THE EFFECT OF DIFFERENT PRE-TREATMENT METHODS ON DEWATERED SLUDGE FOR ELECTRICITY GENERATION USING MEMBRANE-LESS MICROBIAL FUEL CELL

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by

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LIST OF SYMBOLS

°C	Degree Celsius
%	Percentage
+	Plus
-	minus
Ω	Ohms

LIST OF ABBREVIATIONS

μ	Specific growth rate
A	Ampere
A	Area
AAS	Atomic absorption spectroscopy
Ag_2NO_3	Silver nitrate
ANOVA	Analysis of variance
A/m^2	Ampere per meter square
BS	Bacillus subtilis
C	Carbon
CCD	Central composite design
CHN	Carbon, hydrogen, oxygen
CO_2	Carbon dioxide
COD	Chemical oxygen demand
DNA	Deoxyribonucleic acid
DS	Dewatered Sludge
EAB	Electrogenic aerobic bacteria
EB	Electrogenic bacteria
EPA	Environmental protection agency
Fe	Iron
FTIR	Fourier-transform infrared spectroscopy
g	gram
GDL	Gas diffusion layer
GW	Giga watt
h	Hour
H	Hydrogen

H_2O_2	Hydrogen peroxide
H_2SO_4	Sulphuric acid
HCl	Hydrochloric acid
HNO_3	Nitric acid
ICP-OES	Optical emission spectroscopy
I	Current
IEA	International energy agency
IWK	Indah water consortium
K	Potassium
KBr	Potassium bromide
K_2CrO_7	Potassium dichromate
kg	kilogram
kWh	Kilowatt hours
L	liter
M	Mega
m	meter
mA	Milliampere
MET	Mediator electron transfer
MFC	Microbial fuel cell
mg	milligram
Mg	magnesium
Mg/L	Milligram per liter
min	minute
mL	millimeter
ML-MFC	Membrane-less microbial fuel cell
mV	millivolts
mW	milliwatts

mW/m^2	Milliwatts per meter square
mW/m^3	Milliwatts per meter cube
N	nitrogen
NaOH	Sodium hydroxide
nm	Nanometer
O	oxygen
OD	Optical density
OFAT	One-factor-at-a time
ORR	Oxygen reduction reaction
P	Power
P	phosphorus
PEM	Proton exchange membrane
ppm	Parts per million
pd	Power density
R	Resistance
RNA	Ribonucleic acid
R^2	Correlation coefficient
rpm	Revolution per minute
RSM	Response surface design
SCOD	Soluble chemical oxygen demand
Td	Doubling time
TS	Total solid
TWh	Terawatt per hour
UV	ultraviolet
V	voltage
W	watts
WAS	Waste activated sludge

w/m^3	Watts pe meter cube
WWTP	Wastewater treatment plant
w/w	Weight per weight
Zn	Zinc

KESAN KAEDAH PRA-RAWATAN YANG BERBEZA KE ATAS ENAP CEMAR SEBELUM DIGUNAKAN DALAM PENJANAAN ELEKTRIK MENGGUNAKAN SEL BAHAN API MIKROB TANPA MEMBRAN

ABSTRAK

Sel Bahan Api Mikrob mendapat minat tinggi daripada penyelidik di seluruh dunia kerana ini adalah teknologi boleh diperbaharui yang menjanjikan yang mempunyai keupayaan dalam menghasilkan tenaga elektrik. Sel bahan api mikrob adalah teknologi menarik yang mempunyai mekanisma yang boleh menukar bahan buangan kepada satu bentuk tenaga yang boleh digunakan. Sel bahan api mikrob tanpa membran adalah salah satu jenis teknologi yang menunjukkan memberikan kesan besar dalam menyediakan sumber kuasa yang mampan. Enap cemar yang dirawat kemudiannya digunakan dalam ML-MFC dengan mendedahkannya kepada suhu inkubasi dengan parameter malar ialah pH, kandungan lembapan awal dan jarak elektrod selama 7 hari tempoh inkubasi. Komposisi DS ditentukan untuk menilai kegunaannya sebagai sumber substrat untuk pertumbuhan bakteria elektrogenik untuk penjanaan kuasa. Dalam kajian ini, kesan kaedah prarawatan terma (60, 80, 100, 120 dan 140 ºC), sonikasi (10, 20, 30, 40 dan 50 kHz) dan pra-rawatan beralkali dengan pH (8, 9, 10, 11). dan 12) pada enap cemar sebagai substrat untuk bakteria elektrogenik (BE) dalam sel bahan api mikrob tanpa membran telah dioptimumkan menggunakan kaedah satu faktor pada satu masa (OFAT). Prestasi terbaik sel bahan api mikrob tanpa membran untuk penjanaan ketumpatan kuasa (12.92 mW/m^2), kadar degradasi enap cemar (89.48 %) dan biojisim (1.91 mg/L) di bawah keadaan optimum 100 °C (terma), pH 10 (beralkali) dan 30 kHz (ultrasonik) telah diperolehi. Analisis statistik matematik, metodologi permukaan tindak balas melalui reka bentuk komposit pusat di

bawah model kuadratik telah dijalankan untuk mengoptimumkan lagi prestasi sel bahan api mirob tanpa membran dalam penjanaan ketumpatan kuasa (71.53 %) (R^2 = 0.886), degradasi DS (51.7 %) (R^2 = 0.889) dan biojisim (1.45 mg/L) (R^2 = 0.857). Enap cemar ditentukan untuk kepekatan tingginya dalam unsur makronutrien dan mikronutrien melalui analisis proksimat menggunakan Spektroskopi Penyerapan Atom (AAS), penganalisis unsur organik (CHN), dan kaedah Spektrometer Pelepasan ICP (ICP-OES). Kaedah peningkatan menggunakan litar bersiri telah dijalankan dalam kajian ini menggunakan kaedah pra-rawatan yang dicadangkan oleh kaedah reka bentuk komposit pusat untuk prestasi yang lebih tinggi bagi sel bahan api mikrob tanpa membran dari segi biojisim (1.81 mg/L), degradasi enap cemar (74.5 %) dan ketumpatan kuasa (137.9 mW/m^2).

THE EFFECT OF DIFFERENT PRE-TREATMENT METHODS ON DEWATERED SLUDGE FOR ELECTRICITY GENERATION USING MEMBRANE-LESS MICROBIAL FUEL CELL

ABSTRACT

Microbial Fuel Cell (MFC) is gaining high interest from researchers around the globe as this is a promising renewable technology that has capability in producing electrical energy. MFC is an attractive technology that has a mechanism that can convert waste substances into a form of usable energy. Membrane-less MFC (ML-MFC) is one of the types of MFC technology that shows great promise in providing a sustainable power source. In this study, the effect of the thermal pretreatment method (60, 80, 100, 120 and 140 ºC), sonication (10, 20, 30, 40 and 50 kHz) and alkaline pretreatment with pH (8, 9, 10, 11 and 12) on dewatered sludge (DS) as substrate for electrogenic bacteria (EB) in ML-MFC was optimized using one-factor-at-a-time (OFAT) approach. These pretreatments were selected for their potential to enhance sludge degradation, improve organic matter availability, and boost power generation through distinct physical and chemical mechanisms. The best performance of ML-MFC for generation of power density (11.27 mW/m^2), degradation rate of DS (89.48 %) and biomass (1.92 mg/L) under optimum condition of 100 °C (thermal), pH 10 (alkaline) and 30 kHz (ultrasonication) had been obtained. The statistical mathematical analysis, response surface methodology (RSM) via Central Composite Design (CCD) under quadratic model was conducted to further optimized the performance of ML-MFC in power density generation (R^2 = 0.886), degradation of DS (R^2 = 0.889) and biomass (R^2 = 0.857). The treated sludge was then used in ML-MFC by exposing them to the constant incubation temperature with constant parameter of pH, initial moisture

content and electrodes distance for 7 days incubation period. The composition of DS was determined to assess its utility as a substrate source for the growth of electrogenic bacteria for power generation in ML-MFC. DS were determined for their high concentration in macronutrient and micronutrient elements through proximate analysis using Atomic Absorption Spectroscopy (AAS), organic elemental analyzer (CHN), and the ICP Emission Spectrometer (ICP-OES) method. The upscaling method using series circuit ML-MFC was conducted in this study using pre-treatment method proposed by RSM method for a higher performance of ML-MFC in term of EB growth (1.81 mg/L), DS degradation (74.5 %) and power density (137.9 mW/m^2).

CHAPTER 1

INTRODUCTIONS

1.1 Background Study

Energy is one of the most important survival aspects for persons in today's technologically evolved environment. Energy is required in many aspects of everyday life, including agriculture, transportation, telecommunications, and industrial operations, all of which impact economic growth (Azam et al., 2015). Economic growth benefits the environment, and both areas are mutually supportive of one another (Azam et al., 2015). Electricity was being investigated more frequently than other types of energy because energy use was shifting away from outdated fuels and toward cleaner and safer energy sources (Hussain Ali Bekhet, 2016).

As the world advance toward more sustainable and accessible energy sources, it is vital to remember that 1.3 billion people still lack access to electricity and about 940 million people equal with 13 % global population were suffer from energy poverty, with the majority living in southern Asia and Africa (Clerici & Alimonti, 2015). There were about only 3 % of the population of African continent have access to electricity with majority of people that have access to electricity were living in, south Africa (Clerici & Alimonti, 2015). More than 120 million people in South Asia, or 20 % of the total population, are still without electricity, while 45 %, or 276 million people, rely on solid fuels such as charcoal and firewood (Erdiwansyah et al., 2019).

Electricity is widely available in numerous areas, such as housing, transportation, and manufacturing to 97 % of Malaysians (Hussain Ali Bekhet, 2016). Malaysia's energy demand in 2009 is 16,132 MW but the electricity demand was only 9690 MW in 1999 (about 66 % increment) the increase in electricity demand in

Malaysia due to the fast economic expansion that happen as the population was increased over time (Azam et al., 2015) Moreover, half of Malaysia's energy consumption comes from the industrial sector, which accounts for around 49 % of the country's total demand, commercial and residential demand account for 30 % and 21 %, respectively, and transportation and agriculture account for less than 1% (Azam et al., 2015). As Malaysia's population in 2021 reached 33.57 million people, the amount of electricity consumed in Malaysia reached more than 145 billion kWh, suggesting that the demand for energy in Malaysia increased as the population expanded. The increase in electricity demand has led Malaysia to diversify its power generation of fuel mix and increase electricity capacity.

Malaysia relies heavily on petroleum and other liquids and natural gas as its principal energy sources, which account for 37 % and 36 % respectively of total consumption, coal accounts for approximately 21 % of the country's energy consumption, and renewable energy makes up 6 % of total consumption (U.S. Energy Information Administration, 2021). Figure 1.1 depicts the net generation of energy in Malaysia from 2009 to 2018. According to the graph, Malaysia generated roughly 160 GWh of net power in 2018, which was the highest value obtained since 2009 and it also indicates that Malaysia's power generating capacity and reliance on renewable energy sources have both risen over time with hydropower generation being the most often utilized renewable energy system in Malaysia (U.S. Energy Information Administration, 2021).

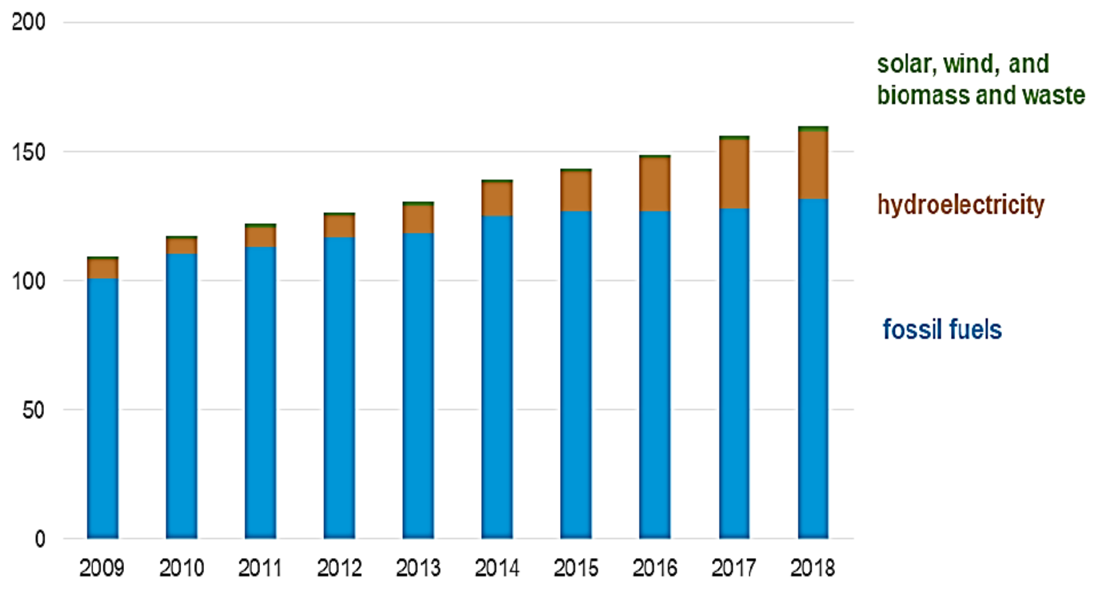

Figure 1.1 Malaysia electricity generation trend in 2009-2018 by fuel type (U.S. Energy Information Administration, 2021).

Most countries now rely on non-renewable sources in the production of electricity, but the detrimental impact of using non-renewable energy sources on the environment has prompted researchers to look for alternate energy sources of sustainable energy (Hussain Ali Bekhet, 2016). Renewable energy is derived from renewable sources of energy that are replenished regularly. These renewable energy sources may be continuously created as and when they are required. There has been rapid development of renewable energy worldwide, especially in Southeast Asia, because its presence can help reduce greenhouse gas emissions while also being ecologically beneficial (Erdiwansyah et al., 2019).Renewable energy policies generate demand for environmentally beneficial technologies that would not otherwise exist (Mardani et al., 2015).

Renewable energy could have a life cycle that has an efficiency of less than 100 % and is still superior to fossil fuel in terms of energy sources of sustainability (Mardani et al., 2015). It is very necessary to promote and develop renewable energy to decrease greenhouse gases, allowing taking a very active role in improving the environment and meeting the clean energy demand for both industry and non-industrial applications worldwide (Midilli et al., 2006). Globally, renewable energy consumption rose by 3.7 % in 2019, a minor improvement over the previous years (Glob. Energy Rev., 2020). According to Figure 1.2, worldwide renewable energy output increased by 440 TWh (6.5 % year on year) in 2019, the second-largest increase in renewable energy generation after 2018, and 2019 was a record-breaking year with growth in all corners of the world, with China leading the way once again with a 190 TWh increase in renewables-based electricity generation in 2019 (over 40 % of the global total) (Glob. Energy Rev., 2020). Figure 1.2 concluded that renewable energy overtook total power consumption in 2019 for the first time since 2010.

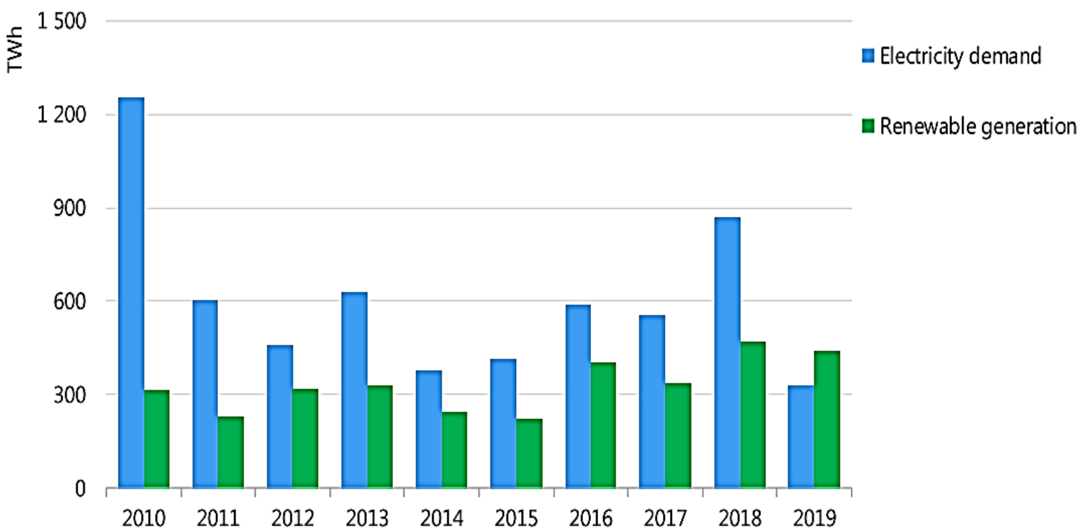

Figure 1.2 Electricity demand and renewables generation growth trend from 2010-2019 (Glob. Energy Rev. 2020)

The growing interest in renewable technologies as a means of generating energy has prompted the development of innovative solutions among which is the Microbial Fuel Cell (MFC) technology. MFC has emerged as a popular sustainable energy source in both wastewater treatment technology and green energy production

(Khaloufi & Elasli, 2019). The device works by converting chemical energy directly into electrical energy through electrochemical and biological enzymatic processes using organic matter as a source of energy through bioremediation process. Studies has shown that MFC is one of the most efficient technologies for producing electrical energy from microorganism (Tekle & Demeke, 2015). MFC technology has the potential to reduce reliance on non-renewable energy sources such as fossil fuels which offering a sustainable method for the treatment of wastewater and electrical energy generation. In Malaysia the abundance of unused sludge provides a valuable resource that can be harnessed to address the country's energy need. By leveraging MFC technology to valorise this waste. Malaysia can make a significant contribution to the global effort to transition to cleaner renewable energy sources (Raychaudhuri & Behera, 2020).

1.2 Problem Statements

The growing Malaysian population has contributed to a significant increase in the production of dewatered sludge (DS) at wastewater treatment plants (WWTPs). Although DS is abundantly generated, especially at facilities managed by Indah Water Consortium (IWK), there is still a lack of detailed studies on its composition, particularly from major plants such as IWK Juru and Butterworth. Both of these facilities serve areas with rapid population growth and significant industrial activity, making them ideal locations for studying DS as they produce large quantities that reflect the actual conditions of DS production in Malaysia. Furthermore, there lack of specific study has been conducted on the composition of DS from these plants, creating a gap in knowledge that limits efforts to explore its potential as a renewable energy resource.

This is especially relevant for electricity generation using microbial fuel cell (MFC) technology, which offers a sustainable and ecofriendly solution by harnessing the metabolic activity of microorganisms to directly convert organic matter in waste into electricity. Utilizing DS as a substrate in MFC not only helps manage sludge overproduction but also provides a pathway to reduce carbon dioxide emissions associated with conventional energy sources. Research focusing on DS for MFC technology is therefore essential, as it integrates waste management with clean energy production, supporting the circular economy and advancing Malaysia's goals for sustainable development.

The current research on MFC has shown promising results in converting waste into electricity. However, there is a lack of knowledge on how to optimize various pre-treatments to enhance the growth of electrogenic bacteria (EB) in MFCs, resulting in higher power density. The focus of most studies has been on parameters within the MFC system without modification of the MFCs environmental conditions. This lack of research is particularly evident in the study of thermal, alkaline and ultrasonication pretreatment of DS as pseudo-membrane and substrate of MFC for power production. Therefore, there is a need to investigate the optimization of pre-treatment to promote the growth of EB in MFC and improve power density. The lack of data on numerous DS pretreatment in ML-MFC and statistical analysis and optimization of ML-MFC using response surface methodology (RSM) is significant issue that need address in order to improve power density output, soluble chemical oxygen demand (SCOD) and biomass of EB. Addressing this gap is critical for improving the efficiency of ML-MFC system.

This research aims to use the one-factor-at-a-time (OFAT) and RSM:CCD optimization technique to investigate the link between power density output, SCOD and biomass of EB in ML-MFC. OFAT will be used to examine the impact of individual pre-treatments on DS while RSM:CCD will be used to investigate the combined impacts of these pre-treatments on DS. Additionally, the assessment of power generation in ML-MFC in series circuit has not been well studied making it crucial area to explore in this research. The use if OFAT and RSM technique will allow for comprehensive understanding of the impact of different pre-treatment on DS, which will ultimately improve the efficiency and effectiveness of ML-MFC systems.

1.3 Research Objectives

i) To investigate the proximate analysis of the dewatered sludge sample (Butterworth WWTP and Juru WWTP) as a substrate towards the ML-MFC performance.

ii) To optimize the ML-MFC performance (sludge bioremediation and power generation) by optimizing the pre-treatment methods under OFAT and RSM:CCD methods.

iii) To assess the power generation from optimized ML-MFC condition under the series circuit configuration.

1.4 Significance of Study

This study is significant as it advances sustainable waste to energy technology through the innovative use of DS in ML-MFC systems. By exploring and optimizing thermal, alkaline, and ultrasonication pretreatments on DS, the research provides new insights into enhancing the growth of electrogenic, degradation of DS and improve the power density output of ML-MFC system. The conversion of DS into renewable energy not only helps DS overproduction but also contributes to reducing reliance on non-renewable energy sources. These findings support circular economy initiatives and align with Malaysia's sustainable development goals

Using DS as substrate for EB in an ML-MFC system is a promising method for producing renewable energy from waste. The study addresses a notable gap in the existing literature by investigating the effect of various pre-treatment methods on enhancing the growth of EB and improving power density output in ML-MFC systems. Furthermore, the application of response surface methodology (RSM) for the optimization of ML-MFC conditions represents a novel approach, as the use of RSM:CCD for this technology has not been extensively explored. The study also focuses on the performance of ML-MFC systems configured in series circuits, an area that has received limited attention compared to single circuit MFC configurations.

1.5 Thesis Organization

Chapter 1 emphasizes the world's energy and power supplies, particularly in Southeast Asia and Malaysia. The chapter also emphasizes the research's problem statements, objectives, the significance of the study, and thesis organization

Chapter 2 provided an overview of the relevant sources and literature on Microbial Fuel Cell hypotheses, including substrate type and performance-affecting factors. In this chapter, RSM: CCD optimization approach was explained theoretically.

Chapter 3 focuses on research methods and materials for the building and operation of Microbial Fuel Cells (MFCs), pretreatment methods which were purposed by OFAT analysis and RSM with their Central Composite Design (CCD), analysis of sample data, and profiling of the growth of electrogenic bacteria.

Chapter 4 compressive on the outcomes of the study, which were represented by the results and discussion of the parameters that were purposed using RSM: CCD for optimization of pre-treatment conditions for optimization of power generation, biomass, and Chemical Oxygen Demand (COD).

Chapter 5. summarizes the overall conclusion of the study based on the acquired results along with its discussion. In particular, concerning the summary, recommendations for future research were also included.

CHAPTER 2

LITERITURE REVIEW

2.1 Power Generations

According to 2013 statistics from the World Energy Congress and the World Bank, resolving the issue of how people throughout the world access to energy resources may have been one of humanity's top priorities. The demand for global energy in 2019 rose at a rate that was much lower than the average rate seen and this growth rate was significantly lower than the rate seen in 2018 (Glob. Energy Rev., 2020). Slower global economic development and the effect of milder weather on heating and cooling were the key factors for this slowdown (Glob. Energy Rev., 2020). Demand for electricity rose at the weakest rate since the financial crisis and energy efficiency has continued to increase, albeit at a rate much below what is required to accomplish the Sustainable Development Goals and energy-related to CO2 emissions were steady, despite significant reductions in emissions from power generation in industrialized nations (Glob. Energy Rev., 2020).

Access to renewable energy is limited for households, leading to dependence on inefficient and hazardous conventional fuels. In Southeast Asian countries, statistics from the 2013 congress of the World Bank show that average energy consumption per year per person in Indonesia was 800 kW/h, surpassing that of the Philippine's, Cambodia and Myanmar but failing behind Brunei and Singapore, whose energy usage levels are comparable to those of Australia and Japan (Erdiwansyah et al., 2019). Malaysia, while not as high as Brunei or Singapore, consumed four to five times more power per capita than we do and Thailand and Vietnam have somewhat higher scores than us (Erdiwansyah et al., 2019).

2.2 Non-Renewable Energy

Non-renewable energy sources were quite limited. This sort of energy was created under unique conditions, and it might take several generations to recreate (Energy Education, 2016). Based on the time scale, geological processes can regenerate this resource; but, on a much shorter time period of hundreds of millions of years. Most of the per capita economic growth have been fueled by relatively cheap non-renewable oil, that is expected to be economically depleted within 40 to 80 years (Abdullah, 2017). At the moment, three-fourths of the world's energy needs are met by fossil fuels. The burning of fossil fuel sends greenhouse effect into the environment contributing into the climate change and global warming (Ali et al., 2017). As global temperatures and sea levels rise, experts throughout the world anticipate that extreme weather events such as floods or heat waves may occur in the future, mandating a move from non-renewable energy sources to safer and more ecologically friendly energy.

2.3 Types of Non-Renewable Energy

2.3.1 Coal Energy

Based on energy information administration (EIA), the burning of coal energy power plant become number one source of electricity in United State and this burning coal is an inexpensive way to generate electricity compare to renewable resources (Energy Education, 2016). In 2022, worldwide coal-fired power generation increased by approximately 2 %. Though the year-on-year rise is significantly smaller than the 8 % increase witnessed in 2021 when the world recovered from Covid-19.

In absolute terms, coal-fired generation continues to break records for the second year in a row, reaching about 10 400 TWh (Administration, 2023). Figure 2.1 depicts an example of coal production caused by the pressure of biological stuff buried below over millions of years.

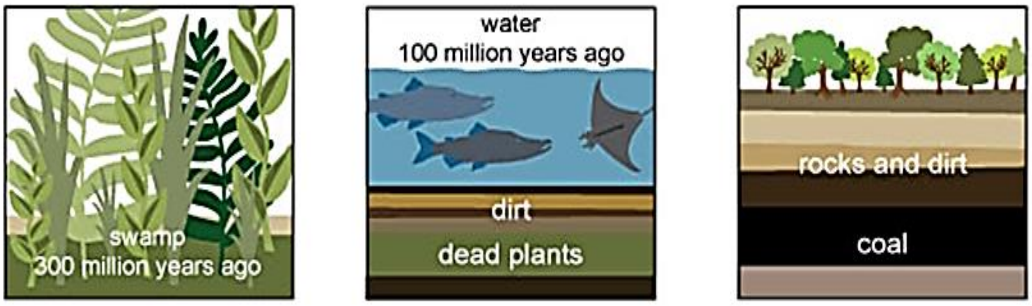

Figure 2.1 Coal formation (Abdullah, 2017).

2.3.2 Crude Oil and Natural Gas

This type of sources is available in abundance in most of the Middle East countries including Saudi Arabia, Kuwait, Iran, Iraq and UAE while there are some limited oil wells are presented in North America and Canada (Abdullah, 2017). These countries mostly have huge economic reliability and dependency for their oil and natural gas requirement. These resources are resulted from decomposed animals and plant over years and have the same process as coal energy sources. It will eventually deplete once it finishes. The wide usage of this energy has been the result of massive air pollution. It is the main major source of fuel that is used to generate vehicles. Due to the process of combustion, harmful gases like carbon dioxide are released when the oil is burnt. The leakage of oil in the ocean by the ship affects the animals and plant that lives inside and around the sea (Abdullah, 2017). Figure 2.2 depicts an example of the formation of natural gas and petroleum.

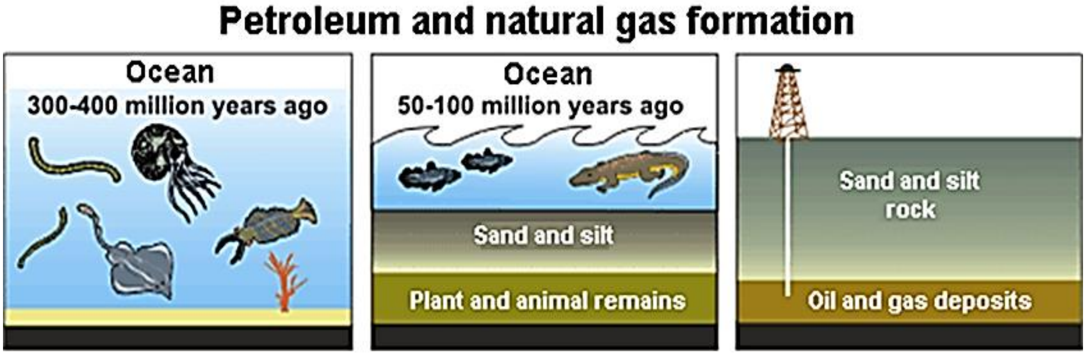

Figure 2.2 the formation of natural gas and petroleum Oil (Abdullah, 2017).

2.3.3 Nuclear Energy

Uranium and plutonium are highly radioactive elements, which decay over time releasing energy as heat. In nuclear power station uranium and plutonium fuel rods are involved in nuclear fission reaction where atoms split into smaller nuclei to release large amounts of energy. This energy has become a demanding technology nowadays as more and more countries are opting to switch to nuclear energy to fulfill their future energy demand. About 16 % of world electricity production are coming from the generation of nuclear energy (Abdullah, 2017). Nuclear energy does not emit greenhouse gases, but it does generate a type of nuclear waste known as radioactive elements. Compared to all of the energy choices available today, many experts feel nuclear energy is one of the cleanest. Many nuclear energy supporters also argue that nuclear power is responsible for the fastest decarbonization effort in history, with big nuclear players like France, Saudi Arabia, Canada, and South Korea being among the countries that recorded the fastest decrease in carbon intensity and experienced a clean energy transition by building nuclear reactors and hydroelectric dams (Igini, 2023). However, radioactive nuclear waste comprises very toxic substances such as plutonium and the uranium pellets used for fuel. These materials may be exceedingly dangerous for tens of thousands of years; thus, they must be properly and permanently disposed of. Since the 1950s, a stockpile of 250,000 tons of highly radioactive nuclear waste has been accumulated and distributed globally (Igini, 2023). Despite the catastrophe that occurred, nuclear power stations have nevertheless been erected, as seen in Figure 2.3.

Figure 2.3 The example of nuclear power plant in France (Igini, 2023)

2.4 Renewable Energy

Renewable energy often being called clean or green technologies because they currently produce less pollutant problem (Erdiwansyah et al., 2019). The idea of sustainable development and the use of renewable sources of energy came into existence within the past quarter of a century. Both of these ideas have just come into existence and are being put into practice in an effort to lessen the adverse effects that will result from the exhaustion of natural resources like fossil fuels (Mardani et al., 2015). Researchers have become interested in the implementation of sustainable and renewable energy as a means of securing the energy consumption and protecting the environment as a result of climate change and other environmental disruptions that have occurred (Mardani et al., 2015).

It is predictable that by 2025 the global energy demand could boom to 5 times of current energy demand (Ali et al., 2017). Renewable energy regulations are based on the idea that they create demand for environmentally beneficial technology that would not exist otherwise (Mardani et al., 2015). As a result of its ability to cut greenhouse gas emissions and be ecologically beneficial, renewable energy technology has grown significantly over the world, especially in Southeast Asia (Erdiwansyah et al., 2019). A wide range of renewable energy sources may be found in the Southeast Asia region's member countries: wind energy; biomass; solar power; hydropower; hydroelectricity; and tidal power and since the economies and populations of several Southeast Asian nations are expanding rapidly, it is imperative that these governments work to create sources of renewable energy (Erdiwansyah et al., 2019).

2.5 Type of Renewable Energy

2.5.1 Solar Energy

Solar technologies are the source of energy that have infinite supply that is captured directly from the sun and the energy is used to produce heat, light, and power (Koons, 2023). Within the last decade the usage of power plant based on the solar system is been taken in consideration by countries such as Japan and Germany that are vigorously looking any other alternative resources due to this country have a very limited availability of natural primary energy source (Abolhosseini et al., 2014). Solar power in Malaysia is still in its early phases, accounting for less than 1 % of total energy consumption (Koons, 2023). However, the government's goal of increasing the country's renewable energy contribution to 31 % by 2025 places a strong focus, since solar power plants are being expanded in 2022, as illustrated in Figure 2.4 (Koons, 2023).

Figure 2.4 Solar power plant builds in Malaysia (Zaki, 2023)

2.5.2 Wind Energy

Wind energy is one of the fastest growing renewable energy sources since its development in 1990 and have been increased at an average rate of over 25 % per years (Koons, 2023). The installed capacity of this power plant system has also been increased from 4.8 MW in 1995 and predicted to growing more in 2013 (Abolhosseini et al., 2014). The estimation from IEA that global capacity of wind power system installation will continuously increase from 238 GW in 2011 to 1100 GW by 2035 as 80 % of this power generation will be derived by the onshore wind turbines (Abolhosseini et al., 2014). Malaysia's present wind generating capacity was almost nil as of 2021, with the International Renewable Energy Association (IRENA) estimating it to account for 0 % of the country's entire energy mix. Meanwhile, nations like China claim an installed wind power capacity of over 300 GW, while India has upwards of 40 GW (Koons, 2023). Malaysia's wind energy capacity is restricted owing to geographic and climate considerations. There are some limitations on the successful installation of wind power system based on financial sense factor this include on the cost on both installation and operation expenditures where these is energy power plant dependent on the wind resources, turbines performance and quantity of the energy produced (Abolhosseini et al., 2014). Figure 2.5 shown the example of a wind power plant in Searsburg, Vermont.

Figure 2.5 Wind power plant in Searsburg, Vermont (society, 2022).

2.5.3 Hydropower Energy

This energy is currently the largest renewable energy that is been used in the worldwide. Since 1950, this energy has generated more than 340 terawatt-hours (TWh), which is equivalent to covering about one-third of the total demand for the generation of power across the globe (Abolhosseini et al., 2014). This energy has seen a significant growth to 1500 TWh in 1975, and then further rose to 2900 TWh in 2009, as the worldwide output and demand for electricity continued to rise (Abolhosseini et al., 2014). According to a survey conducted in 1997 by the International Journal on Hydropower and Dams, hydropower has contributed to the generation of at least 50 %

of the nation's total energy supply in 63 nations, and at least 90 % in 23 countries (Magazine, 2020).

Malaysia has very substantial hydropower resources, however unevenly spread across the nation, with higher concentrations in Sabah and Sarawak (Magazine, 2020). The first large hydroelectric dam, the Chenderoh Dam (27 MW), was built in 1930 as shown in Figure 2.6. In the decades that followed, methodical development of the country's natural resources provided about 27,300 GWh of energy per year from an aggregate installed capacity of 6240 MW (Magazine, 2020). Nowadays, this energy source has developed difficulty due to large initial fixed investment cost and environmental concern due to the construction of the dam. This issued have caused problem for local resident nearby that need to be relocated due to the construction involve in building the dam for hydrothermal plant (Abolhosseini et al., 2014). This power plant does not produce air pollution and is very safe and clean energy generation but the production of electricity from nearby dam can affect the water quality and wildlife habitat that live around the power plant (Magazine, 2020).

Figure 2.6 The hydroelectric power station in Chenderoh, Perak (Energy Education, 2016).

2.5.4 Geothermal Energy

The radioactive decay that occurs deep inside the ground is responsible for the production of this form of energy (Abolhosseini et al., 2014). Between 2010 and 2020, the levelized cost of electricity (LCOE) for geothermal power plants ranged from USD 0.049 to USD 0.085 per kWh (Agency, 2022). Geothermal, a renewable resource, accounts for a large part of energy consumption in nations such as Iceland, El Salvador, New Zealand, Kenya, and the Philippines, as well as more than 90 % of heating demand in Iceland (Agency, 2022). The potential energy of geothermal in the uppermost 6 miles of the earth's crust might generate up to 50,000 times more energy than all the energy produced from oil and gas resources worldwide (Administration, 2023). In terms of energy production viability, geothermal energy has a significant advantage over wind and solar energy since it is available 24 hours a day, 365 days a year (Abolhosseini et al., 2014).

2.5.5 Biomass Energy

Biomass chemicals are commonly linked with trash and residue. Figure 2.7 is an example of the type of biomass utilized for energy. Biomass is a renewable biological resource that comes from plants and animals. Biomass can be burnt directly for heat or transformed to liquid and gaseous fuels using a variety of method (Administration, 2023). Figure Based on (Abolhosseini et al., 2014), which based on Tester (2005), the biggest advantage of using biomass material availability to create power system and electricity is that this source is the simplest to find because it is available everywhere in the globe. It is regarded as a viable feedstock for the manufacture of biofuel due to its low cost and availability, as well as the fact that it does not compete with food security. Biomass is a key contributor to both the agricultural sector and the forestry industry (Jothinathan, 2018). When compared to renewable energy fuels, biomass from animal waste sources, fuel wood, and other solid fuels may be obtained for free and because of this, a rise in wealth does not speed up the shift to contemporary energy solutions (Erdiwansyah et al., 2019). In addition to the time and money it takes to gather firewood, land degradation and deforestation have major financial consequences but this does not immediately influence the poor's consumption of fuel (Erdiwansyah et al., 2019).

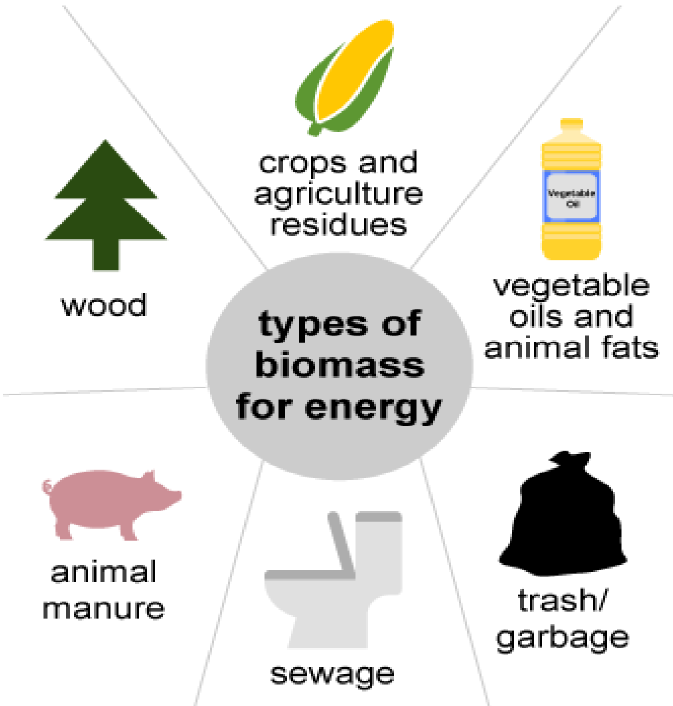

Figure 2.7 Type of biomass energy (Administration, 2023)

Table 2.1 Advantages and disadvantages of renewable energy and why it needs to be shift to biomass energy (Erdiwansyah et al., 2019)

Renewable energy source	**Advantages**	**Disadvantages**	**Needs to be shift to biomass energy**
Hydropower Energy	1. Clean and renewable energy sources 2. no greenhouse gas emissions 3. Reliable and consistent source of energy 4. Low operating costs 5. Can provide both power and waste management benefits	1. Expansive to builds 2. limited availability in some areas	Biomass energy is more widely available and versatile renewable energy source that can be use in wider range of location and circumstances.
Wind Energy	1. Clean and renewable energy sources 2. no greenhouse gas emissions 3. Abundant widely and available 4. low operating costs 5. Can be used on both small and large scales	1. Can be affected by weather patterns 2. Can be expansive to build and maintain 3. Can have limited availability in some areas	Provides more stables and reliable source of energy that is less dependent on weather patterns as well as more flexible sources of energy that can be used in wider range of applications
Solar energy	1. Clean and renewable sources 2. No greenhouse gas emission 3. abundant and widely available 4. Low-cost operation 5. can be used on large and small scales	1. Can be affected by weather pattern 2. Can be expansive 3. Can have limited availability in some areas 4. Can have negative impacts on environment	Biomass energy can provide a more stable and reliable sources of energy that less dependent on weather patterns as well as more flexible source of energy that be used in wider range of application.
Geothermal energy	1. Clean and renewable energy sources 2. no greenhouse gas emissions 3. can provides both heating and cooling benefits 4. Can be used in large and small scales 5. Can be reliable and consistent sources of energy	1. Can have negative environment impacts 2. Can be expansive to build and maintain 3. Can have limited availability in some areas	Biomass energy can provide a more widely available and versatile renewable energy sources that can be used in wider range of location and circumstances

Table 2.1 (Continued)

Renewable energy source	**Advantages**	**Disadvantages**	**Needs to be shift to biomass energy**
Biomass energy	1. Widely available and versatile 2. Can be used in variety application of application 3. Can provide both heat and power 4. Can be produced locally 5. Can help reduce waste and create jobs	1. Can be negative environmental impacts 2. Can be expansive to build and maintain 3. Can compete with food production and resources	N/A

The reason why the national need to shift to biomass energy is because it provides a more widely available and versatile renewable energy source that can be used in a wider range of locations and circumstances. Additionally, biomass energy can provide a more stable and reliable source of energy that is less dependent on weather patterns, as well as a more flexible source of energy that can be used in a wider range of applications. Furthermore, biomass energy can help reduce waste and create jobs, making it a valuable resource for sustainable development.

2.6 Microbial Fuel Cell

Microbial fuel cells (MFC) are a promising sustainable solution for meeting rising energy demands since they can cleanse wastewater and generate electricity while degrading harmful chemicals and contaminants (Raychaudhuri & Behera, 2020). Because it is able to transform the chemical energy that is present in organic and inorganic substances into electrical energy, MFC technology has developed into an appealing technology in today's world (Kumar et al., 2018). MFC have the ability to use a wide range of organics and inorganics as substrates, including organic wastes, lipids, carbohydrates, and proteins and also have a higher energy transformation efficiency than other technologies because they convert the chemical energy stored in the substrates into electrical energy (Pandit et al., 2021). This technology has the potential to not only lessen reliance on fossil fuels and the negative environmental implications that are linked with them, but also to offer a method that is environmentally friendly for the treatment of wastewater and electrical energy generation (Raychaudhuri & Behera, 2020). This is the environmentally friendly component of microbial fuel cells.

Electricity is produced directly from biowaste and organic stuff and this energy can be utilized to power the waste treatment facility or sold on the open market (Parkash, 2016). In addition, the produced electricity may be utilized to manufacture hydrogen gas (Mohd Zaini Makhtar & Tajarudin, 2020). For home, animal, brewery and food processing wastewater, MFCs have effectively removed organic pollutants and subsequently produced useful energy (electrical power or hydrogen gas) as a byproduct (Tekle & Demeke, 2015). The primary application of MFCs is the generation of electric current, and numerous efforts have been made to improve the current density and some of these efforts include modifications to the electrodes, new designs for MFCs, and the use of metal catalysts at both the anode and the cathode of the device (Kumar et al., 2018).

2.6.1 History of Microbial Fuel Cell

Luigi Galvani, an Italian doctor and physicist who studied the nature of electricity in animal tissue, was the first person to notice a bioelectric phenomenon (Flimban et al., 2019). He saw a frog leg twitch when he ran a short electrical current through it. After that discovery, the word "bioelectricity" was made up to describe it (Flimban et al., 2019). Friedrich Wilhelm Ostwald, one of the people who started the field of physical chemistry, did experiments in 1893 to find out how the different parts of a fuel cell work together and these parts include electrodes, electrolytes, oxidizing and reducing agents, anions, and cations (Flimban et al., 2019). Potter pioneered the initial MFC idea in 1910, using platinum electrodes to produce energy from live cultures of *Escherichia coli* and *Saccharomyces sp.* (Tekle & Demeke, 2015). In 1931, Cohen at Cambridge, UK, revived Potter's idea when he described how a batch of biological fuel cells generated over 35 mV, and the fuel cell concept gained popularity