat[42].

According to the United States Department of Energy, up to 50 percent of the energy from all fuels burned in the U.S. ends up in the atmosphere as waste heat. Research indicates that recovery of the energy waste from industrial facilities could fulfill up to 20 percent of total U.S. electricity demand and simultaneously effect a 20 percent reduction in greenhouse gas emissions. It is estimated that 11GW of power could be generated in the US alone if the best quality waste heat from commercial and industrial operations were collected and converted to electricity[43].

2.8.1 Waste Heat Source and Uses

Recovering industrial waste heat can be achieved via numerous methods. The heat can either be "reused" within the same process or transferred to another process. Ways of reusing heat locally include using combustion exhaust gases to preheat combustion air or feed water in industrial boilers. By preheating the feed water before it enters the boiler, the amount of energy required to heat the water to its final temperature is reduced. Alternately, the heat can be transferred to another process; for example, a heat exchanger could be used to transfer heat from combustion exhaust gases to hot air needed for a drying oven. In this manner, the recovered heat can replace fossil energy that would have otherwise been used in the oven. Such methods for recovering waste heat can help facilities significantly reduce their fossil fuel consumption, as well as reduce associated operating costs and pollutant emissions[44].

Table 2: Examples of Waste Heat Sources and End Uses[44]

Waste Heat Sources	Uses for Waste Heat
1) Combustion Exhausts: • Glass melting furnace • Cement kiln Fume incinerator • Aluminum reverberatory furnace • Boiler 2) Process offgases: • Steel electric arc furnace • Aluminum reverberatory furnace 3) Cooling water from: • Furnaces • Air compressors • Internal combustion engines 4) Conductive, convective, and radiative losses from equipment: • Hall Hèroult cells 5) Conductive, convective, and radiative losses from heated products: • Hot cokes • Blast furnace slags	1) Combustion air preheating 2) Boiler feedwater preheating 3) Load preheating 4) Power generation 5) Steam generation for use in: • power generation • mechanical power • process steam 6) Space heating 7) Water preheating 8) Transfer to liquid or gaseous process streams

2.8.2 Waste Heat Recovery from the Exhaust of Diesel Gensets (DGs)

Heat balance of a diesel engine indicates that the input fuel energy is divided into three major parts: energy that converts to useful work, energy that loses through the exhaust gas and energy that dissipates to the coolant[45]. In general, diesel engines have a thermal efficiency of about 35% and thus the rest of the input energy is wasted. A considerable amount of energy is expelled to the ambient environment with the exhaust gas despite recent improvement of diesel engine efficiency. In a water-cooled engine about 25% and 40% of the input energy are wasted into the coolant and exhaust gases, respectively[46]. Johnson found that the total waste heat dissipated can vary from 20 kW to as much as 40 kW from a typical 3.0 l engine having a maximum output power of 115 kW. It is also suggested that for a typical and representative driving cycle, the average heating power available from the waste heat is about 23 kW[47].

The steam utilized for this purpose needs to be super-heated before it expands in the turbine. Therefore, one heat exchanger, explicitly named as the ‘vapor generator’, was utilized to produce vapor from the liquid and the second heat exchanger named as the ‘super heater’ was employed to create super-heated vapor. These two heat exchangers could be positioned in two configurations, parallel and series arrangements, as illustrated in Fig. 7. In the instance of parallel arrangement, the exhaust from the engine was divided into two streams; one stream was traveled into the vapor generator and the other one into the super heater. Contrariwise, in the series arrangement, the exhaust from the engine traveled into the super heater first and then into the vapor generator as a single stream[48].

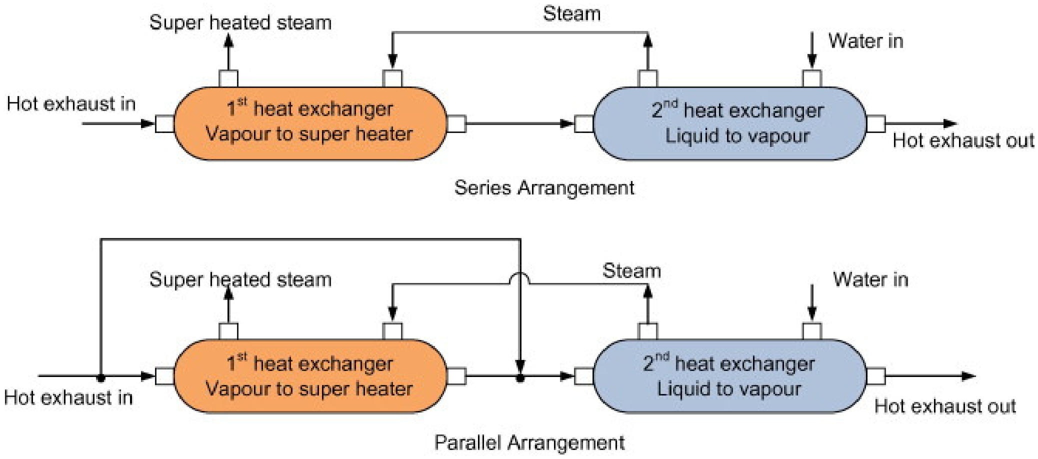

Figure 7: Heat exchangers arrangements [48]

2.9 Nuclear Fuel

Nuclear fuel also one of the sources of heat to heat water to generate electricity. This is typically used in nuclear power plant. Nuclear plants, like plants hat burn coal, natural gas or oil, produce electricity by using nuclear reaction as fission to boil the water into steam. The steam then turns turbine in order to generate electricity. The difference is that nuclear plants do not burn anything. Instead, they use uranium fuel, consisting of solid ceramic pellets, to produce electricity through a process called fission.

Nuclear power plants obtain the heat needed to produce steam through a physical process. Nuclear energy is released by way of a fission chain reaction. In this process, neutrons emitted by fissioning nuclei induce fissions in other fissile or fissionable nuclei; the neutrons from these fissions induce fissions in still other fissile or fissionable nuclei; and so on. Such a chain reaction can be described quantitatively in terms of the multiplication factor. The uranium fuel consists of small, hard ceramic pellets that are packaged into long, vertical tubes. Bundles of this fuel are inserted into the reactor[49].

There are two common commercialized types of nuclear power plant either boiling water reactor or pressurized water reactor. In United States, two-third of nuclear power plant is pressurized water reactor while the other one-third is boiling water reactor.

Pressurized water reactor is different from boiling water reactor in its generation of electricity process and its components. In typical design concept of a commercial pressurized water reactor, first process is generation of heat from fuel element inside the core. This happens in the reactor vessels. Next, pressurized water in primary loop carries the heat to steam generator. Inside steam generator, heat is transferred from primary loop to secondary loop which makes the water to be vaporized into steam. A steamline directs the steam is used to turn the turbine generator which then produces electricity. A pressurized water reactor may contain between 150-200 fuel assemblies.

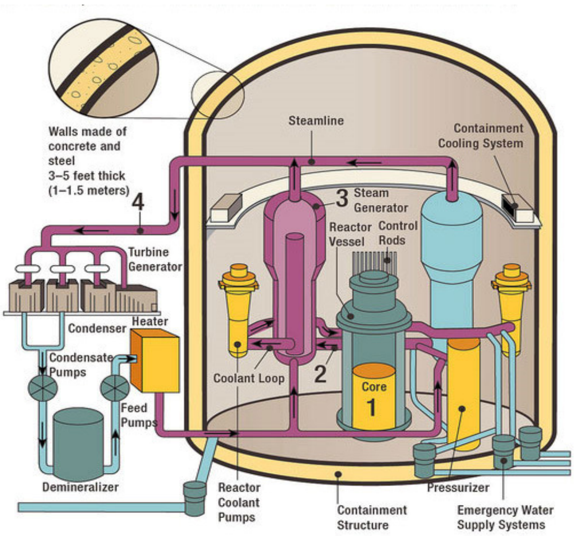

Figure 8: Diagram of commercial typical pressurized water reactor [50]

Meanwhile, boiling water reactor operates different way than pressurized water reactor. The core inside the reactor vessel creates heat. The heat than absorbed to the reactor coolant which contain a very pure water. Then, a steam-water mixture is produced. The steam-water mixture then leaves the top of the core and enters two stages of moisture separation process where water droplets are removes before the steam is allowed to enter the steamline. The steamline directs the steam to the main turbine, making it to turn the turbine generator, which then produces electicity. Different from pressurized water reactor, boiling water reactor contain between 370-800 fuel assemblies.

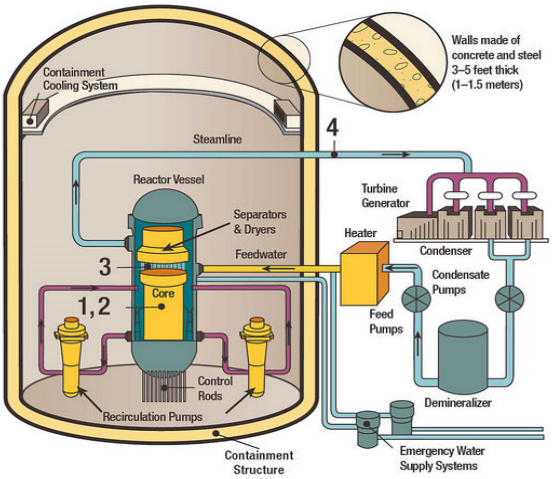

Figure 9: Diagram of a commercial boiling water reactors [51]

In both reactors, the common fuel used is uranium, MOX or thorium. Commonly, these fuels undergo same process before it is used in reactor. In industry, especially for uranium, the steps before it is used and after usage is called nuclear fuel cycle.

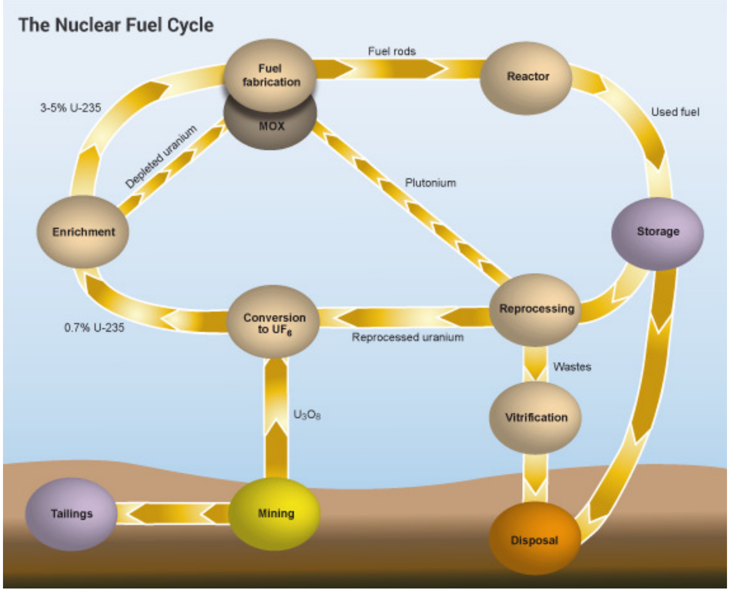

Figure 10: The nuclear fuel cycle [52]

2.9.1 Uranium

The most common types of nuclear fuel are uranium. Uranium is a relatively common element that can be found throughout the world. Uranium is a slightly radioactive element that can be found on Earth's crust. It is more abundant than gold[52]. To fuel existing nuclear power plants, uranium must first be extracted from natural deposits and converted into a form suitable for use in a reactor[53]. Commonly, uranium in power plant exists in form of small pellet called uranium dioxide. To undergo controlled fission reaction, the uranium fuel is enriched to a certain percentage depends on the type and capacity of power plant. Usually, 96.7% of U-238 and 3.3% of U-235 is used to run a nuclear power plant[53].

Approximately once every 2 years, the reactors are shut down and a portion of the fuel (one third of the core of a PWR, one quarter of the BWR) is removed and placed in a spent fuel pool adjacent to the reactor containment building. In the once-through cycle, the spent fuel, after much of its radioactivity has died away, is removed from the pool and disposed of as radioactive waste or reprocessed back as fuel known as Mixed uranium-plutonium oxide(MOX) fuel. Because of the limited capacity of reactor spent fuel pools, it is necessary to transfer the spent fuel to special storage facilities. There the fuel is stored in dry storage casks prior to its ultimate disposal[54].

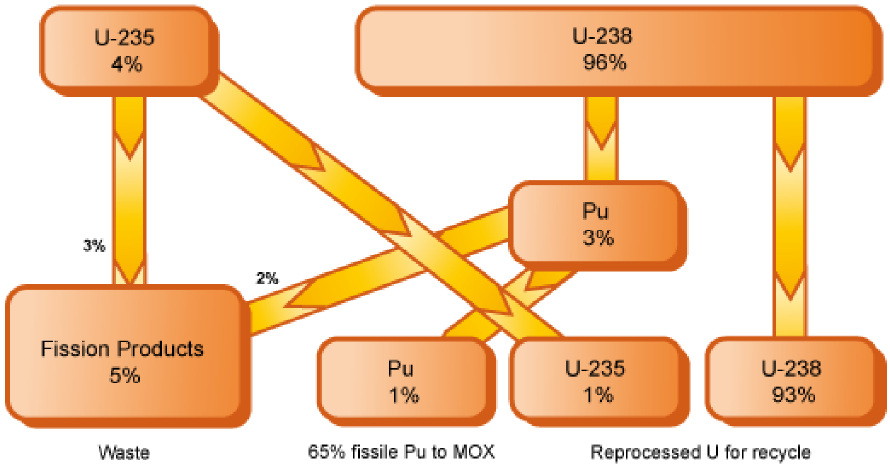

Figure 11: Reaction in UO_2 fuel [55]

2.9.2 Waste Product of Uranium

Spent fuel is the most problematic of all radioactive wastes. During the three to four years a uranium fuel rod spends in a power reactor, much of the U-235 and a small amount of the U-238 are converted into fission products and transuranic isotopes. In average, spent fuel composition is about 94.3% of U-23, 0.81% of U-235, 0.51% of U-236, 0.52% of Pu-239, 0.21% of Pu-240, 0.1% of Pu-241, 0.01% of Pu-242 and 3.5% other fission products[53].

2.9.3 Advantages of Uranium

Nuclear energy by far has the lowest impact on the environment because it does not release any gases that responsible for greenhouse effect such as carbon dioxide and methane. Also, nuclear energy has no adverse effect on water, land or any habitats due to the use of it. Though some greenhouse gases are released while transporting fuel or extracting energy from uranium.

Also, nuclear energy is reliable energy. Nuclear energy can be produced from nuclear power plant even on rough weather condition unlike traditional sources of energy like solar and wind which require sun or wind. They can produce power 24/7 and need to be shut down for maintenance purposes only.

The initial construction costs of nuclear power plants are large. On top of this, when the power plants first have been built, we are left with the costs to enrich and process the nuclear fuel control and get rid of nuclear waste, as well as the maintenance of the plant. The reason this is under advantages is that nuclear energy is cost-competitive. Generating electricity in nuclear reactors is cheaper than electricity generating from oil, gas and coal.

2.9.4 Disadvantages of Uranium

The waste from nuclear energy is extremely dangerous and it has to be carefully looked after for 10 000 years according to United States Environmental Protection Agency standards.

High risks are also a disadvantage of nuclear power plant. Although with a generally high security standard, accidents can still happen. The consequences of an accident at nuclear power plant would be a massive devastating both for human being and nature. The more nuclear power plants (and nuclear waste storage shelters) are built, the higher is the probability of a disastrous failure somewhere in the world.

Nuclear power plants as well as nuclear waste could be preferred targets for terrorist attacks. A terrorist act would have catastrophic effects for the whole world.

2.9.5 Used of Uranium Fuel

Uranium fuel is used all over the world in almost every nuclear power plant except the ones that uses plutonium. Example of plant uses uranium fuel is Seabrook Station nuclear power plant.

2.9.6 Cost of Uranium

Production from world uranium mines today supplies over 90% of the requirement of power utilities. World mines production has expended significantly since 2005. All mineral commodity market tends to be cyclical. The prices of uranium rise and fall over the years. In the late 70s the uranium market states high prices of uranium and gave way to depressed prices in the whole of the period of the 1980s and 1990s, with spot prices below the cost of production for all but the lowest cost mines. In 1996 spot prices briefly recovered to the point where many mines could produce profitably, but they then declined again and only started to recover strongly late in 2003.

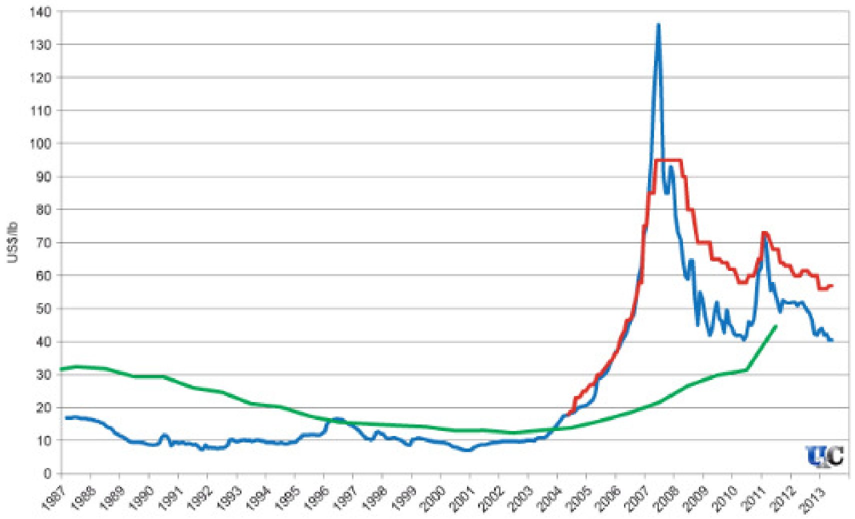

Figure 12: Graph courtesy of Uranium prices [56]

2.10 MOX

Mixed Oxide fuel (MOX) is a fuel from reprocessing of spent fuel that contain 4-9% of Pu-239, 1% of U-235 and 90-95% of U-238. MOX fuel was first used in thermal reactor in 1963 but only commercialized used in 1980. MOX fuel provides almost 5% of new nuclear fuel used today. Currently there are about 40 reactors are licenses to used MOX fuel. The burnup of MOX fuel are almost the same as uranium fuel. MOX fuel of 7-10% reactor grade plutonium is equivalent to 4.5% of U-235 enriched uranium fuel.

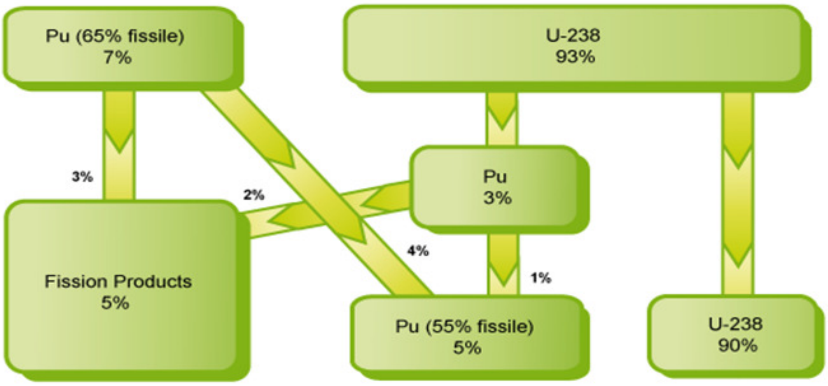

Figure 13: Reaction of MOX fuel [55]

2.10.1 Waste Product of MOX Fuel

Waste of used MOX fuel is extremely dangerous and currently are not being reprocessed and only being exposed. Wastes of MOX fuel are more dangerous than natural uranium fuel.

2.10.2 Advantages of MOX Fuel

MOX fuel is far cheaper than uranium fuel. Thus, MOX fuel is more economical as uranium price rises. The fissile concentration is easily increased by adding a bit more of plutonium while enriching uranium to a higher level of U-235 is expensive. MOX fuel also reduced the volume of spent fuel because seven of Uranium dioxide fuel gave rise to one MOX fuel.

2.10.3 Disadvantages of MOX Fuel

Used MOX fuel is generally much dangerous than natural uranium fuel and need to be stored away with much protection.

2.10.4 Cost of MOX Fuel

Cost of MOX fuel is cheaper than uranium fuel because of its easily enriching and recycles back the spent fuel.

2.11 Thorium

Thorium (Th-232) is an element that is more abundant in natural compared to uranium and is not itself fissile and so is not directly usable in a thermal neutron reactor. Also, thorium is slightly radioactive metal that is found in 1828 and is ‘fertile’rather than fissile. Upon absorbing a neutron will transmute thorium to uranium-233 (U-233), which is an excellent fissile fuel material. All thorium fuel concepts therefore require that Th-232 is first irradiated in a reactor to provide the necessary neutron dosing to produce protactinium-233. Thorium fuels need a fissile material as a driver so that chain reaction can be sustained. The examples of driver are U-233, U-235 and Pu-239[57].

2.11.1 Advantages of Thorium Fuel

Thorium is more abundant in earth's crust than natural uranium.

2.11.2 Disadvantages of Thorium Fuel

Less experienced in thorium handling makes its disadvantages. High prices in operational experiences with thorium also a major problem. Thorium fuel is a bit harder to prepare than uranium fuel. Thorium melts at 550 degrees higher than natural uranium making it to be harder to form a good quality solid fuel.

Irradiated thorium is more dangerous than natural uranium in short term. Also, Th-U does not work well is fast breeder reactor compared to U-Pu.

2.11.3 Used of Thorium Fuel

Molten Salt Reactor uses Thorium-Uranium fuel. Currently there are no these type of reactor that commercialized used to generate electricity.

3.0 CONCLUSION

Steam power plant have been used for about 200 years to generate electricity. There are several types of steam power plant such as thermal power plant, gas power plant and nuclear power plant. Among the various power plants, thermal power plant or coal power plant account for almost 41% of the world electric generation with efficiency ranges from 32% to 42% while natural gas power plant covered almost 20% of the world electricity generation with efficiency ranges from 32% to 38%. The efficiency for nuclear power plant is only 0.27%[58].

This study examines the common types of fuel used in the various type of steam power plant such as thermal, gas and nuclear power plants. Based on the study, it is found that the common fuel used in steam power plant are fossil fuel, waste heat, waste fuel and nuclear fuel. Fossil fuel consist of coal which used in thermal power plant, oil and gas which used in gas power plant. Gas turbine exhaust and diesel are the common waste heat while biomass is the waste fuel which used in biomass fuelled power plant. Nuclear fuel consist of uranium, MOX and thorium which used in fission process to produce steam in nuclear power plant.

REFERENCES

[1] Teir, Sebastian. "Basics of Steam Generation." Helsinki: Energy Engineering and Environmental Protection Publications (2002).

[2] Kenneth, W. (n.d.). Chapter 2. In Fundamentals of Steam Power (p. 35). doi: http://www.personal.utulsa.edu/~kenneth-weston/chapter2.pdf

[3] Williamson, A. R. (Oct 17, 1989). U.S. Patent No. US4873829 A. Washington, DC: U.S. Patent and Trademark Office.

[4] Hans, P. (Nov 22, 1977). U.S. Patent No. US4058974 A. Washington, DC: U.S. Patent and Trademark Office.

[5] Robert, H., & Lothrop, M. (May 20, 1952). U.S. Patent No. US2596968 A. Washington, DC: U.S. Patent and Trademark Office.

[6] Chaplin, R. A. "Power plant technology." Vol-1, Encyclopedia of life support system (1986).

[7] Thermal Power Generation Plant or Thermal Power Station. (n.d.). Retrieved May 17, 2016, from http://www.electrical4u.com/thermal-power-generation-plant-or-thermal-power-station/

[8] Nuclear Power Station or Nuclear Power Plant. (n.d.). Retrieved May 17, 2016, from http://www.electrical4u.com/nuclear-power-station-or-nuclear-power-plant/

[9] Heinemann, B., Soares, C., & Hill, M. (1998). Gas Turbines In Simple Cycle & Combined Cycle Applications (2nd ed., Bloch & Soares, C.). doi:https://www.netl.doe.gov/File Library/Research/Coal/energy systems/turbines/handbook/1-1.pdf

[10] Thermal Power Plant Classification [Web log post]. (2009, October 4). Retrieved May 18, 2016, from http://thermal-powerplant.blogspot.my/2010/05/thermal-power-plant-classification.html

[11] http://www.mpoweruk.com/fossil_fuels.htm

[12] IAEA (International Energy Agency). http://www.iea.org/statistics/topics/ CO2 emissions/

[13] CAESAR, 2009. European Best Practice Guidelines for Assessment of CO2 CaptureTechnologies. D 4.9 Report, http://www.gecos.polimi.it/research/EBTF bestpractice guide.pdf

[14] Atsonios, K., K. Panopoulos, P. Grammelis, and E. Kakaras. "Exergetic comparison of CO 2 capture techniques from solid fossil fuel power plants."International Journal of Greenhouse Gas Control 45 (2016): 106-117.

[15] NGSA;NaturalGasSupplyAssociation. ⟨http://www.naturalgas.org⟩; 2012 [accessed 30.10.12].

[16] Wood, David A., Chikezie Nwaoha, and Brian F. Towler. "Gas-to-liquids (GTL): A review of an industry offering several routes for monetizing natural gas." Journal of Natural Gas Science and Engineering 9 (2012): 196-208.

[17] Al-Sobhi, S. A., and A. Elkamel. "Simulation and optimization of natural gas processing and production network consisting of LNG, GTL, and methanol facilities." Journal of Natural Gas Science and Engineering 23 (2015): 500-508.

[18] Energy Information Administration (EIA), 2013. International Energy Outlook 2013. Electricity. Report Number: DOE/EIA-0484(2013). http://www.eia.gov/ forecasts/archive/ieo13/electricity.cfm (accessed 17.02.16).

[19] Gupta, Sreenath B., Bipin Bihari, Munidhar Biruduganti, and Raj Sekar.Natural gas fired reciprocating engines for power generation: Concerns and recent advances. INTECH Open Access Publisher, 2012.

[20] LM6000 on-site operation and maintenance manual, GEK 105059, vol. 1; 2003.

[21] General electric LM6000. http://en.wikipedia.org/wiki/; 5 Dec 2012

[22] Aydin, Hakan. "Exergetic sustainability analysis of LM6000 gas turbine power plant with steam cycle." Energy 57 (2013): 766-774.

[23] Islas, Jorge, and Genice Grande. "Abatement costs of SO 2-control options in the Mexican electric-power sector." Applied energy 85, no. 2 (2008): 80-94.

[24] Statistical Report on 42 Years of Activities of Iran Electric Power Industry, 2009. Ministry of Energy, Tavanir Company, Iran. Available via /http://www2. tavanir.org.ir/farsi/projects/web-amar-latin/>.

[25] Huang, C., C. H. Chen, L. Li, Z. Cheng, H. L. Wang, H. Y. Huang, D. G. Streets, Y. J. Wang, G. F. Zhang, and Y. R. Chen. "Emission inventory of anthropogenic air pollutants and VOC species in the Yangtze River Delta region, China." Atmospheric Chemistry and Physics 11, no. 9 (2011): 4105-4120.

[26] Al-Gharib, S. A., A. Elkamel, and C. G. J. Baker. "A multi-criteria decision approach for choosing and ranking SO2 emission reduction measures for a network of power stations." World Review of Science, Technology and Sustainable Development 4, no. 2-3 (2007): 196-225.

[27] Nazari, S., O. Shahhoseini, A. Sohrabi-Kashani, S. Davari, H. Sahabi, and A. Rezaeian. "SO 2 pollution of heavy oil-fired steam power plants in Iran."Energy Policy 43 (2012): 456-465.

[28] UNFCCC (United Nations Framework Convention Climate Change), 2010. Fuel Switching of AmirKabir Sugarcane Plant. Germany. Available via /http: //cdm.unfccc. int/ Projects/ Validation/DB/JG2327UBTYKD59K1IY7HT5ADANH89Z/view.html>.

[29] What is biomass? <<http://www.reenergyholdings.com/renewable-energy/what-is-biomass/>> [accessed 14.05.2016]

[30] Herbert, GM Joselin, and A. Unni Krishnan. "Quantifying environmental performance of biomass energy." Renewable and Sustainable Energy Reviews 59 (2016): 292-308.

[31] Rahman, Shaikh Rashedur, Mumtahina Rahman Nahid-Al-Mahmud, Md Yeakub Hussain, and Md Sekendar Ali. "Overview of biomass energy." InInternational Journal of Engineering Research and Technology, vol. 2, no. 11 (November-2013). ESRSA Publications, 2013.

[32] United Nations Environment Programme. Int. Environmental Technology Centre, Converting waste agricultural biomass into a resource, compendium of technologies. Osaka/Shiga,Japan.DTI/1203/JP.

[33] Luoranen, Mika, Risto Soukka, Gintaras Denafas, and Mika Horttanainen. "Comparison of energy and material recovery of household waste management from the environmental point of view–Case Kaunas, Lithuania."Applied Thermal Engineering 29, no. 5 (2009): 938-944.

[34] Advantages and disadvantages of recycling, conserve energy future, be green. Stay green. <<http://www.conserve-energy-future.com/advantages-and-disadvantages-of-recycling.php> [accessed 16.05.16].

[35] Conserve energy future, Be green green. Stay green. <<http://www.conserve-energy-future.com/ethanol-fuel.php>> [accessed 17.05.2016]

[36] Demirbas, Ayhan. "Political, economic and environmental impacts of biofuels: a review." Applied energy 86 (2009): S108-S117.

[37] Suntana, Asep S., Kristiina A. Vogt, Eric C. Turnblom, and Ravi Upadhye. "Bio-methanol potential in Indonesia: forest biomass as a source of bio-energy that reduces carbon emissions." Applied Energy 86 (2009): S215-S221.

[38] David Pimentel, "Biomass Utilization, Limits of", Cornell University, Encyclopedia of Physical Science and Technology, March 14, 2001

[39] Gumartini T. Biomass energy in the Asia-Pacific region: Current status, trends and future setting. Asia-Pacific forestry sector outlook study II; 2009. Working Paper No. APFSOS II/WP/2009/26

[40] Advantages and disadvantages of biofuels, conserve energy future, be green green stay green. <<http://www.conserve-energy-future.com/advantages-and-disadvantages-of-biofuels.php>[accessed 17.05.16]

[41] Singhal, Shaleen, and Suneel Pandey. "Solid waste management in India: status and future directions." TERI Information Monitor on Environmental Science 6, no. 1 (2001): 1-4.

[42] Heat recovery, "Find out how heat recovery systems to recover and re-use waste heat can reduce your organisaton's energy consumption" <<https://www.carbontrust.com/resources/guides/energy-efficiency/heat-recovery>> [accessed 18.05.2016]

[43] Waste heat recovery, <http://coolenergy.com/waste-heat-recovery/> [accessed 18.05.2016]

[44] U.S Department of Energy, Industrial Technologies Program, "Waste Heat Recovery: Technology and Opportunities in U.S. Industry", BCS, Incorporated, March 2008

[45] Hossain, Shekh Nisar, and Saiful Bari. "Waste heat recovery from the exhaust of a diesel generator using Rankine Cycle." Energy Conversion and Management 75 (2013): 141-151.

[46] Hatazawa, M., H. Sugita, T. Ogawa, and Y. Seo. "Performance of a Thermoacoustic Sound Wave Generator driven with Waste Heat of Automobile Gasoline Engine." Nippon Kikai Gakkai Ronbunshu B Hen(Transactions of the Japan Society of Mechanical Engineers Part B)(Japan) 16, no. 1 (2004): 292-299.

[47] Johnson, Valerie H. Heat-generated cooling opportunities in vehicles. No. 2002-01-1969. SAE Technical Paper, 2002.

[48] Boretti, Alberto A. "Transient operation of internal combustion engines with Rankine waste heat recovery systems." Applied Thermal Engineering 48 (2012): 18-23.

[49] Institute, N.E. How Nuclear Reactors Work. 2016; Available from: http://www.nei.org/Knowledge-Center/How-Nuclear-Reactors-Work

[50] USNRC. Pressurized Water Reactors. 2015; Available from: http://www.nrc.gov/reactors/pwrs.html.

[51] USNRC. Boiling Water Reactors. 2015; Available from: http://www.nrc.gov/reactors/bwrs.html.

[52] Association, W.N. The Nuclear Fuel Cycle. 2016; Available from: http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/introduction/nuclear-fuel-cycle-overview.aspx.

[53] Shultis, J.K. and R.E. Faw, Fundamentals of Nuclear Science and Engineering Second Edition. 2007: CRC press.

[54] Lamarsh, J.R., Introduction to nuclear engineering. 1975.

[55] Association, W.N. Mixed Oxide (MOX) Fuel. 2016; Available from: http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/fuel-recycling/mixed-oxide-fuel-mox.aspx

[56] Association, W.N. Uranium Markets. 2015; Available from: http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/uranium-resources/uranium-markets.aspx

[57] Whatisnuclear.com. Thorium as nuclear fuel. 2016; Available from: https://whatisnuclear.com/articles/thorium.html

[58] The Efficiency of Power Plants of Differnt Types. (n.d.). Retrieved May 17, 2016, from http://www.brighthubengineering.com/power-plants/72369-compare-the-efficiency-of-different-power-plants/