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Emerging biorefinery technologies for Indian forest industry to reduce GHG emissions

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ABSTRACT

The production of biofuels as alternative energy source over fossil fuels has gained immense interest over the years as it can contribute significantly to reduce the greenhouse gas (GHG) emissions from energy production and utilization. Also with rapidly increasing fuel price and fall in oil wells, the present scenario forces us to look for an alternative source of energy that will help us in the operation of industrial as well as the transportation sector. The pulp mills in India are one of the many options. The pulp mills in India can help us to produce bio-fuels by thermo-chemical/biochemical conversion of black liquor and wood residues. These technologies include extraction of hemi-cellulose from wooden chips and black liquor, lignin from black liquor, methanol from evaporator condensates, biogas production from waste sludge, syngas production from biomass using gasification and bio-oil production from biomass using pyrolysis. The objective of this paper is to overview these emerging bio-refinery technologies that can be implemented in Indian Forest Industry to get bio-fuels, bio-chemicals and bio-energy to reduce GHG emissions.

1. Introduction

Climate change due to global warming and variation in oil prices in recent years has led to significant interest in the biological feedstock-based fuels and chemicals. Increase in GHG emissions contributes to global warming and utilization of the fossil fuels is one of the main contributors. Biomass based fuels and chemicals are being promoted as effective low-carbon energy sources which could reduce dependence on fossil fuels and also significantly lower the GHG emissions. Biomass-based energy technologies are at different stages of development, deployment and commercialization. Biomass is the only renewable energy resource which can directly be converted to liquid fuels. However, substantial research and policy formulations are required to ensure sustainability of biomass production and conversion. Compared to fossil fuels, biomass is clean, renewable and is nearly carbon neutral. It can be used to produce heat and power as well as a range of fuels and chemicals; these include transportation fuel such as bioethanol, biodiesel and renewable diesel (Smith, 2011).

There is a lot of focus on production and utilization of transportation fuel because it produces about 13.5% of the world's GHG emissions (Smith, 2011; Smook, 2002; Marinova et al., 2009). Vehicle emissions can be reduced using many different pathways such as use of improved engine efficiency, electric vehicles, electric-gasoline hybrid vehicles, hydrogen fuel cell vehicles, and biomass-based transportation fuels. Biomass-based fuels also reduce GHG emissions because the growth of biomass would absorb the CO_2 which was produced during the utilization process. Also they burn more efficiently than fossil fuels due to a higher octane number in case of ethanol fuels, and a higher cetane number in the case of biodiesel. Bio-based transportation fuels are a promising option to mitigate GHGs. In order to increase the utilization of sustainable energy, use of biofuels is an option. Biofuels can make use of the infrastructure already in place for fossil fuels like gasoline and diesel. But it is critical to assess the techno-economic feasibility and viability of these fuels.

The global pulp and paper industry consists of about 5000 industrial pulp and paper mills, and an equal number of very small companies. The US is the largest market for paper products and possess high financial gain. Asia's main markets are India, Japan, China, Malaysia, Singapore and Thailand.

A biorefinery is a facility that integrates biomass conversion processes and equipment to produce fuels, power, heat, and value-added chemicals from biomass. The biorefinery concept is analogous to today's petroleum refinery. However, biorefinery uses

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renewable resources whereas petroleum refinery uses non-renewable resources (Smith, 2011). The feedstock for the biorefinery can be obtained from agriculture, forestry, aquaculture, transportation, domestic, industrial sectors from which forestry sector seems to be promising one. The pulp mills have large energy producing capacity due to the presence of cellulose, hemicellulose, and lignin (lignocellulosic materials).

Cellulose is the main constituent of wood. It is a glucose polymer consisting of linear chains with an average molecular weight of approximately 100,000 g per mole (Smook, 2002). Hemicellulose is a heterogeneous polymer composed of five-carbon and six-carbon monomeric sugars, with an average molecular weight of $< 30,000$ (Marinova et al., 2009). Lignin can be regarded as a group of amorphous, high molecular weight, chemically related compounds. The building blocks of lignin are believed to be a three-carbon chain attached to rings of six carbon atoms, called phenyl-propanes (Doherty et al., 2011). The composition of lignocellulose materials in wood is cellulose (40–47%), hemicellulose (25–35%) and lignin (16–31%) (Smook, 2002).

In this paper we will discuss about conventional process to produce pulp in Indian kraft mills and emerging biorefinery technologies that can be implemented in Indian Kraft mills to obtain biofuels, bio-chemicals and bioenergy.

2. Process carried out in Kraft mills of India

In India traditional methods are being followed for paper production. This process usually involves digesting wood chips at high temperature and pressure. A solution of sodium hydroxide and sodium sulfide in water is added to wood chips. This solution is called white liquor. It chemically dissolves the bonds that interconnect the cellulose fibers. The delignification of wood takes place in a vessel called a digester, which can withstand high pressure. There are three types of digester used in Indian Kraft mills:

- Rotary Spherical Digester
- Continuous Digester
- Stationary Vertical Digester

The digester receives steam from boiler, which is run by burning of coal. A part of steam is also send to turbine for energy production that can be used for mechanical screening process. At this stage, the solid pulp is brown and is called brown stock. The combined liquids are known as black liquor, and contain the lignin fragments along with chemicals and by-products. The pulp is separated from the used cooking liquors by a series of washes.

The brown stock produced by the Kraft process contains about 5% residual lignin, and is further delignified by a series of bleaching stages. Bleaching removes additional lignin, making the paper brighter. Sometimes, the paper required is brown and for this bleaching is avoided because bleaching decreases the pulp yield. Fig. 1 shows the entire operation carried out in Indian pulp mills.

Current Kraft factories are self-contained and recover most of their chemicals, producing very little water pollution. The way to recover white liquor is by introducing recausticizing plant. The black liquor from digester is sent to the recausticizing plant with the help of pump where white liquor is recovered and is send back again to digester. This process is a cyclic process and continues till the entire operation is performed.

In a case study of Indian pulp mill it is found that to produce 1 t of pulp, 3.5 t of steam is required which is cope up by burning 0.34 t of coal. The yearly paper demand of India is about 11.66 million tonne (Paper Age, 2014). A large amount of exploitation of

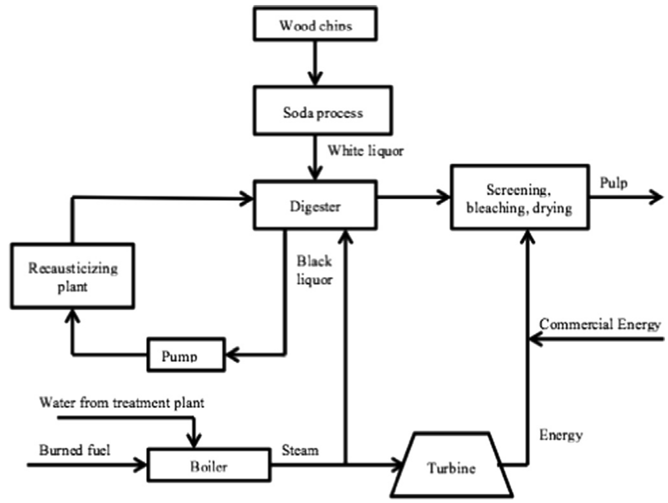

Fig. 1. Conventional Kraft process in Indian pulp industry.

fossil fuels is needed to cope up this large demand that can cost us very much in near future.

During the process of paper making from pulp, various by-products such as hemicellulosic fraction, lignin and black liquor that are produced which are of high energy content byproducts (Sixta, 2006). These byproducts can be utilized for the production of fuels and chemicals. In the process of leaching before pulping, the hemicellulosic fraction and acetic acid is released. This hemicellulosic fraction can be utilized for the production of bioethanol. Black liquor has high energy content and can be gasified, and the syngas produced can be utilized for the production of energy. The black liquor can also be used for the production of Fischer–Tropsch liquids, di methyl ether, diesel-like fuels, mixed alcohols, ethanol and hydrogen etc. A large proportion of black liquor can be used for the production of electric power in recovery boilers. Lignin is a highly value added byproduct which is released during the process of pulping. Lignin can be used for the production of phenols, sorbents, motor fuel, activated carbon, binders, plastic materials and carbon fibers, renewable batteries. The tall oil produce in the paper and pulp industry can also be utilized for the production of biodiesel (Smook, 2002; Paper Age, 2014; Sixta, 2006; Leschinsky et al., 2007).

3. Production of alternative biofuels in pulp mills

Threats such as depletion of fuels, high energy demand, stringent environmental regulations and growing competition forced us to look for an alternative source thereby encouraging us for the development of technologies and implementing the use of renewable resources. Indian Forest Industry one of the alternative sources is currently looked as a potential market for bioproducts. The technologies that can be implemented in Indian Forest Industry can be explored in this paper. Fig. 2 represents new and emerging biorefinery technologies integrated with Indian pulp industry.

3.1. Extraction of hemicellulose from wood chips

Extraction of hemicellulose is an essential process and requires lot of attention. The hemicellulose is recovered from the wood chips in two ways by auto-hydrolysis (using steam or water) (Sixta, 2006; Leschinsky et al., 2007) or acid-hydrolysis (Springer and Harris, 1982). In acidic pre-hydrolysis processes, hemicelluloses are hydrolyzed to oligomeric and monomeric sugars and dissolved