The Study of Sustainable Waste to Energy Management for Community Power Plant

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Abstract

Waste-to-Energy (W2E) technologies are not only the way of disposing of Municipal Solid Waste Management (MSWM) but are also recognized as a clean and sustainable renewable energy (RE) source. In particular, the trend of net zero emissions is coming, so we must rapidly phase out fossil fuels as coal, oil, and gas will be replaced with renewable energy. Using fossil fuels for energy in the future is not an option. In this work, a hybrid system was to combine solar PV, anaerobic digestion (AD), and 3-Stage Gasification for energy recovery from waste. The system is in the Thailand Institute of Scientific and Technological Research (TISTR) at the Lamtakong Research Centre in Pakchong, Nakhon Ratchasima Province. It is designed to be able to handle 412 kW. This paper does a literature review of W2E technologies, does some experiments, and then look at the results to see how well they work. Furthermore, determine the best input for 3-Stage Gasification regarding technical constraints and the possibility of converting waste into energy. This study found that this small hybrid power plant is suitable for rural community power plants because of its flexibility regarding various input fuels, less social and environmental impact, less waste disposal, and easy operation. Therefore, this power plant can be a footprint for community power plants. Furthermore, it can be a commercial power plant in the future, which needs to be developed and studied more in detail as the simulation of the process and cost Analysis for upscaling the plant, Etc.

Keywords:

Waste-to-Energy; Net Zero Emission; Hybrid System; Anaerobic Digestion;Gasification

1. Introduction

Over the next two decades, the Thai government plans to increase the number of renewable energy power plants as the Alternative Energy Development Plan (AEDP) 2018, which has been incorporated into the Power Development Plan (PDP) 2018 Rev.1. In order to meet its energy needs, the government has set a target of increasing the share of renewable energy from its current 26% to 46% (including hydropower) of total energy consumption by the year 2037. And if we investigate electricity from each renewable source, electricity from Biomass will move from 3,267 MW to 6,763 MW 107% increase, electricity from waste will move from 273 MW to 717 MW 162% increase, and electricity from Biogas will move from 500 MW to 1,046 MW is 109% increase as shown in Fig.1 [1].

The increase the renewable energy power plants have an impact. A rise in atmospheric concentrations of greenhouse gases (GHGs) is the primary cause of climate change. Human activities, such as the burning of deforestation, agriculture for Biomass and livestock for Biogas, and waste deposition processes, are the primary contributors to the release of greenhouse gases into the atmosphere. The goal of Thailand's Climate Change Master Plan (2015-2050) [5] is to make the country more prepared to deal with the effects of climate change so that it can achieve sustainable development, low carbon growth, and climate change resilience by 2050. It focuses on the following missions: (i) enhancing the capacity of all sectors to withstand climate change through the implementation of coordinated policies and practices; (ii) developing emission-cutting strategies that promote long-term carbon-neutral development.; and (iii) getting ready to implement the master plan by improving the potential and awareness of stakeholders.

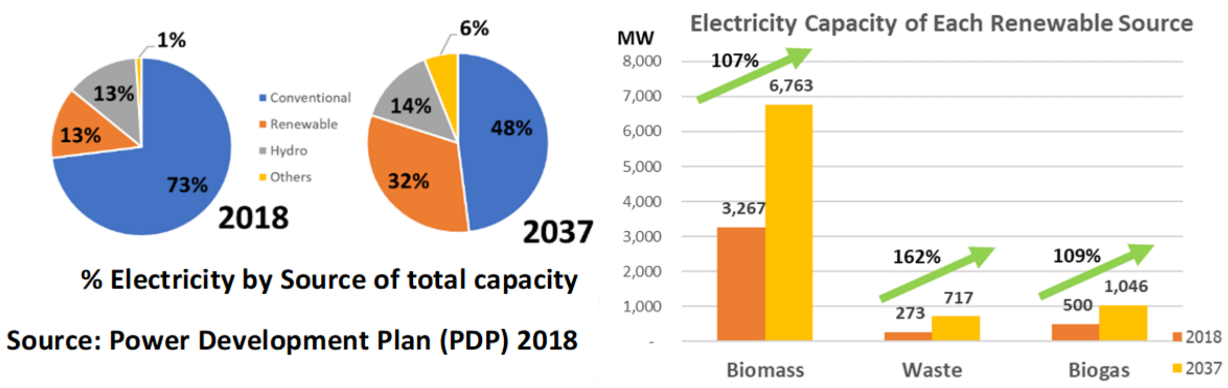

Fig.1 Electricity Capacity of Each Source for 2018 and 2037 [1].

The waste sector is the fourth most significant source of GHG emissions, accounting for 2.81% of the total in 2019. Most emissions come from combusting fuels (50.31%), followed by industrial processes (29.21%) and agriculture (17.68%) as shown in Fig.2 [2]. In the past, landfills and mass burning were the simplest ways to dispose of MSW. While the land will be scarcer in the future, landfills should be limited to MSWM because the overuse of landfills has led to the release of methane (CH_4), which is a higher global warming potential than CO_2. This change is attributed to the population increase and the shift in consumption patterns associated with GDP growth .

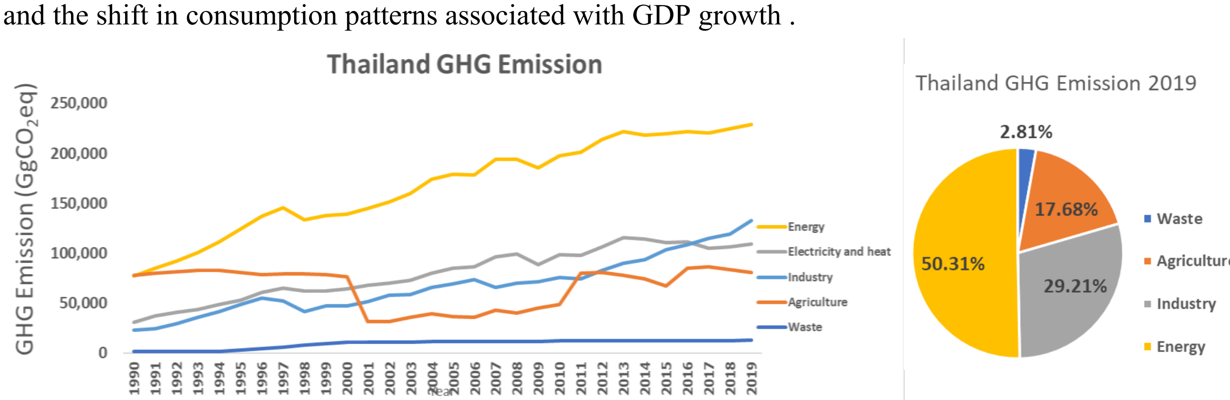

Fig. 2 Thailand GHG Emission [2].

Recycling municipal solid waste (MSW) presents logistical, technical, and financial challenges. There have been two main methods of trash removal used in the past. Both used landfills to dispose of MSW, but one burned their trash. Implementing the Municipal Solid Waste (MSW) provisions of Directive 2008/98/EC [3] requires using energy-from-waste generation technologies. "Waste-to-Energy" refers to the methods used to convert municipal solid waste (MSW) into usable thermal or electrical energy, such as combustion or the production of combustible fuels, methanol, ethanol, or synthetic fuels. The W2E generates clean energy and reduces GHG emissions. Partially meeting the energy demand and guaranteeing efficient MSWM, W2E is essential in combating many environmental problems, including global warming, and ensuring a steady supply of clean energy. Moreover, the utilization of MSW for energy as a resource can be combined with other resources such as solar Photovoltaics (PV), wind, hydro generation, and batteries in a hybrid system. W2E is the way to replace fossil fuel, which is the target of Net Zero Emission.

This paper aims to study the sustainable waste to Energy Management for Community Power Plants, which is now the policy of the Thai Government in PDP2018. This policy aims to help off-grid communities in Thailand generate their own electricity and reap economic benefits from the process. Specifically, this policy encourages using small-scale power plants to generate electricity using renewable fuels like biogas and biomass (less than 3 MW). This paper is organized into five sections. Section 1 is an introduction. Section 2 is a literature review on W2E. Section 3 is experimental investigation and analysis. Section 4 presents findings from the experiment. Section 5 is the conclusion.

2. Literature review on W2E

Disposal of municipal solid waste, also known as municipal solid waste management or MSWM, entails all the steps involved in waste management, from collection to disposal. This entails garbage picking, transportation, treatment, disposal, and subsequent monitoring and regulation. Waste management laws and regulations, including recycling regulations, are also included. Municipal (including institutional and commercial), agricultural, and social waste are all included under the umbrella term "waste," which also includes waste from the extraction of raw materials, the processing of those materials into intermediate and final products, and the consumption of those goods (healthcare, household hazardous waste, sewage sludge).

A form of waste management known as "mass burning" involves the controlled combustion of large quantities of solid organic waste, resulting in ash and gases. This process helps eliminate solid waste and waste left over from treating wastewater. This method can reduce solid waste volume by as much as 30 percent. "Thermal treatment" can refer to incineration or other high-temperature waste treatment systems. Waste incinerators release energy as heat, gas, steam, and ash. The emission of gaseous pollutants makes mass burning a contentious waste disposal method. Due to health and environmental concerns, incinerator emissions have been a source of controversy. Some persistent organic compounds, such as dioxins, furans, and polycyclic aromatic hydrocarbons, may be produced and severely affect the environment, so researchers are paying close attention.

The most efficient MSWM is waste-to-energy (W2E) conversion technology because it diverts garbage from landfills and turns it into valuable energy. The first W2E process is waste segregation, in which MSW must be separated using a systematic waste segregation method such as trommels, magnetic separation, or plastic separation. Separating biodegradable from non-biodegradable trash is possible. Biodegradable is the disintegration of materials by bacteria, fungi, or other biologicals as organic material or decomposable, which is used to be the raw material in biochemical processes. Moreover, non-biodegradable is used as the fuel of the thermo-chemical process as Refuse Derived Fuel (RDF). W2E has been identified as a viable resource and alternative to the waste generation problem. Biodegradable and non-biodegradable materials can be converted into thermal and biochemical energy sources [4]. Waste-to-resource processing has the potential to reduce greenhouse gas emissions from landfills by converting methane gas to carbon dioxide gas. This choice has been identified as a crucial component of effective waste and energy management. We can combine many energy sources from the utilization of MSW with other resources, such as solar PV or a wind turbine, as a hybrid system.

W2E technologies bring MSW to life through technologies that can be classified into five categories. as shown in Fig.3. Sorting machines and hand sorting must be used to separate recyclable waste for recycling, organic waste for biochemical processes, and RDF waste for thermo-chemical processes. Using organic decomposed waste for biochemical processes, there are two categories, including anaerobic digestion and hydrolysis fermentation. Using RDF as fuel for thermochemical processes, two categories are pyrolysis, steam turbine or incineration, and gasification.

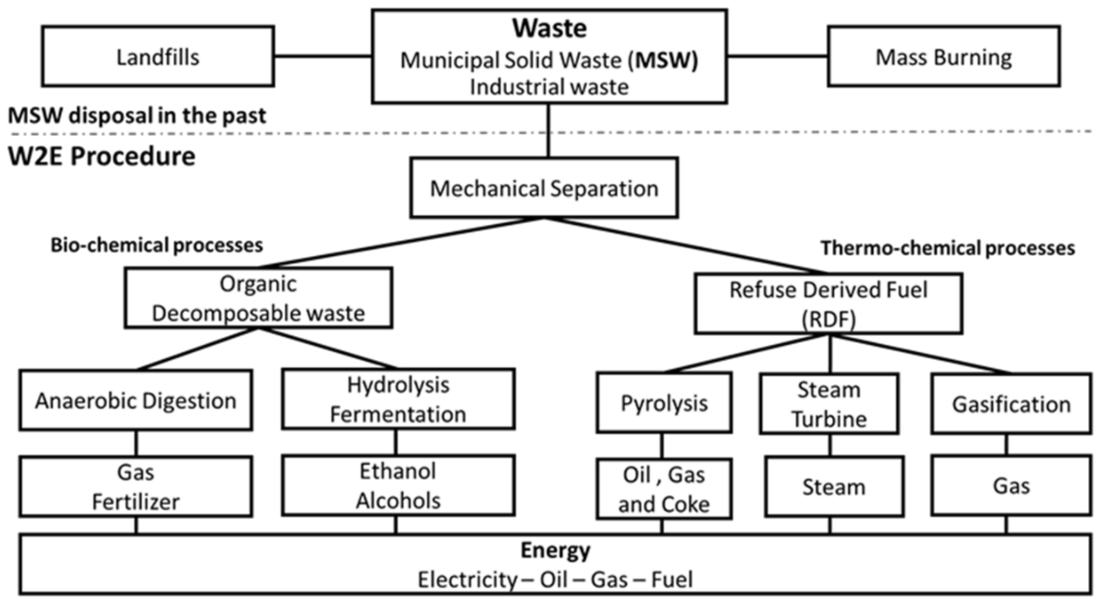

Fig. 3 W2E Technologies.

2.1. Anaerobic Digestion (AD)

The energy sector is increasingly interested in Biomass's anaerobic digestion (AD) [5]. Microorganisms break down biodegradable material into biogas in an oxygen-free biochemical process called anaerobic digestion. Methane (CH_4) accounts for 55–75% of the AD product biogas, while carbon dioxide (CO_2) makes up 30–45%. A gas engine turns the biogas into electricity, and the solid waste becomes fertilizer. The AD process has been used with various organic wastes, such as municipal solid waste, industrial organic waste, agricultural waste, and animal manure [6]. The advantages of AD-generated energy over competing renewable sources are numerous. Unlike wind and solar power, which depend highly on the weather, biogas generated by AD can be stored for later use. As a result, biomass power plants can reliably meet the nation's energy needs [7] as a hybrid system.

The produced biogas can also use in subsequent procedures. Fifty-five percent of all biogas produced is used to produce ammonia for fertilizer production, with hydrogen production in refineries coming in a close second [8]. pH, volatile acids/alkalinity ratio, inoculum-to-substrate ratio, temperature, hydraulic retention time, and non-ideal mixing conditions are some of AD's fundamental principles and operating parameters that have been extensively analysed and discussed. While anaerobic digestion (AD) has many benefits over traditional waste management techniques, there is room for advancement in the post-treatment of AD residue. Anaerobic digestion is superior to the heating and cooling processing stages regarding waste volume reduction. The residue from anaerobic digestion of anaerobic sludge may contain toxic microorganisms and heavy metals, rendering it unfit for direct landfill or further utilization as fertilizer. A significant amount of organic matter is still in the residue after the AD process is complete because the lignin fraction is resistant to breakdown by microorganisms.

2.2. Hydrolysis and Fermentation

To produce ethanol from sugars, a biochemical process called fermentation is required. In addition to ethanol, carbon dioxide is produced as a by-product of this reaction, useful in the Separated Hydrolysis and Fermentation (SHF) method of producing ethanol from cellulosic material [9].

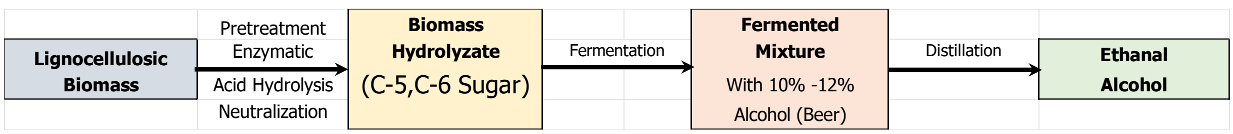

Fig. 4 The scheme of Separated Hydrolysis and Fermentation (SHF).

As seen in Fig.4, the configuration calls for a sequential process involving different units for the hydrolysis of cellulose and fermentation. This method uses Biomass hydrolysate or C-5 or C-6 sugar solutions via enzymatic or acid hydrolysis. The second step is fermentation, which takes place in a separate vessel from the sugar solution and last step is distillation which produce ethanol alcohol.

2.3. Pyrolysis

Pyrolysis is a thermochemical process that turns non-biodegradable materials, like used plastics, into oil and coke which can be used as fuel. Plastics are pyrolyzed, and condensed hydrocarbons are used as fuel. The process of reducing a substance to its constituent elements using heat and an inert gas such as nitrogen is known as pyrolysis. Plastics that can be converted into liquid fuel are put into a reactor and decomposed at temperatures ranging from 350 to 550°C. Carbonaceous matter gradually develops as a deposit on the inner surface of the reactor, depending on the pyrolysis conditions and the type of plastic used. The reactor's heat conduction efficiency would suffer if this deposit were left there. When the temperature inside the reactor reaches the reaction temperature, the waste plastics evaporate, leaving behind the resulting oil (a mixture of liquid hydrocarbons). Catalysts are used to crack the oil that has been evaporated even further. The boiling point of the oil depends on how well the reactor, cracker, and condenser function.

Depending on the end user's specific needs, distillation equipment may be set up to perform fractional distillation. Some of the resulting hydrocarbons, including those with high boiling points like diesel, kerosene and gasoline are condensed in a water-cooled condenser after being distilled from the reactor. Next, a receiver tank collects the liquid hydrocarbons before they are stored. The flare stack is used to incinerate gaseous hydrocarbons like methane, ethane, propylene and butanes which cannot be condensed. A flare stack is necessary when the amount of waste gas released from the reactor is large.

Methods of feeding waste plastic can vary according to their individual properties. The simplest option is to throw the trash plastic into the reactor [10].

2.4. Steam Turbine / Incineration

Incineration is a thermo-chemical process involving burning non-biodegradable materials to recover heat for the production of steam which can then be used to generate power via steam turbines, resulting in energy in the form of electricity. When burned, most fuel is turned into carbon dioxide and water vapor. Incomplete combustion of MSW also produces significant amounts of toxic dioxins, heavy metals, and gases containing chlorides, sulphur, nitrogen, and furans. Aqueous waste with a high moisture content, a low calorific value (CV), or chlorinated is not a good candidate for this technology. Adverse effects on net energy recovery occur when there is an abundance of moisture and static content, and additional fuel support may be necessary to maintain combustion. The norms for pollution control, including those about particulate matter (PM), nitrogen oxides (NO_x), sulphur oxides (NO_x), chlorinated compounds (HCl, dioxin), and emission standards are not met by this technology.

2.5. Gasification

Gasification is a thermal induced chemical reaction that produces gaseous fuel such as hydrogen and syngas. The gasification process, biomass is partially oxidized at high temperatures (500^{o}C-800^{o}C) to produce syngas, a gaseous mixture of hydrogen (H_2) 21%-30%, carbon monoxide (CO) 30%-60%, methane (CH_4) 0%-5%, and carbon dioxide (CO_2) 5%-15% [11]. Recycling biomass into usable energy is considered a viable option because it produces fewer emissions than traditional burning methods.

The fuel composition, gasifying medium, operating pressure, reactor temperature, equivalence ratio of O_2, moisture content of the feedstock, and gasifier design are all factors that affect the composition of the syngas produced [12] as shown in Fig.5.

The gasification reactor has 5 types as shown in Fig.6, In this project the reactor is 3-Stage Gasification reactor. The 3-Stage Gasification is designed as a down draft gasification for all types of municipal solid waste and any type of biomass despite differences in chemical composition and for producing a synthesis gas, less of tar and dioxins. The proposed 3-stage gasification scheme comprises of three stages as: a) pyrolysis, b) combustion and c) gasification as shown in Fig.7. The innovation of 3-stage gasification scheme is based on the fact that the transition between normal and reverse operation and vice versa is achieved only by setting the proper rotation and flow of air blowers, thus creating a new model of gaseous flow management between the three aforementioned stages. The presented model can achieve a safe industrial-scale operation while producing a gas free of harmful components. The proposed gasification model is validated as suitable for small-to-medium scale capacities, achieving an overall electrical efficiency of 30% and minimum environmental impacts well below all existing thresholds, including those set by the Directive 2000/76/EC on solid waste incineration. [13] Development of refuse-derived fuel (RDF) including gasification technology can pave way to reach a goal where municipal solid waste will no longer be viewed as waste material but instead as energy source that is sustainable. [15]

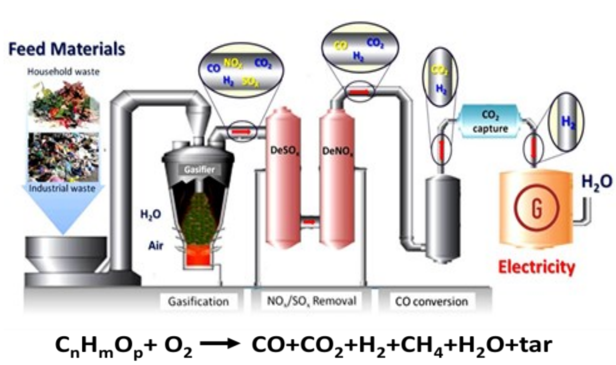

Fig. 5 The scheme of gasification.

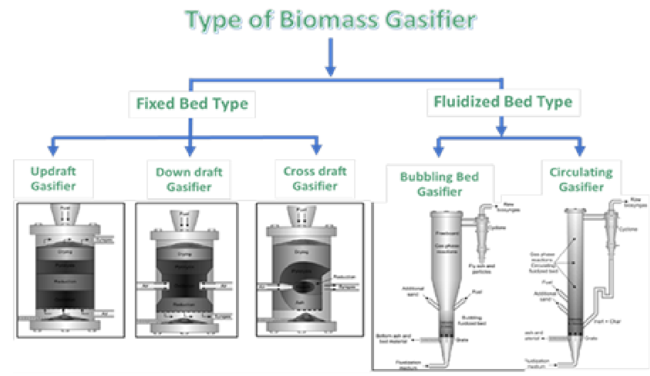

Fig. 6 Type of gasification reactors.

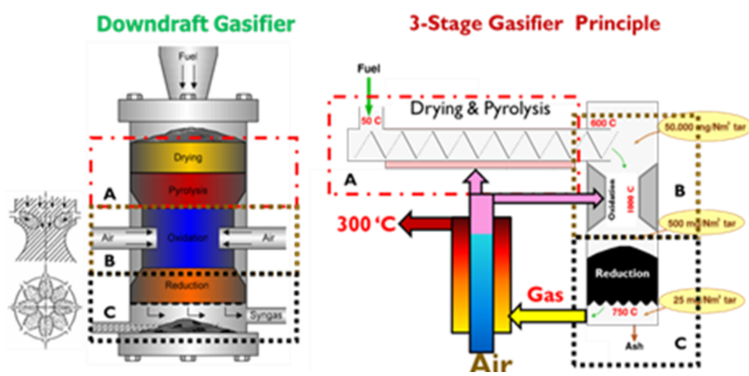

Fig.7 3-Stage Gasification scheme.

3. Material and Methods

3.1. System Description

The case study of the hybrid energy system at Lamtakong TISTR's research center in Pakchong, Nakhon Ratchasima Province, Thailand, is designed to produce 412 kW of electricity. The system combines three systems: 1st 200 kW AD Biogas (No.2 in Fig.8); 2nd 200 kW 3-Stage gasification (No.3 in Fig.8); and 3rd 12 kW Solar PV (No.4 in Fig.8). The hybrid system has a waste separator (No. 1 in Fig. 8) to separate recycled and organic waste, an RDF for raw materials (biogas and biomass) to make hybrid energy and have a waste-water treatment system to clean wastewater before letting it go back into nature. As shown in Fig.8.

Fig. 8 TISTR 's Hybrid Energy System.

3.2. Experimental Investigation and Analysis

3.2.1 MSW Sorting and Separator

The compositions of municipal solid waste (MSW) 86%, which can be recycled, are mainly organic waste (48%), paper (15%), plastic (14%), glass (5%), and metal (4%) and 14% which cannot be recycled as well. Moreover, through several processes, 70% of waste can generate cleaner and more economical energy. However, the first step is that MSW must be segregated by material into three categories: wet organic, dry organic, which are used for making fertilizer and RDF (plastic and paper), and leachate water from waste trucks. Then, the recycled material is sorted by humans through conveyors, magnetic separators for metal, plastic and paper RDF, and a trommel or drum screen. The Refuse Derived Fuel (RDF) is further subjected to being the fuel for gasification. Finally, wet and dry organics are used as the raw material in biochemical processes in leachate water, subjected to biogas production, or composted as fertilizer. The designed capacity for loading MSW in this project is 30 tons per day for the demonstration plant, and the size of the drum screen hole is 50 mm. which is suitable for screening RDF size as shown in Fig.9

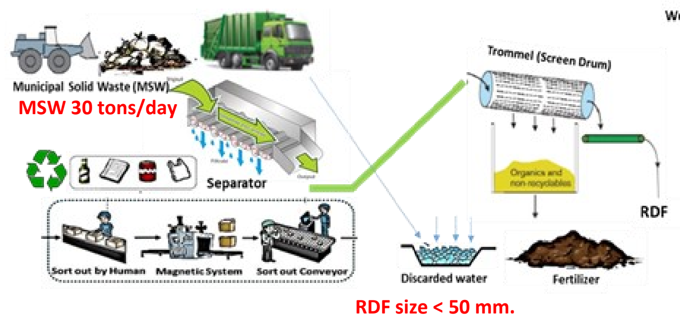

Fig. 9 Municipal Solid Waste (MSW) Separator.

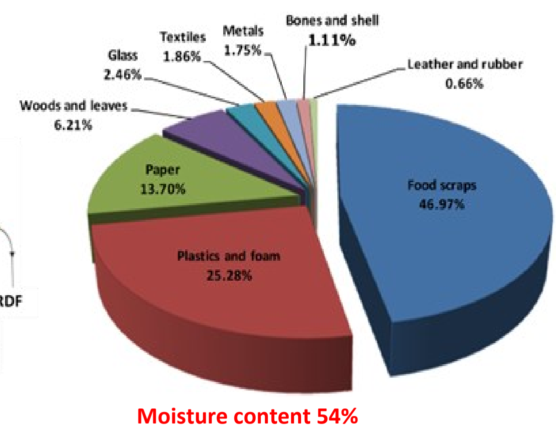

Fig. 10 Component of incoming MSW.

The components of incoming MSW are shown as in Fig.10. The production of this MSW sorting and separator systems, we can conclude the results are as follows:

- Recycle Material = 5% by Hand Sort
- RDF = 35%, Moisture 50% by Machine
- Organic = 30%, Moisture 54% by Machine
- Leachate Water = 70 Liters/10Tons Truck
- Electricity Cost = 40 THB/Ton MSW
- Total O&M Cost = 150 THB/Ton MSW

3.2.2 3-Stage Gasification System.

We discovered that 3-Stage Gasification Systems have an advantage in varying feedstocks such as woodchip, agriculture waste, and biomass, as well as an advantage in tar with less combustion [14]. As shown in Fig.11.

Biomass fuel will be transferred to the pyrolysis system by pneumatic conveyor to transform solid waste into fluid form and then transferred to the Char-Bed Gasifier to be combusted and turned to syngas. Dust will be transferred to the filter and turned into clean gas. This clean gas is fuel for electricity generation and can then be distributed to power plants.

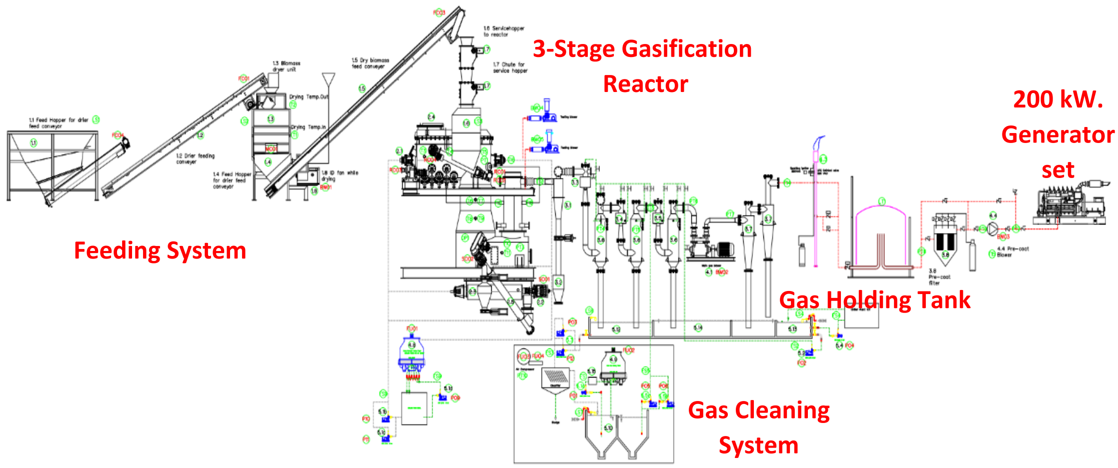

Fig.11 TISTR 200 kW 3-Stage Gasification system.

For this study, we need to find the optimization of load feed in terms of gas flow calorific value (CV) and components. The experiment used woodchip size not more than 50 mm., which keeps the outdoors dry, and the Lower Heating Value (LHV) is 3,800 Kcal/kg. The experiment varied the feedstock in six values: 100, 125, 150, 175, 200, and 225 kg/hr which each value operating the plant for 72 hours. The value of the gas component was measured using a Portable Syngas Analyzer "ETG" model MCA 100 Syn-P. The results are shown in the graph Figure 12 and Table 1.

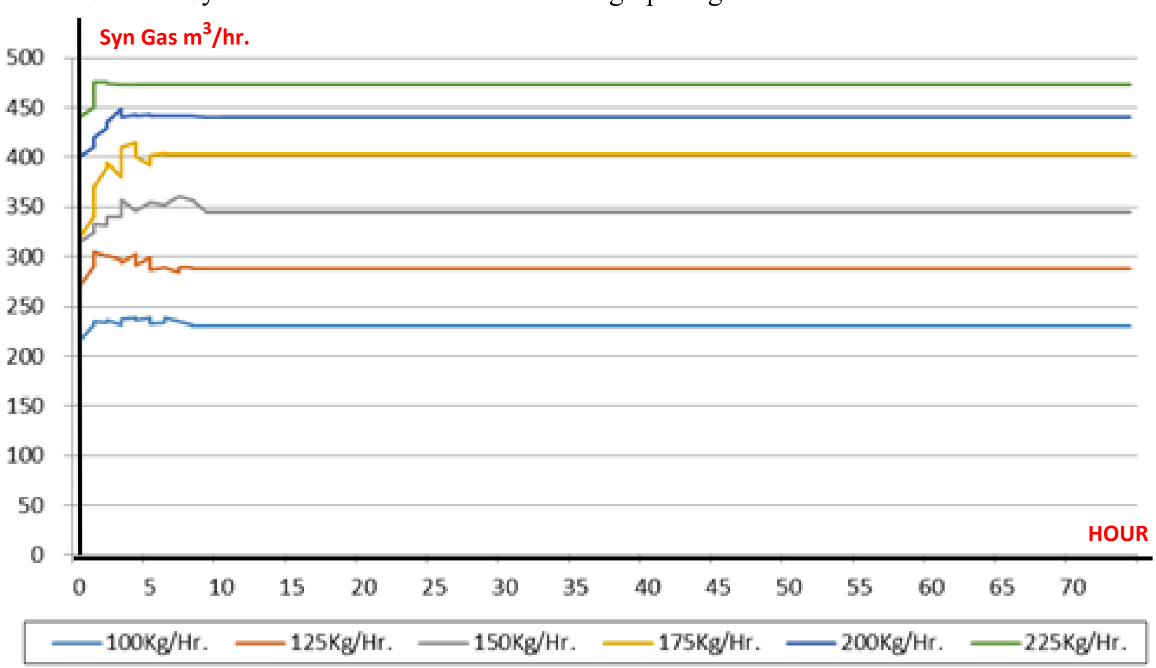

Fig.12 Fuel Feed rate and Gas Flow of TISTR 3-Stage Gasification system.

Average Gas Flow and Gas Components at Vary Feeding Wood Chip (LHV 3,800 kCal/kg)

Feed Rate (kg/hr)	Average Syn GaS (m^3/hr)	Average CV (MJ/m^3)	% Average Syn Gas Components						Reactor Efficiency
			CH_4 (%)	CO (%)	CO_2 (%)	O_2 (%)	H_2 (%)	N_2 (%)	
100	230.00	4.80	4.30	19.80	14.20	0.25	8.30	53.80	69.39%
125	287.50	4.90	4.40	19.80	13.80	0.25	8.30	53.10	70.83%
150	**345.00**	**5.00**	**4.50**	**20.60**	**13.70**	**0.23**	**8.30**	**52.50**	**72.28%**
175	402.00	5.00	4.70	19.60	14.80	0.23	8.40	52.50	72.19%
200	440.00	5.10	5.80	17.50	16.50	0.23	8.50	52.00	70.52%
225	472.00	5.20	6.30	16.50	17.50	0.23	8.70	51.30	68.63%

Efficiency of reactor = (Flow syn Gas X CV Syn gas) / (Fuel Feed Rate X Fuel LHV)

Table 1 Fuel Feed rate and Gas Flow of TISTR 3-Stage Gasification system.

From Table 1, the experiment revealed that the optimal fuel feedstock for this system is 150 kg/hr, which results in the best efficiency is 72.28%. The average flow of syngas is 345 m^3/hr. which results in the best efficiency of 72.28%, CO is 20.60% and the gas CV is 5 MJ/m^3. Synthetic gas 345 m^3/hr. is the fuel for 200-kW. Generator set. The electricity production cost from this 3-Stage Gasifier Plant is 3.30 THB/ kWh. At a fuel cost of 1,400 THB/Ton, in this experiment, the Tar value was measured at the site using liquid soluble equipment (Tar Measurement [14], and the Tar value of this experiment is 50 mg/m^3. For the following reasons, 3-stage gasification is biomass's most suitable combustion system.

- The system produces less Tar than another system that produces more than 200 mg/m^3; in this experiment, the Tar value was 50 mg/m^3 that can be reduced by increasing the oxygen generator instead of simple airflow.
- The system could be multi-feed stock in terms of loading multi-size and type of fuel. However, if we use RDF, which has more alkaline metal for fuel, we still need 20%- 25% of another biomass for cracking Tar.
- The system is easily comparable to others.
- The system has high efficiency because it has a controlled temperature and time for combustion in each stage.

3.2.3 Biogas System.

Fig.13 and 14 shows organic waste, such as food scraps, garbage, etc., will be collected by truck to the shredder machine (No.1). The shredded organic waste will be conveyed to the mixing tanks (No.2) and then filtered by Solid Screen and fed to the Anaerobic Baffled Reactor (ABR) (No.3). The ABR will hold the wastewater for 1-3 weeks or more, depending on operator requirements. The outcomes of ABR are biogas, wastewater, and sludge. Biogas will be first stored in the Gas Storage Pond (No.4). After that. Biogas will be cleaned by Bio Scrubber (No.5) and Cyclones (No.6). In some cases, the automatic gas flare (No.7) also provides for the elimination of unwanted gas and good gas is supplied to the 200-kW generator set (No.8). The effluent from ABR will be retreated by an aerobic system and a particular membrane reactor. Finally, the effluent is the treated water, ready for reuse.

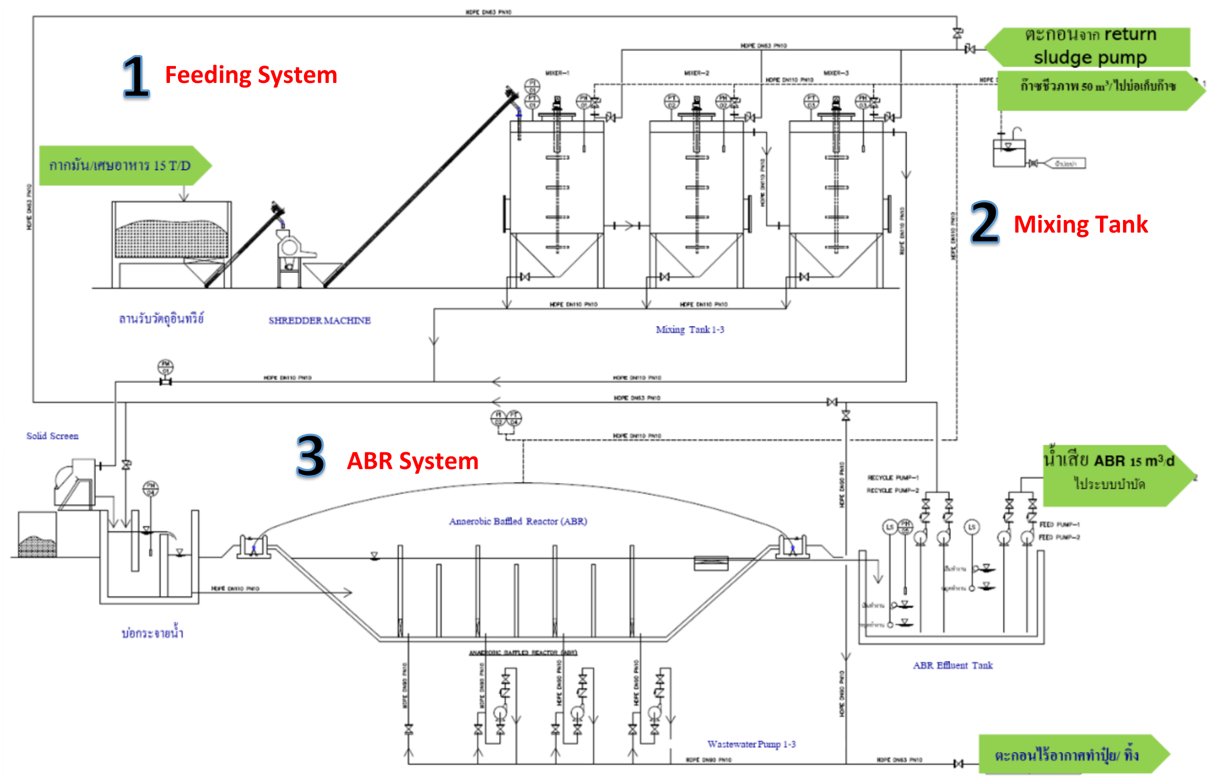

Fig.13 TISTR 200 kW. Biogas System Feeding & ABR system.

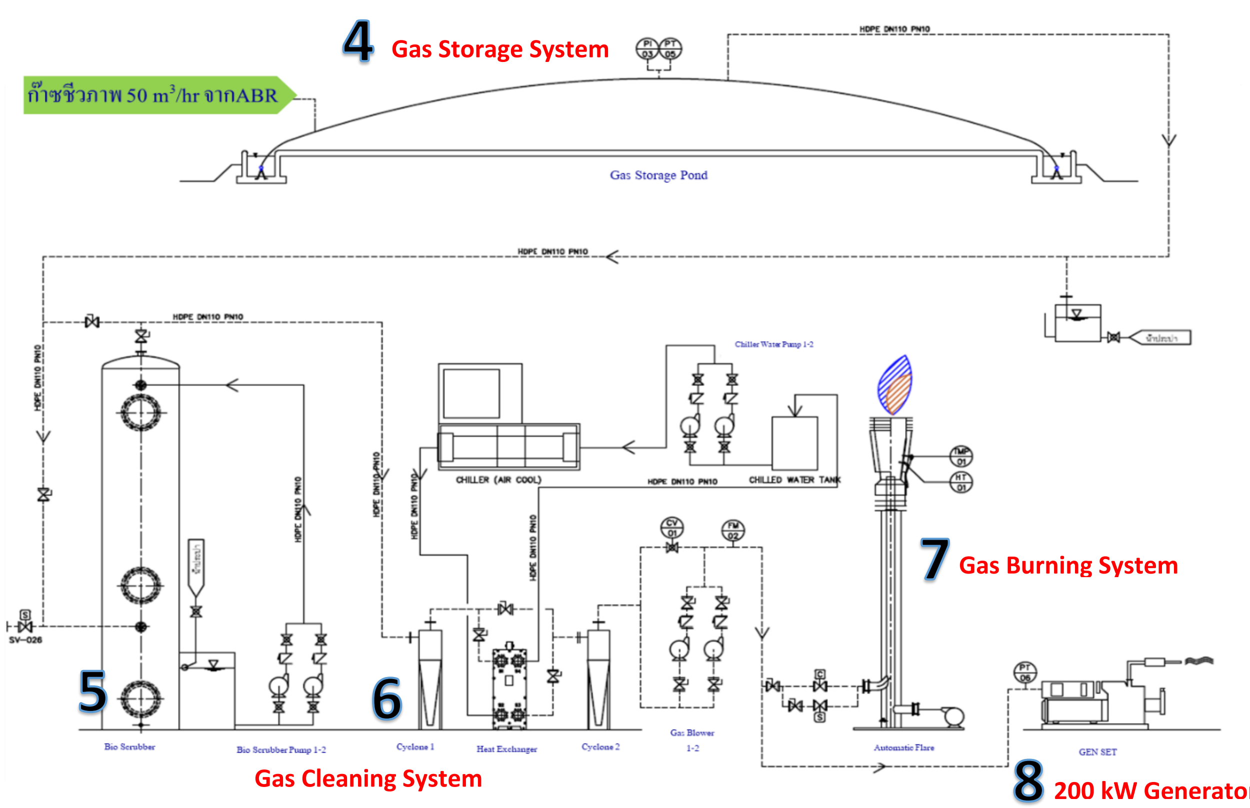

Fig.14 TISTR 200 kW. Biogas System Gas Storage & Gas cleaning and Generator.

In this case study, tapioca waste is decomposed into biogas by microorganisms in an oxygen-free environment in ABR. The ABR product biogas is composed primarily of methane (CH_4) 55.5%, carbon dioxide (CO_2) 23.9%, and H_2S 20ppm. Gas CV 21MJ/m^3 (as measured by Portable Biogas Analyzer MRU model OPTIMA7), and the capacity of the gas product is as follows.

Anaerobic digester (AD) Mixing tank 3 sets

- Flow rate 15 m^3/day
- Hydraulic detention time 3 days
- Size Dia.2.5 m x H 3.0 m. & Cone H 1.25m
- Volume 16.77 m^3/set
- pH control 6.5-7.5 at temperature < 40 °C

Anaerobic Baffled Reactor (ABR) Biogas production

- Flow rate 15 m^3/day
- Hydraulic detention time 107.98 days
- Influent COD 54,857 mg/l
- Effluent COD 2,194 mg/l
- Efficiency 96 %
- Biogas production 3,949.71 m^3/day at 60 % methane
- Size W 20 m. x L 38 m x D 4 m. (Effective depth 3.6 m)
- Slope (X:Y) 1.5:1
- Volume 1,619.71 m^3
- Gas Storage Pond 1,000 m^3
- Total volume 2,620 m^3
- Microbial name Pandora
- pH control 6.5-7.5 at temperature < 40 °C

The electricity production cost from this biogas plant is 1.80 THB/ kWh at organic biomass cost 5 THB/kg. Biogas systems have many designs for AD systems concerned with the type of input organic or biodegradable material in the form of leachate water. Because microorganisms decompose organics into biogas, they require high COD leachate water for a high yield and must also understand the operation and maintenance Biogas system. Another outcome from ABR, wastewater 0.625 m3/hr (COD 2,194 mg/l) is sent to the 2x500 m^3 Contract Aeration Process tank, then sludge and effluent are separated by Submersible membrane, the sludge is returned to the tank and wastewater is conducted to reservoir with COD < 120 mg/l.

3.2.4 Solar PV System.

Solar PV systems are "on-grid," meaning they only produce power when the utility power grid is on and do not have a backup battery. The "CSUN" Solar PV Module Polycrystalline 300 Watts x 44 sets are installed at the top of the control room. The total capacity is 13.5 kW. The "GROWATT" grid tie inverter model 1500 TL3-SL is 15 kW. In addition, a 3-phase 380-volt inverter is installed to convert and control the electricity. This can save electricity costs of 5,600 THB/per month (1,400 kWh per month) in the daytime but also help the system stabilize.

4. Conclusions

The experiment demonstrates that generating energy from municipal solid waste is possible. However, we must modify the various equipment to fit the process properly and identify the proper management process to operate and maintain the system. For instance, MSW sorting, and separator systems could sort the product according to market demand. RDF should be the right size for the power plant, relative humidity, and calorific value (CV). To achieve a high yield, such as increased recycling waste products, RDF, and cost savings, we must also evaluate our operation and maintenance systems. We must sort municipal solid waste to achieve our goal of zero waste disposal. Biogas systems have numerous designs for AD systems that consider the organic or biodegradable material introduced as leachate water input. Because microorganisms decompose organics into biogas, they require high COD leachate water for a high yield and must also comprehend the process's operation and maintenance Biogas system.

This study found that the cost per kilowatt-hour to generate electricity at this biogas plant is 1.80 THB/ kWh at 5 THB per kilogram for organic biomass, the electricity production cost from this 3-Stage Gasifier Plant is 3.30 THB/ kWh at a fuel cost of 1,400 THB/Ton biomass. In case the Hybrid system (AD biogas 200 kW,3-Stage Gasification 200 kW systems) is operated under the condition of operation 7,000 hours/year at 80% efficiency and 13.5 kW Solar PV then the production of electricity per year for this Hybrid system is 2,256.8 MWh and the average cost of electricity from this Hybrid system is 2.53 THB/kWh at a fuel cost of 1,400 THB/Ton biomass and organic biomass cost 5 THB/kg. Furthermore, biogas and 3-stage Gasification are the best solutions for community power plants because they are tiny power plants with easy-to-set-up and flexible feedstock such as local agricultural materials or waste from agriculture suitable for rural areas far away from the city. It, moreover, figured out the best inputs for 3-Stage Gasification regarding technical limits and the ability to turn waste into energy. From this study, we found that this small hybrid power plant is suitable for rural community power plants because of their flexibility in terms of various input fuels which we can find the fuel as waste in the local, friendly environment, less disposal of waste, zero fossil fuel and easy operation. This power plant can be a footprint for community power plants. It can be a commercial power plant in the future which needs to be developed and studied more in detail as the simulation of the process and cost analysis for upscale the plant. That means if we have a commercial community power plant that has good cooperation and participation with the community, sustainable waste-to-energy management will achieve significant results. This hybrid power plant is suitable for rural community power plants because of its flexibility regarding various input fuels follow up to local geography, easy to have community involvement, less social and environmental impact, less waste disposal, and easy operation. Which will be the way of Sustainable Waste to Energy Management for Community Power Plant in future.

References

[1] Energy Policy and Planning Office (EPPO). (2018). *Power Development Plan*. Thailand.

[2] CLIMATEWATCH. (n.d.). Historical GHG Emissions. Retrieved September 20,2023, from https://www.climatewatchdata.org/ghg-emissions?end_year=2020&start_year=1990.

[3] EUR-Lex. (2018). Directive 2008/98/EC of the European parliament and of the council of 19 November 2008 on waste and repealing certain Directives. Retrieved September 20,2023, from https://www.legislation.gov.uk/eudr/2008/98/contents

[4] Lal, B. & Sarma, M. P. (2011). Wealth from Waste: trends and technologies. (Third Edition). New Delhi, India: The Energy and Resources Institute.

[5] Demirbas, A. (2008). Biofuels sources, biofuel policy, biofuel economy and global biofuel projections. *Energy Conversion and Management, 49*(8), 2106-2116.

[6] Rawat, J., Kaalva, S., Rathore, V., G., D.T., & and Bhargava. (2016). Environmental Friendly Ways to Generate Renewable Energy from Municipal Solid Waste. *Procedia Environmental Sciences, 35,* 483–490.

[7] Evans, A., Strezov, V., & Evans, T.J. (2010). Sustainability considerations for electricity generation from biomass. *Renewable and Sustainable Energy Reviews, 14*(5), 1419-1427.

[8] Senneca, O. (2007). Kinetics of pyrolysis, combustion and gasification of three biomass fuels. *Fuel Processing Technology, 88*(1), 87-97.

[9] Ananda, S. A. (2013). *Handbook of Cellulosic Ethanol.* Massachusetts, USA: Wiley-Scrivener.

[10] Bridgwater, A.V. (2012). Review of fast pyrolysis of biomass and product upgrading. *Biomass and Bioenergy, 38*, 68-94.

[11] Knoef, H. (2005). *Handbook of biomass gasification. 2nd* ed. Enschede, NL: BTG Biomass Technology Group.

[12] Wang, L., Weller, C. L., & Jones, D. D. (2008). Contemporary issues in thermal gasification of biomass and its application to electricity and fuel production. *Biomass and Bioenergy, 32*(7), 573-581.

[13] Antonopoulos, I., Karagiannidis, A., Perkoulidis, G., & Elefsiniotis, L. *Development of an innovative 3-stage steady-bed gasifier for municipal solid waste and biomass, 92*(12), 2389-2396.

[14] van de Kamp, W., de Wild, P., Zielke, U., Suomalainen, M., Knoef, H., Good, J., Liliedahl, T., Unger, C., Whitehouse, M., Neeft, J., van de Hoek, H., & Kiel, J. (2005, October 17-21). *Tar measurement standard for sampling and analysis of tars and particles in biomass gasification product gas*. 14th European Biomass Conference & Exhibition, Paris, France.

[15] Yang, Y., Liew, R. K., Tamothran, A. M., Foong, S. Y., Yek, P. N. Y., Chia, P. W., Tran, T. V., Peng, W., & Lam, S. S. (2021). Gasification of refuse-derived fuel from municipal solid waste for energy production: a review. *Environmental Chemistry Letters, 19*, 2127–2140.