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ALTERNATE ENERGY-GENERATING OPPORTUNITIES IN PULP AND PAPER MILLS

1. *Kumar Anupam*, *Scientist B**
2. *Dr. A. K. Dixit*, *Scientist F & Head, Chemical Recovery & Biorefiney Division**
3. *Anshu*, *Research Assistant**
4. *Swati Anand*, *Research Assistant**
5. *Shrutikona Das*, *Junior Research Fellow**
6. *Dr. M. K. Gupta*, *Director**

**Central Pulp and Paper Recearch Institute, Saharanpur*

Abstract:

Identifying diversified platforms for the production of renewable energy from biomass has become obligatory to ensure energy security for mankind keeping in view the depleting non-renewable fossil fuel reserves. Since the pulp and paper mills operate on lignocellulosic raw materials; they offer such feasible and sustainable platforms to produce renewable energy in addition to pulp and paper. The pulp and paper mills contain feedstocks such as biomass residuals, cellulose, hemicellulose, lignin, black liquor, volatile organic compounds, organic-rich wastewater, and sludge which can be converted into a spectrum of renewable fuels such as bioethanol, biodiesel, biogas, biocoal, biooil, bioenergy, green electricity, syngases etc. through chemical, thermo-chemical and biochemical pathways. Implementation of processes such as extraction, fractionation, separation, hydrolysis, pyrolysis, gasification, enzymatic saccharification, fermentation, distillation, cogeneration etc. in paper industries will result in generation of renewable bioenergy. The concept of transforming existing pulp and paper mills into biorefinery by incorporating facilities to produce a range of fuels and power from biomass through upstream, midstream, and downstream processing is a giant step toward this goal and can have significant technological, economic, social and environmental advantages over greenfield biorefinery setup. This paper aims to highlight and discuss various processes, utilities, and strategies that are or can be integrated into the existing facilities of pulp and paper mills for generating renewable bioenergy in addition to their regular business.

Keywords: Pulp and Paper, Integrated biorefinery, Sustainable development, Resource Conservation, Circular economy

1. Introduction:

The rapid economic development and a growing population have resulted in higher energy demand. The excessive consumption of fossil fuels to meet this higher energy demand has created a huge scarcity of natural energy resources. Also, the use of fossil fuels involves various threats such as the release of greenhouse gases like carbon dioxide and nitrous oxide. Approximately, one-third of global greenhouse emissions are contributed by fossil fuels such as coal, oil, and natural gas [1]. India is a strongly coal-dependent country and frequently imports fossil fuels [2]. More than 80% of India's energy requirement is fulfilled by coal and oil. The quest for alternative renewable energy sources other than fossil fuels is

a current need for the world's population. Therefore, the world is slowly shifting towards renewable energy sources like wind, solar, waste, biomass, and hydropower.

According to the Ministry of New and Renewable Energy (MNRE), Government of India India's renewable energy capacity shares 39% of the total installed capacity in the first quarter of year 2022. Among renewable energy, solar energy accounts for 13.22% which is higher than large hydro at 11.73%, biomass at 2.56%, and small hydro at 1.22% of India's total installed capacity in the first quarter of year 2022. Pulp and paper mills are highly energy consuming, steam and electricity consumption of Indian mills are 11 to 15 tonnes and 1300 to 1700 kWh per tonne of paper production. High energy prices and strict environmental regulations have triggered scientists to look for the potential of the pulp and paper industry for generating various alternative energy sources for fulfilling the need for clean energy. In the same context, this study emphasizes possible alternate sources and routes that could be available at pulp and paper mills for production of renewable energy.

There are various feedstocks in a paper mill for energy generation such as biomass containing cellulose and hemicellulose; black liquor containing lignin and organic compounds; effluent containing organic-rich wastewater, sludge etc. The waste biomass such as residues of wood/bark, screening rejects and pith etc. is available in pulp and paper industries through different unit operations of papermaking. Also, different type of sludge such as deinking sludge, mixed sludge, mechanical-chemical sludge and biological sludge is available as waste biomass. Along with this, there are various bioenergy retrofit options available in the sulfate paper industry such as the generation of dimethyl ether, biomethanol, and Fischer tropsch (FT) biofuels through the gasification of black liquor; bio-oil from hydrothermal liquefaction of black liquor; biogas from anaerobic treatment of effluent sludge; hydrochar from hydrothermal carbonization of effluent sludge [3]. Biorefinery integrated with a paper mill is one such approach that can be implemented for converting biomass into various solids (lignin, pellets, and charcoal), gaseous (syngas, biogas, biomethane, and hydrogen) and liquid (bio-oil, Fischer Tropsch fuels, bioethanol, and biodiesel) biofuels.

Thermochemical and biochemical conversions are two general processes in the biorefinery approach for producing a spectrum of biofuels. The thermochemical process involves the gasification of biomass at high temperatures (>700 ^{0}C) which produces syngas and a mixture of gases such as hydrogen, methane, carbon dioxide, and carbon monoxide. Pyrolysis is a type of thermochemical conversion of biomass at intermediate temperatures (300-600^{0}C) to produce charcoal, bio-oil, and light gases. Biochemical conversion involves two processes such as anaerobic digestion and fermentation of biomass at low temperatures and reaction rates to produce ethanol. The biorefinery concept can also be associated with combined heat and power (CHP) generating systems available in pulp and paper mills which utilize biomass such as bark, pith, and chipping waste for generating steam, energy, and biofuels. Agro-based paper mills also offer huge potential for generating alternative bioenergy through combustion in chemical recovery boilers, gasification, biomethanation, and anaerobic treatment of spent pulping liquor. With the aforementioned background, it is aimed in this study to focus on different feedstocks and possible routes for generation of alternate energy from the pulp and paper industry.

2. Feedstocks in pulp and paper industries for energy generation

Pulp and paper mills contain feedstocks such as hemicellulose, lignin, volatile organic compounds, organics in wastewaters, biomass residuals, black liquor etc. which can be converted into spectrum of products such as transportation fuels, commodity chemicals, chemical building blocks, specialty chemicals, biopolymers, and other novel products through chemical, thermo chemical and biochemical processes.

3. Possible pathways pulp and paper industries for energy generation

3.1 Black liquor

Black liquor is a good source of green energy in terms of chemicals and organics present in it. In pulp and paper industries chemical recovery boiler serves as a chemical reactor as well as a steam generator. The black liquor is fired at a higher concentration in the boiler furnace and steam is generated through heat energy liberated by the combustion of black liquor. This steam is fed to a turbo generator to produce green electricity for fulfilling the mill's energy requirements. Power generation by a boiler entirely depends on the pressure and temperature of the steam generated through the combustion of black liquor.

Typically steam and power generation from the recovery boiler can be as high as 3.8 kg and 0.6 kWh per kg of black liquor dry solids [4]. Black liquor can also be utilized for the production of hydrogen through the electrolysis process and alkali lignin separated during the process can use for producing green fuels [5,6]. Hydrogen is a globally recognized clean renewable energy source available today for internal combustion engines and hydrogen fuel cell electric vehicles (FCEV). Kraft black liquor pretreatment with membrane nanofiltration followed by adsorption on granulated activated carbon can produce organic acids which can be utilized for biofuels production [7]. Figure 1 higlights various possible routes for production of biofuels from black liquor generated in pulp and paper mills [8].

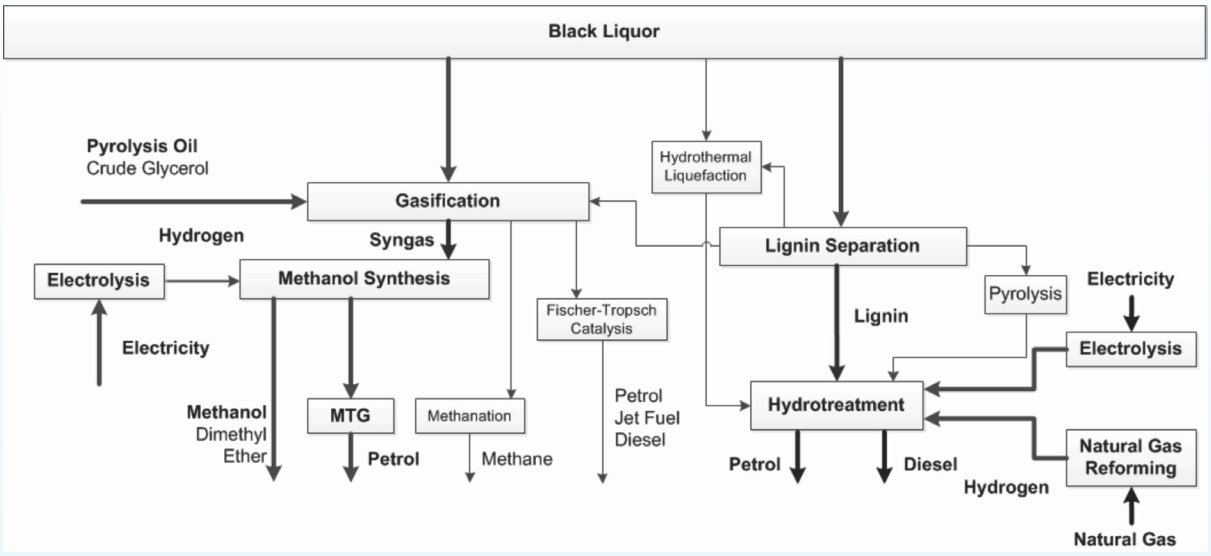

Figure 1: Routes for biofuels production from pulp and paper mill black liquor

3.2 Biomass residues

Biomass is a good source of carbon available other than fossil fuels. There are various sources of biomass residues are available in pulp and paper industries such as bark, pith, rejects, spent liquor, and wastewater sludge. These biomass residues can be subjected to treatment processes such as gasification, pyrolysis/liquefaction, and biochemical conversion for producing renewable energy. Gasification of biomass residues produces syn gas which can be utilized in methanol synthesis and Fischer Tropsch (FT) synthesis to produce renewable gasoline, diesel, and jet fuel. Pyrolysis/liquefaction of biomass produces solid charcoal and bio-oil, bio-oil further goes through hydroprocessing for producing renewable gasoline, diesel, and jet fuel. Hydrolysis of biomass residues followed by fermentation produces biofuels like ethanol. Figure 2 illustrates a variety of potential routes for production of biofuels from the residues of raw materials existing in pulp and paper mills [9].

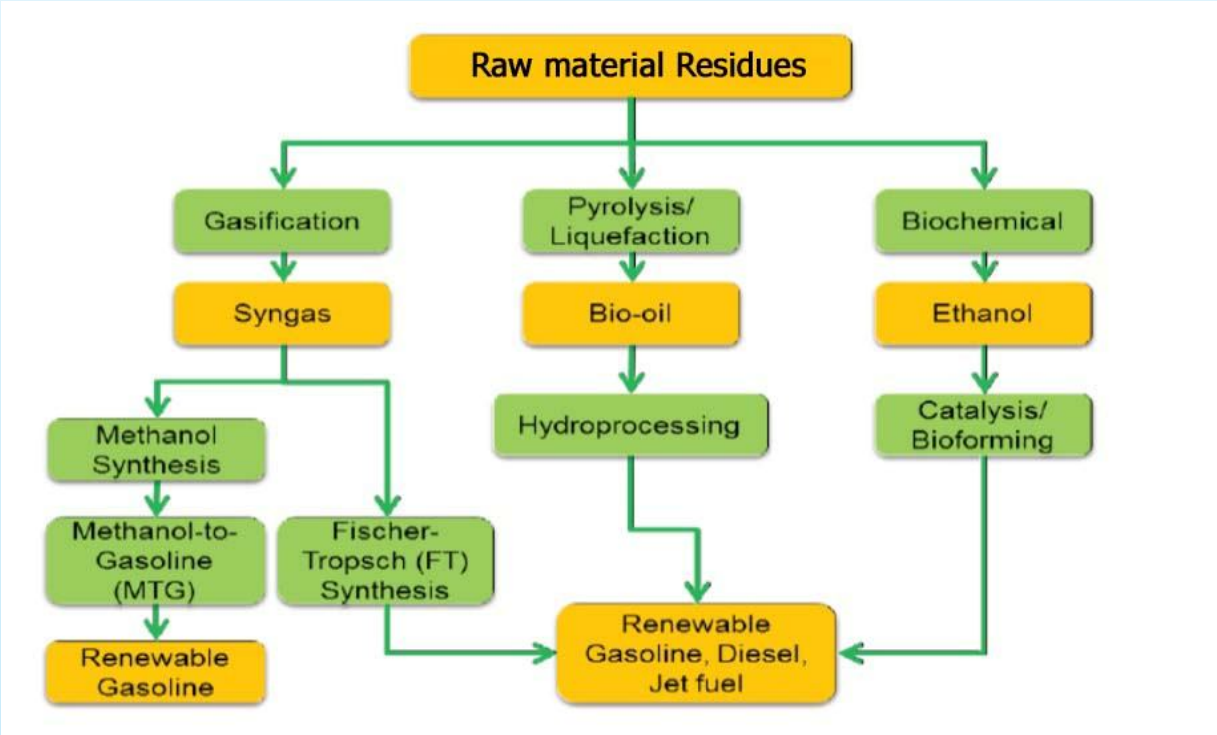

Figure 2: Conversion tracks for raw material residues based hydrocarbon biofuels

3.3. Hemicellulose

Hemicellulose is found in plant cell walls as supporting materials, which is a heterogeneous polymer consisting of various C_5 and C_6 sugars [10]. Raw materials such as wood, bagasse, and wheat straw contain hemicellulose which can be utilized for producing

green energy. For this hemicellulose is extracted from raw materials first and then the extracted hemicellulose is subjected to saccharification followed by fermentation which ultimately produces ethanol. These days, ethanol is blended with gasoline to control the harmful emissions from the vehicle's exhaust system. Figure 3 illustrates a pathway for repurposing a pulp and paper mill for the production of ethanol [11].

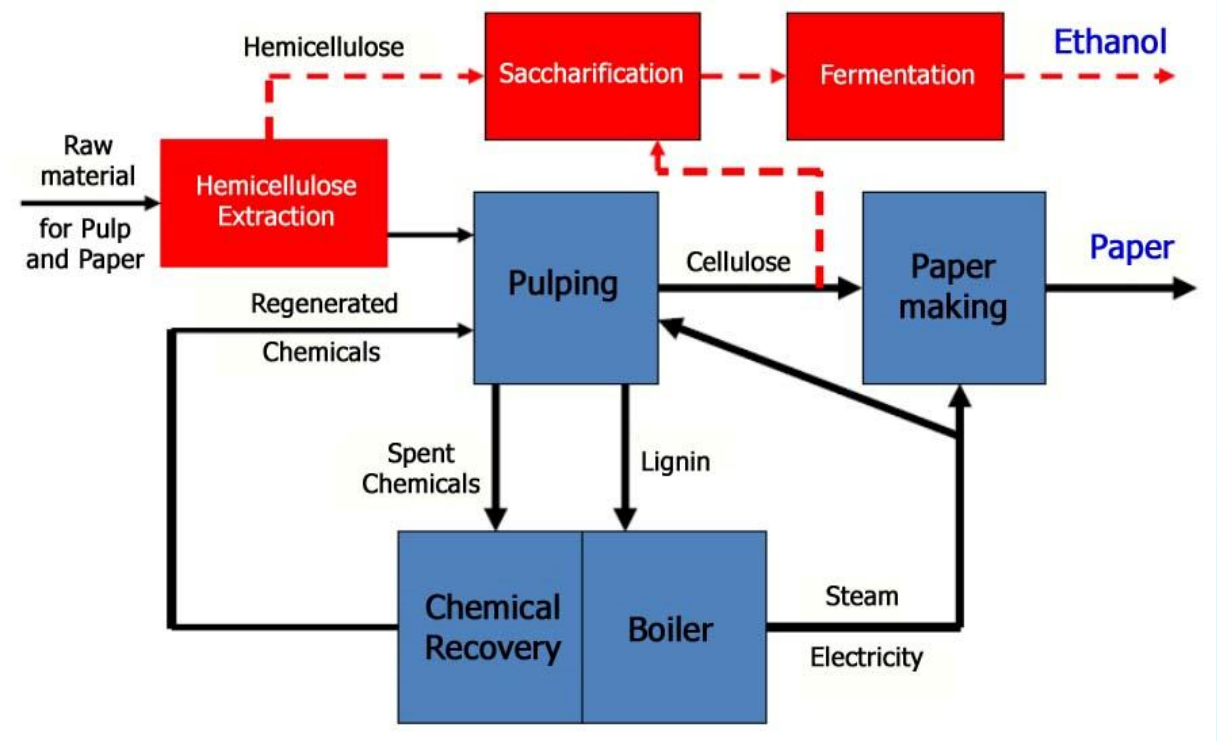

Figure 3: Re-purposing of a pulp and paper mill for the production of ethanol

3.4 Lignin

Lignin is an aromatic complex polymer of phenylpropane units with amorphous, cross-linked, and 3-D structures [12]. Lignin burnt as fuel gives more energy than cellulose. Lignin can be converted to biofuels through thermal or chemical degradation methods. Due to the aromatic nature of lignin, it has huge potential to produce biochemicals, biofuels, and bioelectricity. For this first lignin is separated from black liquor by alkali and acidic procedures which gives different types of lignin such as alkali, kraft, and organosolv lignin [13]. Kraft lignin can be used in refineries for biofuel production. Production of biofuel from organosolv lignin separated from beechwood has been reported in literature [14]. Separated lignin can be subjected to treatment processes such as pyrolysis, hydrogenolysis, oxidation, gasification, and combustion for producing a spectrum of renewable energy sources.

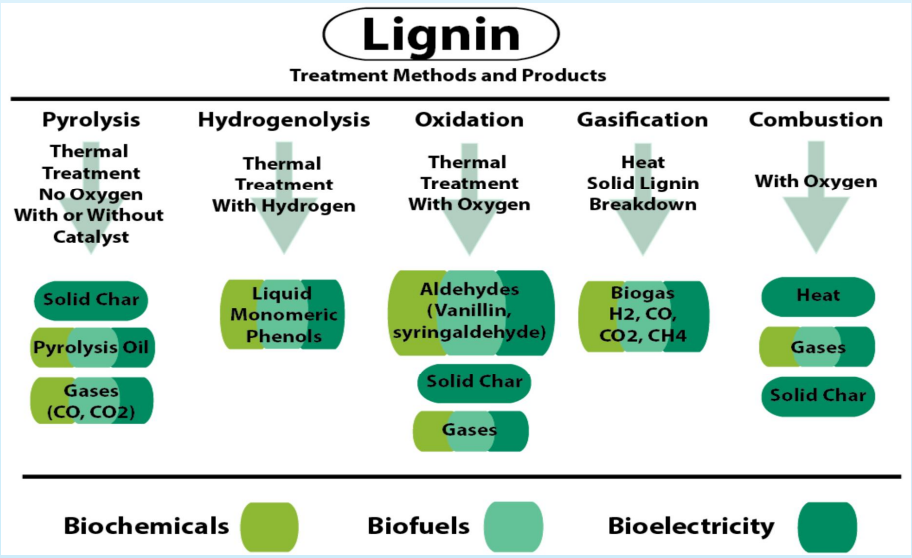

Figure 4: Treatment methods for production of chemicals, fuel and electricity from lignin

Pyrolysis of lignin gives solid char, pyro-oil, and gases (CO, CO2). Hydrogenolysis of lignin produces liquid monomeric phenols. Oxidation and combustion of lignin produce solid char, heat, and gases. Gasification of lignin gives syngas which can be further converted to methanol, ethanol, dimethyl ether, light gases, and Fischer Tropsch biofuels. Also, liquid lignin produced from the

carbonation of black liquor can be fired directly in a biomass boiler to produce steam which can be further used for producing green electricity. Researchers have reported the use of lignin-based oil in jet fuel aromatics [15]. Figure 4 depicts chemical methods production of chemicals, fuel and electricity from lignin [16].

3.5 Wastewater sludge

Wet sludge can be subjected to a gasification process to produce heat, power, and solid residue. The incineration of sludge after the dewatering process gives solid residue and solid fuel. Pulp and paper sludge contains organic materials, and anaerobic digestion of this sludge after dewatering can produce biogas. Purification of this biogas can give pure biomethane which can be utilized for producing electricity or directly used as vehicle fuel. Pulp and paper sludge is low in nitrogen content and high in carbon content which makes it highly suitable for anaerobic digestion to produce methane [17]. Anaerobic co-digestion of pulp and paper sludge can produce biomethane and biohydrogen [18]. Microbial electrolysis cells (MECs) can be used for the electrolysis of paper mill wastewater to produce hydrogen [19]. Treatment of wastewater and sludge fromthe paper mill by the above processes not only reduces the pollution load but also helps to recover renewable energy in terms of solid, gas, and liquid fuels. Figure 5 illustrates the possible pathways for generation of energy from wastewater generated in pulp and paper mills [20].

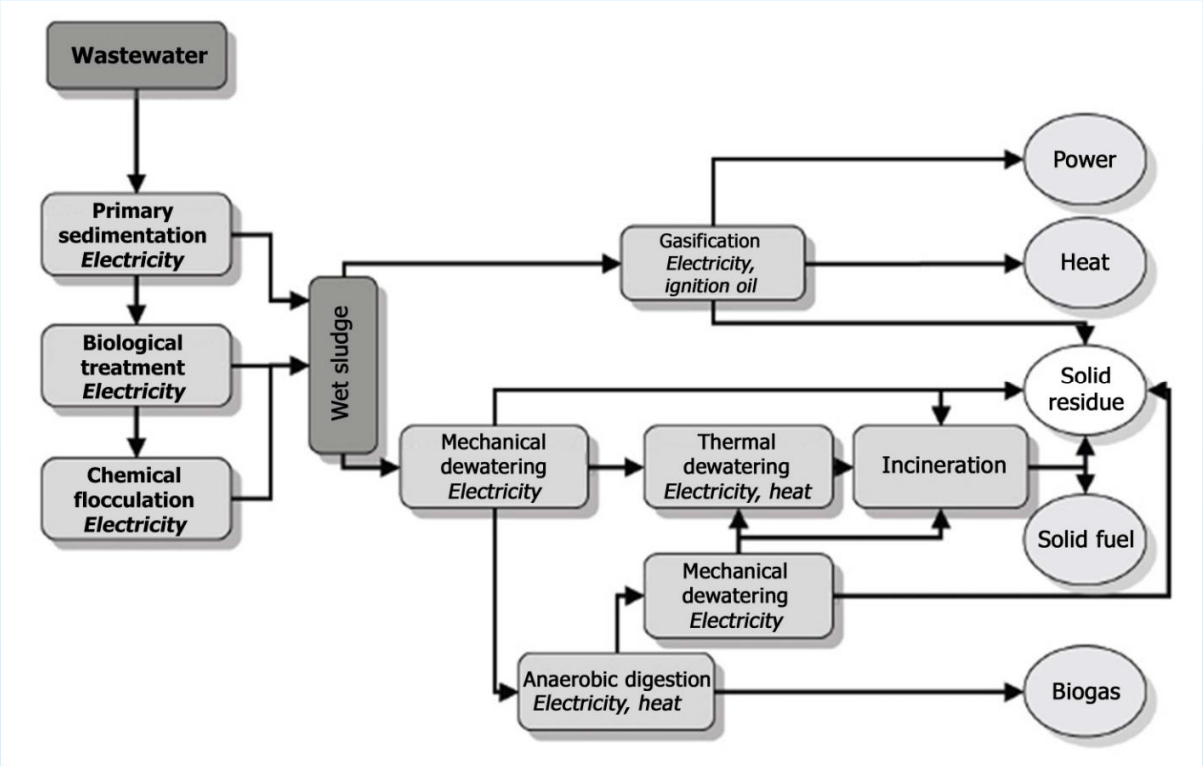

Figure 5: Pathways for generation of energy from wastewater generated in pulp and paper mills

4. Conclusion

The pulp and paper mills have full potential to produce renewable energy and it is the right time to visualize them as biorefinery keeping in view the future energy demand. Future generation of renewable energy from pulp and paper mills, however, depends on the level of production and the technologies employed at mills. The pulp and paper mills will have to be re-purposed for the production of biomass based renewable energy. Integrating pulp and paper mills to renewable energy production facilities in addition to paper will enhance the profitability and hence the socio, economic, energy and environmental condition of country.

This paper discussed various possible routes of producing energy from feedstocks available in the pulp and paper mills. It can be concluded that pulp and paper mills can be transformed into energy harvesting units. The feedstocks available in pulp and paper mills such as black liquor, biomass residues, hemicellulose, lignin and waste water sludge can be converted to various biofuels such as bioethanol, biomethane, biooil, biodiesel etc. via different processes like fractionation, pyrolysis, gasification, fermentation hydrolysis etc. Adoption of these technologies for energy generation can make pulp and paper industry more sustainable and will further enhance the sustainable development goals defined by United Nation through circular economy approach.

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