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A Sustainable Way to Generate Energy through Biomass Flash Pyrolysis in South Asia: A Green Energy Technology

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ABSTRACT

Asian Countries mostly lying in Subcontinent region are the main producers of Sugar canes. On the other hand, these are the developing countries which mostly face potential energy crisis which ultimately gives rise to sustainable electricity demand challenges. This challenge can be mitigated through the conventional way of bagasse-based cogeneration of power. Therefore, sugar industries can contribute in fulfilling at least their own requirement of plant electricity. But this method in turn produces carbon dioxide (CO_2) to the environment which is a major source of Green House gas (GHG) emissions globally. So, it is the most significant contributor to the global warming, which plays diverse impact on social, environmental, and economic costs. So far, the increasing concentrations of GHGs in the atmosphere are a notable issue. Biochar is one of the products of flash pyrolysis which reduces the GHG emissions and enhancement of soil fertility. This paper proposes flash pyrolysis as a sustainable way of meeting electricity demand with additional benefits over conventional way of burning bagasse in cogeneration, giving the environmental and economic benefits of pyrolysis. Bagasse gasification by flash pyrolysis in the sugar mills could be an alternative option for electricity generation with CO_2 negative impact.

Keywords: Bagasse, Renewable Energy, Biomass, Green Energy
JEL Classifications: Q2, Q3, Q4, Q5

1. INTRODUCTION

The availability of traditional fuels such as coal, petroleum, and other fossil fuels is limited by nature, and there will be a scarcity of them to meet current energy demand in the next decade, necessitating the development of alternative energy sources. Power shortages persist in countries such as India and Pakistan, which account for approximately 90% of south Asian electrical generation. Current generation is nearly 40% behind demand. By 2020, consumption from these countries is expected to be 1,350 billion kilowatt-hours (BkWh), up from 378 BkWh in 1996. (According to the Ministry of Agriculture and Natural Resources' report). In Pakistan, there are roughly 83 sugar mills that generate approximately 3.5 million metric tons of sugar per year and have a total crushing capacity of 597900TCD, which can create approximately 3000 MW during crop season (Djulius, 2017).

Bagasse has a gross potential availability of more than 67 million tons per year in India (MT). In India, the potential for bagasse cogeneration to generate electricity is projected to be roughly 34 TWh, or about 5575 MW in terms of plant capacity. Energy consumption is vast these days, and it is a significant important aspect in a country's development, and energy scarcity has become a financial danger for countries all over the world (Kusumo et al., 2017). "Energy is a basic aspect of our existence," it is said. The dream of financial development is impossible without energy.

Despite its critical role, however, not everyone approaches today's vitality administrations' (Habibullah et al., 2015). Because of people's development and growing financial and scientific improvement around the world, the current energy requirement is on the rise. People are still relying on traditional energy sources. As a result, the rate of development of other alternative energy resources can help to reduce the use of traditional fuels by lowering their consumption (Jahirul et al., 2012) On the other hand, the world's warming is getting worse by the day. The CO_2 level in the air has surpassed the dangerous threshold that was predicted to be reached in another 10 years. Furthermore, the depletion of nonrenewable energy sources and the dramatic change in the atmosphere have fueled the quest of elective energies and sustainable power sources so that, the energy demands of the world can be met, reduce ozone-depleting substance discharges, control pollution and maintain the planet's temperature at a constant level (Basu, 2010).

Biomass, among the other energy sources, has the potential to become a viable sustainable energy source due to its wide variety and accessibility. Biomass is made up of biodegradable organic material such as animal waste, plants, agricultural waste, and municipal trash, among other things. Biomass is the third most important source of energy for both power and heating. Agricultural waste, sugarcane bagasse, wood waste, and animal waste are the most well-known biomass feedstocks. Biomass is a mixture of natural resources and trace amounts of minerals that also comprises carbon, oxygen, hydrogen, nitrogen, Sulphur and chlorine (Saletnik, 2018). Pyrolysis is a type of heat breakdown that occurs without the need of oxygen. Pyrolysis is the first step in the ignition and gasification process, followed by aggregation or optional oxidation of key elements. Gasification is a method of generating electricity by burning natural materials in the presence of limited oxygen. Natural resources are used in the ageing process to deliver liquor, which is then controlled in vehicles with the help of yeast. Anaerobic decomposition is a method for supplying biogas while also producing power. This paper focuses more on biogases as main source of for energy production with effective use of pyrolysis technology in the developing countries like India and Pakistan to reduce the CO_2 emissions towards CO_2 negative to move towards a green energy technology.

2. BACKGROUND

2.1. Biochar

Biochar is an excellent soil conditioner. It is a product of pyrolysis of biomass and is full of carbon. Animal dung, timber, water waste, and crop leftovers are all examples of biomass. In addition to being an excellent soil amendment for increasing crop yields. Because biochar is carbon-negative, it can be utilized to actively remove carbon dioxide from the atmosphere when combined with sustainable biomass production. This, in turn, has the potential to have a significant impact on climate change mitigation.

2.2. Benefits of Biochar

Following are few comprehensive benefits of Biochar:

1. In many places of the world, soil improvement is not only a luxury, but a need. The usage of gases released during the pyrolysis process can also be used to combine biochar and bioenergy production (Aslam et al., 2014).
2. A considerable amount of crop wastes from agriculture, as well as animal wastes from dairy and poultry farms, contribute to dangerous ground and surface water contamination. By-products of the pyrolysis process, such as these wastes, have become a valuable resource for producing bioenergy. This also aids in minimizing the time-consuming management of large volumes and weights of waste. As a result, if properly managed, organic wastes can be beneficial. It can be beneficial in reducing the emission due to recycling and waste reduction, reducing the effort/energy used in long distance transport of waste to dump it and indirectly in lessening the climate change by decreasing the methane emission from the landfills (Bridgwater, 2013).
3. It has been proved in many experiments and researches that biochar increases the soil fertility and nutrient retention (Al Arni, 2018). The existence of biochar makes the soil a Carbon enhanced Soil Organic Matter (SOM).

The characteristics of SOM are that it:

- Improves water infiltration and water holding capacity (Luo et al., 2008).
- Enhances cation exchange capacity (Sohi et al., 2009).
- Increases in ammonium ions and soil damaging pesticides absorption (Hawkins et al., 2007)
- Increases soil biological activity such as moisture content, pH, labile C and N pool sizes and structural stability such as soil porosity which in turn reduces fertilizer runoff (Stavi, 2013).
- Gives neutralization of natural toxins in decomposing organic materials and increase in organic content (Novak et al., 2010).
- Works as a CO_2 sink (Oo. 2018). Plant material must be partially burned to make Biochar. In this partial burning, a portion of the carbon collected by the plant (during its growth) is released instantly. More than half of the carbon can be preserved in its new form as biochar (Shoaib et al., 2017). The energy emitted by the plant material during this process can be collected and utilized as heat or electricity in its purest form. Creating transportable liquid fuels similar to petroleum products is still a difficult task, but it is one of the options. Today, there are technologies that create both energy and high-quality biochar (Sohi 2010).
- Since the industrial revolution, the accumulation of GHGs has intensified the greenhouse effect, hence, it increases the global temperature and contributes in climate change. Many greenhouse gases, such as carbon dioxide, methane, water vapor, and nitrous oxide, are produced artificially in the atmosphere (Shareef, 2016). CO_2 is a key contributor to Green House Gases (GHGs), and its concentration in the atmosphere is steadily growing (Shen, 2018). Intensive agriculture is one of the biggest causes to the growth in GHGs (Melillo, 2002). Approximately 12% of annual GHG emissions come directly from soil, with soil accounting for 39% (Mofijur et al., 2013; Scott, 1984). The impact of Biochar on carbon exchange in various ecosystems throughout the world has yet to be fully assessed. The short- and medium-term impacts of biochar on CO_2 emissions from semiarid farms were investigated in (Shen et al., 2017) experiments based on laboratory and a 2-year field investigation. There was no rise in biochar soil during the course of the 46-day trial, but there was a considerable increase in CO_2 emissions with the addition of nitrogen to the soil. In semiarid

farms, soil temperature impacts more than soil water content, suggesting that biochar amendment is a better management approach to assist maintain or improve carbon sequestration with fewer CO_2 emissions and higher dry matter production over a longer period (Naomi et al., 2019). Figure 1 give a concise overview of the benefits of Biochar on the environment.

3. PYLROLYSIS OF BIOMASS

Biomass is a renewable energy source that is readily available all over the world. The relatively successful use of petroleum derivatives and atomic energy can be replaced by the sustainable use of biomass energy. Biomass energy is used by the rural public in emerging countries, which account for roughly half of the world's population (Rahimi et al., 2021; Yogalakshmi et al., 2022). Biomass aids the globe in achieving its greenhouse gas reduction goals. Biomass can now be used as a sustainable power source with low outflows and natural consequences because to increased accessibility and technological breakthroughs in recent years. Biogas, biofluid, and biochar are all examples of biomass energy. It is commonly used to replace petroleum-based products in electricity and transportation. It is regarded as a long-term power source because the energy is mostly derived from the sun and it requires only a short length of time to regenerate (Lee et al., 2022). The thermal decomposition of solid fuels, which includes the breakage of carbon–carbon bonds and the formation of carbon–oxygen bonds, is the most prominent feature of the pyrolysis process. Despite the fact that it is usually done at much higher temperatures, pyrolysis necessitates temperatures of up to 400-550°C.

3.1. Sources of Bio Mass

Figure 2 depicts agricultural goods and leftovers, animal residues, sea garbage, municipal solid waste, sewage from chicken manure, biogases, and other biomass sources. Biomass is a flexible feedstock in terms of morphology and physical qualities. It could be highly wet or dry, thick or soft, cinder-rich or cinder-free, little or huge, homogeneous or inhomogeneous, and so on (Erixno et al., 2022). This makes employing biomass fuels in specialized gasifier reactors problematic, and biomass pretreatment is usually necessary in most cases. Physical and chemical properties of pyrolysis feedstocks are becoming increasingly relevant (Li et al., 2021).

The maximum biochar yields are obtained when feedstocks with a high lignin content are pyrolyzed at moderate temperatures (about 500°C). Fixed carbon concentrations, wetness, unstable issue, and slag content are all indicators of pyrolysis item yields. Fixed carbon improves the creation of biochar, while biomass with a lot of variability produces a lot of syngas and bio-oil.

3.2. Pyrolysis

Pyrolysis is a process in which biomass is heated in a confined container with little or no air (Sridhar, 2021). Pyrolysis is the chemical decomposition of organic molecules at high temperatures in the absence of oxygen. The procedure is commonly carried out at temperatures over 430°C and under pressure (Ayyadurai, 2022). It is an irreversible process involving both a physical phase transition and a chemical composition change. Pyrolysis is derived from the Greek words "pyro" for "fire' and "lysis" for "separation." Pyrolysis does not necessitate the use of water, oxygen, or any other reagents. However, because an oxygen-free environment is extremely impossible to achieve, oxidation occurs in every pyrolysis system. The decomposition reaction is the most basic idea in pyrolysis (Calixto, 2022). A decomposition reaction is a chemical reaction in which a single compound is broken down into two or more components or new compounds. To break apart the bonds of molecules, these reactions typically require an energy source, such as heat, light, or electricity. As seen in Figure 3, if ammonium nitrate is the predominant chemical, it will break down into two elements i.e. dinitrogen monoxide and water.

Figure 1: Benefits of bio char

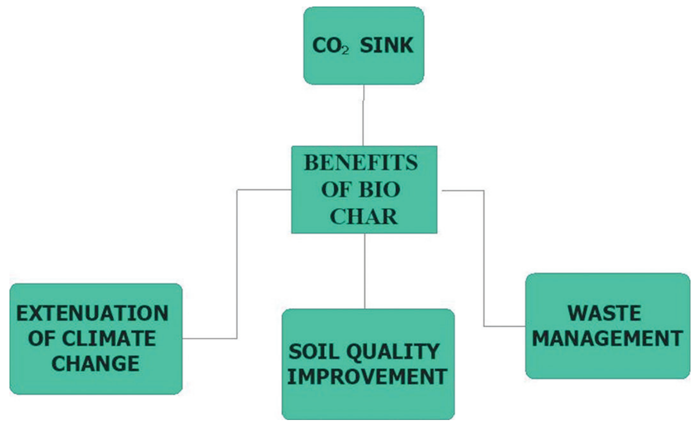


Figure 2: Sources of biomass

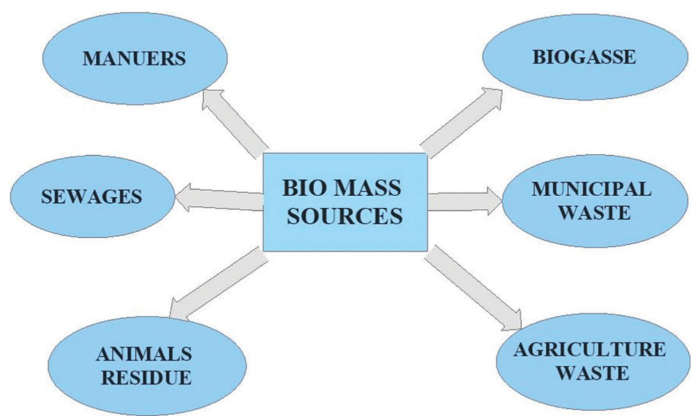


Figure 3: Decomposition process of molecules

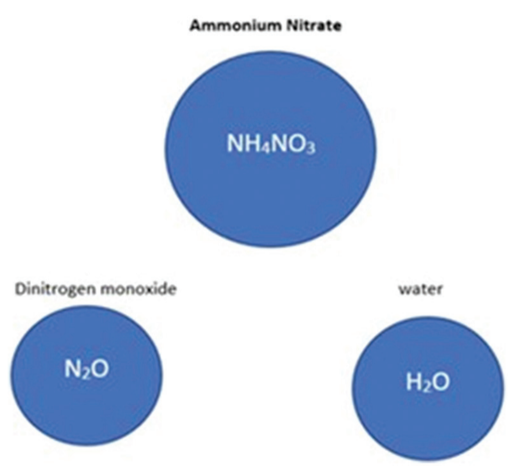


Figure 4: Pyrolysis setup

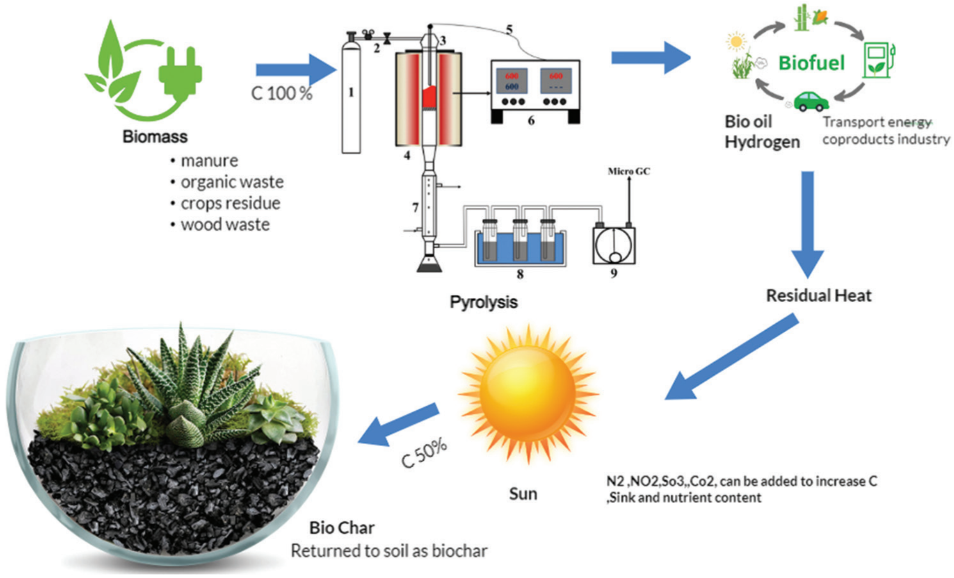
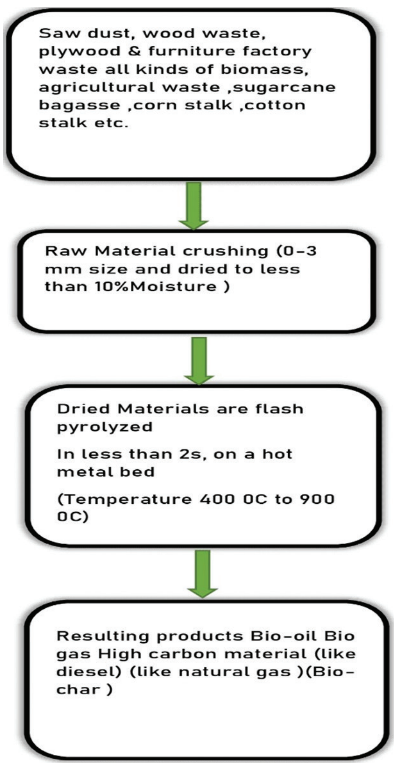


Figure 5: Steps involved in flash pyrolysis



In general, there are following 4 methods of thermochemical conversion of biomass,
1. Biomass Gasification
2. Biomass Direct Liquefaction
3. Biomass Combustion
4. Biomass Pyrolysis

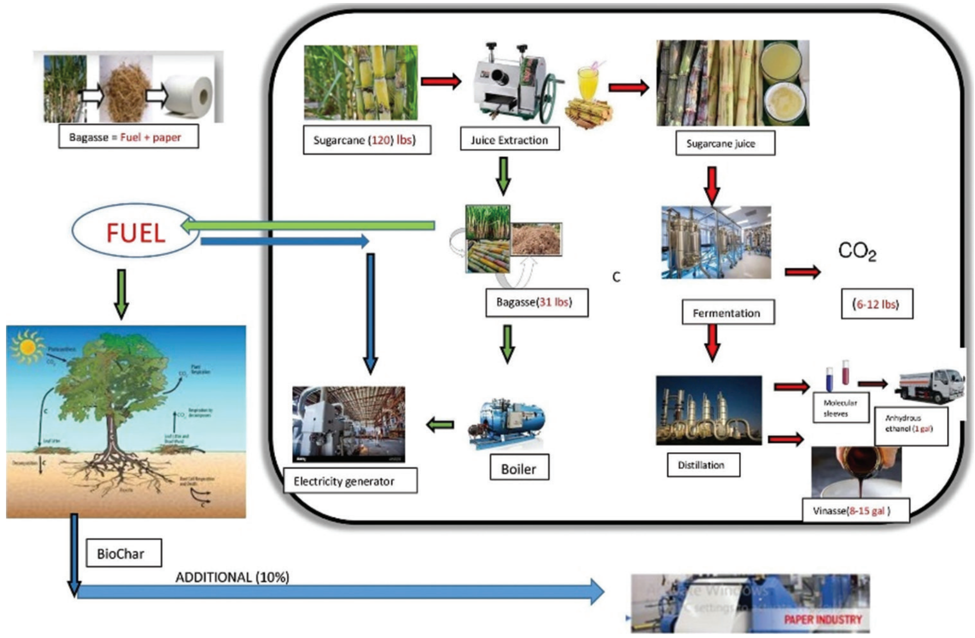
Among these techniques are: Isn't biomass pyrolysis the most efficient and advantageous method? Pyrolysis is a thermochemical reaction that takes place in the absence of oxygen at temperatures ranging from 400 to 600°C. Bio-oil, bio-gases, and biochar are all produced as a result of the process (Michailos, 2021). The kind and composition of the output will be determined by the process's pressure, temperature, and heating rate. Figure 4 shows the setup of pyrolysis (Abuelnour et al., 2020).

3.3. Steps of Pyrolysis

Combustion, breakdown processes, mass transfer, mixing with O_2, and combust are the many steps involved in the pyrolysis process. The first phase is combustion, which is the act of burning; the second step is the breakdown of a single compound into two or more elements or new compounds; mass transfer happens in processes such as absorption, evaporation, and drying. After this, oxygen is mixed in, and lastly, burning occurs, which is referred to as combust. The process of Pyrolysis is categorized in 3 types: conventional/slow pyrolysis, fast pyrolysis, and ultra-fast also called as flash pyrolysis.

1. Conventional/slow pyrolysis: the pyrolysis process includes numerous phases such as combustion, breakdown processes, mass transfer, combining with O_2, and combust. The first phase is combustion, which is the act of burning; the second phase is the breakdown of a single compound into two or more elements or new compounds; and the third phase is mass transfer, which is accomplished through processes such as absorption, evaporation, and drying (Zhang et al., 2021). After that, oxygen is added, and finally, combustion happens, which is known as combust.
2. Fast pyrolysis: The process of fast pyrolysis is primarily utilized to create bio-oil and gas. Depending on the amount of bio-oil or gas products sought, biomass is rapidly heated to temperatures ranging from 650 to 1000°C during the process. Char accumulates in significant quantities and must be removed on a regular basis (Wang et al., 2021).
3. Flash pyrolysis: Rapid heating rates and moderate temperatures between 400 and 900°C are used in flash pyrolysis. This method, however, has a vapor residence duration of <2 s. Flash pyrolysis yields less gas and tar while producing more charcoal. Figure 5 depicts the

Figure 6: Process in sugar factory



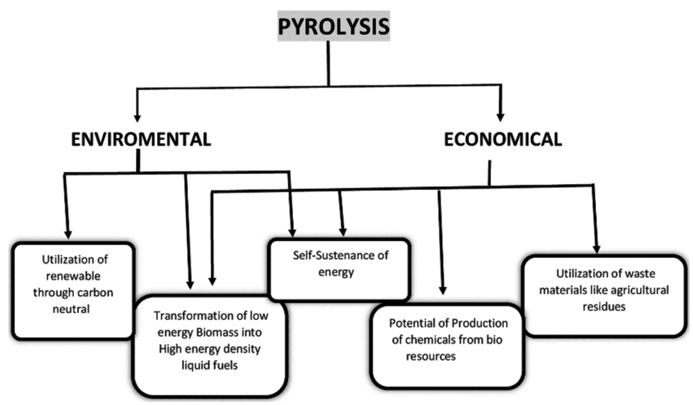
many stages involved in flash pyrolysis. In boilers, glass melting units, steel rolling mill re-heating furnaces, iron ore palletization plants, alumina sintering plants, aluminum and copper melting units, refractory ceramic kilns, DRI making tunnel kilns, and other applications that require high-temperature gases, flash pyrolysis is used to replace natural gas and furnace oil. For some thermal applications, the investment will pay off within a year (Amenaghawon et al., 2021). It is used by sugar mills, rice mills, and independent power plants to produce electricity at half the present cost. Syn-oil and high-carbon materials can recover 50% of the raw material's cost. Electricity can be generated in one of two ways: traditional boiler-turbine technology or low-RPM gas generators with capacities ranging from 0.3 MW to 1 MW. Figure 5 explains various steps involved in flash pyrolysis.

3.4. Application of Pyrolysis

Figure 6 shows different process in sugar factory and utilization of waste. Heat is primarily necessary here for boilers to heat the juice. Bagasse generates heat, which results in the production of CO_2, which is then released into the atmosphere, increasing pollution levels. The majority of the factories claim to be CO_2 neutral. However, if this traditional boiler heating is replaced with flash pyrolysis, CO_2 neutral can be turned to CO_2 negative, reducing pollution and making the environment greener.

The author of [9] has offered a comparison of two forms of pyrolysis from bagasse to syngas (synthesis gas, the major product created by biomass gasification). They discovered that high-temperature fast pyrolysis favors hydrogen production, slow pyrolysis favors syngas production, and fast pyrolysis favors char creation. Figure 7 gives the environmental and economic benefits of pyrolysis.

Figure 7: Benefits of pyrolysis



4. CONCLUSION AND FUTURE SCOPE

Presently bagasse is used as fuel and directly fired in the furnaces in the sugar industries and cogeneration plants and proved to have been technically feasible, economically viable for current scenario of sugar industries. In comparison with existing technology of sugar industries and cogeneration plants, pyrolysis process for producing heat energy, electricity and additional benefit of biochar with CO_2 negative impact on environment will be the most economical, technology feasible, environment friendly. Further biochar produced from sugarcane bagasse by pyrolysis into soils have great future potential for improving soils properties, fertility and promoting plant growth.

The use of pyrolysis plant for producing biochar is flexible, any kind of feedstocks and animal manures could be pyrolyzed at different temperatures. Since biochar produced from bagasse is amorphous, containing sufficient amount of phosphorus and carbon structure formed during pyrolysis of organic matter results in a high porosity. Due to its porous nature porosity of soil and further develops microorganisms in the soil which further takes parts in increase fertility of soil. The phosphorus contains in the BC produced from sugarcane bagasse is less as compared to BC produced from animal manure. In nutshell bagasse pyrolysis plants with initial investment and technical modification in sugar industries can be great potential to meet the future demand of energy and electricity of countries with additional benefit of biochar as a fertilizer and reducing greenhouse effect of environment.

REFERENCES

Abuelnour, A.A., Abuelnour, M.A., Ali, M.A., Ahmed, M.A. (2020), Experimental study on Pyrolysis of Sugarcane Bagasse for Bioenergy Production. In: 2020 International Conference on Computer Control Electrical, and Electronics Engineering (ICCCEEE). IEEE, p.1-6.

Al Arni, S. (2018), Comparison of slow and fast pyrolysis for converting biomass into fuel. Renewable Energy, 124, 197-201.

Amenaghawon, A.N., Anyalewechi, C.L., Okieimen, C.O., Kusuma, H.S. (2021), Biomass pyrolysis technologies for value-added products: A state-of-the-art review. Environment Development and Sustainability, 23(10), 14324-14378.

Aslam, Z., Khalid, M., Aon, M. (2014), Impact of biochar on soil physical properties. Scholarly Journal of Agricultural Science, 4(5), 280-284.

Ayyadurai, S., Arunachalam, K.D. (2022), Experimental investigations on sugarcane bagasse pyrolytic oil production from flash pyrolysis using a rotary screw reactor. Biofuels, Bioproducts and Biorefining, 16(2), 576-586.

Basu, P. (2010), Biomass Gasification and Pyrolysis: Practical Design and Theory. Cambridge: Academic Press.

Bridgwater, A.V. (2003), Renewable fuels and chemicals by thermal processing of biomass. Chemical Engineering Journal, 91(2-3), 87-102.

Calixto, G.Q., Melo, D., Melo, M.A., Braga, R.M. (2022), Analytical pyrolysis (Py-GC/MS) of corn stover, bean pod, sugarcane bagasse, and pineapple crown leaves for biorefining. Brazilian Journal of Chemical Engineering, 39(1), 137-146.

Djulius, H. (2017), Energy use, trade openness, and exchange rate impact on foreign direct investment in Indonesia. International Journal of Energy Economics and Policy, 7(5), 166-170.

Erixno, O., Rahim, N.A., Ramadhani, F., Adzman, N.N. (2022), Energy management of renewable energy-based combined heat and power systems: A review. Sustainable Energy Technologies and Assessments, 51, 101944.

Habibullah, M., Masjuki, H.H., Kalam, M.A., Rahman, S.A., Mofijur, M., Mobarak, H. M., Ashraful, A.M. (2015), Potential of biodiesel as a renewable energy source in Bangladesh. Renewable and Sustainable Energy Reviews, 50, 819-834.

Hawkins, R., Nilsson, J., Oglesby, R., Day, D. (2007), Utilization of Biomass Pyrolysis for Energy Production, Soil Fertility and Carbon Sequestration. UN Commission on Sustainable Development Partnerships Fair-Partnership in New Technologies for Small Island Developing States.

Jahirul, M.I., Rasul, M.G., Chowdhury, A.A., Ashwath, N. (2012), Biofuels production through biomass pyrolysis-a technological review. Energies, 5(12), 4952-5001.

Kusumo, F., Silitonga, A.S., Ong, H.C., Masjuki, H.H., Mahlia, T.M.I. (2017), A comparative study of ultrasound and infrared transesterification of *Sterculia foetida* oil for biodiesel production. Energy Sources Part A Recovery Utilization and Environmental Effects, 39(13), 1339-1346.

Lee, T., Jung, S., Kim, K.H., Kwon, E.E. (2021), Catalytic pyrolysis of pine bark over Ni/SiO_2 in a CO_2 atmosphere. Energy, 220, 119827.

Li, H., Chi, H., Hu, S., Wang, Y., Song, G., Abdulmajid, A.S., Xiang, J. (2021), Comprehensive study on intrinsic combustion behavior of non-premixed coal-biomass pellet at rapid heating rate. Fuel, 287, 119496.

Luo, W., Lu, Y., Wang, G., Shi, Y., Wang, T., Giesy, J.P. (2008), Distribution and availability of arsenic in soils from the industrialized urban area of Beijing, China. Chemosphere, 72(5), 797-802.

Melillo, J.M., Steudler, P.A., Aber, J.D., Newkirk, K., Lux, H., Bowles, F.P., Morrisseau, S. (2002), Soil warming and carbon-cycle feedbacks to the climate system. Science, 298(5601), 2173-2176.

Michailos, S. (2021), Kinetic modelling and dynamic sensitivity analysis of a fast pyrolysis fluidised bed reactor for bagasse exploitation. Biofuels, 12(2), 161-170.

Mofijur, M., Masjuki, H.H., Kalam, M.A., Atabani, A.E., Shahabuddin, M., Palash, S.M., Hazrat, M.A. (2013), Effect of biodiesel from various feedstocks on combustion characteristics, engine durability and materials compatibility: A review. Renewable and Sustainable Energy Reviews, 28, 441-455.

Namoi, N., Pelster, D., Rosenstock, T.S., Mwangi, L., Kamau, S., Mutuo, P., Barrios, E. (2019), Earthworms regulate ability of biochar to mitigate CO_2 and N_2O emissions from a tropical soil. Applied Soil Ecology, 140, 57-67.

Novak, J.M., Busscher, W.J., Watts, D.W., Laird, D.A., Ahmedna, M.A., Niandou, M.A. (2010), Short-term $CO_{2\,min}$eralization after additions of biochar and switch grass to a Typic Kandiudult. Geoderma, 154(3-4), 281-288.

Oo, A.Z., Sudo, S., Akiyama, H., Win, K.T., Shibata, A., Yamamoto, A., Hirono, Y. (2018), Effect of dolomite and biochar addition on N_2O and CO_2 emissions from acidic tea field soil. PLoS One, 13(2), e0192235.

Rahimi, M.J., Ghorbani, B., Amidpour, M., Hamedi, M.H. (2021), Configuration optimization of a multi-generation plant based on biomass gasification. Energy, 227, 120457.

Saletnik, B., Zagula, G., Bajcar, M., Czernicka, M., Puchalski, C. (2018), Biochar and biomass ash as a soil ameliorant: The effect on selected soil properties and yield of giant miscanthus (*Miscanthus x giganteus*). Energies, 11(10), 2535.

Scott, D.S., Piskorz, J. (1984), The continuous flash pyrolysis of biomass. The Canadian Journal of Chemical Engineering, 62(3), 404-412.

Shareef, T.M.E., Zhao, B. (2016), The fundamentals of biochar as a soil amendment tool and management in agriculture scope: An overview for farmers and gardeners. Journal of Agricultural Chemistry and Environment, 6(1), 38-61.

Shen, Y., Zhu, L., Cheng, H., Yue, S., Li, S. (2017), Effects of biochar application on CO_2 emissions from a cultivated soil under semiarid climate conditions in Northwest China. Sustainability, 9(8), 1482.

Sohaib, Q., Muhammad, A., Younas, M. (2017), Fast pyrolysis of sugarcane bagasse: Effect of pyrolysis conditions on final product distribution and properties. Energy Sources Part A Recovery Utilization and Environmental Effects, 39(2), 184-190.

Sohi, S., Loez-Capel, E., Krull, E., Bol, R. (2009), Biochar's roles in soil and climate change: A review of research needs. CSIRO Land and Water Science Report, 5(9), 1-57.

Sridhar, A., Kapoor, A., Kumar, P.S., Ponnuchamy, M., Balasubramanian, S., Prabhakar, S. (2021), Conversion of food waste to energy: A focus on sustainability and life cycle assessment. Fuel, 302, 121069.

Stavi, I., Lal, R. (2013), Agroforestry and biochar to offset climate change: A review. Agronomy for Sustainable Development, 33(1), 81-96.

Wang, G., Dai, G., Ding, S., Wu, J., Wang, S. (2021), A new insight into pyrolysis mechanism of three typical actual biomass: The influence of structural differences on pyrolysis process. Journal of Analytical and Applied Pyrolysis, 156, 105184.

Yogalakshmi, K.N., Sivashanmugam, P., Kavitha, S., Kannah, Y., Varjani, S., AdishKumar, S., Kumar, G. (2022), Lignocellulosic biomass-based pyrolysis: A comprehensive review. Chemosphere, 286(2), 131824.

Zhang, W., Sun, S., Zhu, H., Zhang, L., Zhao, Y., Wang, P. (2021), The evolution characteristics of bituminous coal in the process of pyrolysis at elevated pressure. Fuel, 302, 120832.