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The Green Integrated Forest Biorefinery: An innovative concept for the pulp and paper mills

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HIGHLIGHTS

- The Green Integrated Forest Biorefinery (GIFBR) is a new biorefinery concept.
- A GIFBR includes a pulp mill, a biorefinery, a gasification and a polygeneration units.
- An implementation strategy by phase is proposed to successfully develop a GIFBR.
- To determine achievable level of integration between the GIFBR constituents is crucial.
- GIFBR concept technically and economically feasibility for pulp and paper mills.

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ABSTRACT

The Green Integrated Forest Biorefinery (GIFBR), a new concept suitable for implementation in pulp and paper mills is characterized by low greenhouse gases emissions, reduced water consumption and production of effluents. Its fossil fuel consumption must be nil. Several challenges have to be addressed to develop a sustainable GIFBR facility. An implementation strategy by phase is proposed to schedule the total capital investment over several years and to mitigate the economic risks associated with the transformation of an existing pulp and paper mill into a GIFBR. In the first phase of the methodology, the receptor mill and the biorefinery plant are selected. An intensive energy and material integration of the two plants is performed in the second phase, then a gasification unit is implemented and, finally a polygeneration unit is installed. The methodology is illustrated by application to a case study based on a reference Canadian Kraft mill. Each phase of the implementation strategy of the GIFBR is described.

1. Introduction

The biorefinery has been defined by the National Renewable Energy Laboratory (NREL) as a “facility integrating biomass extraction and conversion processes and equipment to produce fuels, power, heat, and value-added chemicals” [31]. The forest biorefinery is an opportunity for the pulp and paper (P&P) industry to diversify its product mix and to generate revenues from new products. Biorefinery units can be integrated in a P&P facility to manufacture bioproducts in addition to core cellulose-based products [21]. This integrated complex is characterized by the sharing of raw materials, by-products, utilities, and infrastructure resulting in significant economic advantages such as capital investment, reduced operating and utility costs. It also brings in additional revenues.

Among the different pulping processes, the Kraft process is particularly well suited as a receptor of the biorefining technologies, since part of lignin and hemicelluloses, which is normally burnt to recover its energy content, can be extracted from biomass and used as a raw material for the production of high value-added bioproducts [38]. In Canada, there are no less than 43 bleached pulp mills, primarily based on the Kraft process [4]. In addition, Kraft mills have several advantages such as existing energy and water networks, effluent treatment systems, trained manpower, and well developed partnerships with suppliers and consumers. The production capacity of the Kraft mills is important and the operating costs are reasonable.

Biorefineries offers a wide range of potentially attractive products, from biofuels to specialty chemicals. In addition to the traditional commodities used as transportation fuels, twelve building block chemicals have been identified by the NREL as promising

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bioproducts that can be obtained from sugars, either through biological or chemical conversions. Those building blocks can be further processed to produce high-value bio-based chemicals or materials. The final products may be utilized by different industrial sectors such as textiles, housing or health and hygiene [39]. In order to be economically viable, the biorefinery must target the market demand the most suitable for its product mix.

Several examples of biorefinery units integrated in P&P mills have been reported in the literature. Studies have been performed to convert Kraft mills into integrated biorefineries, mainly for ethanol production [2,12,19,38]. Additional research was dedicated to gasification based biorefineries [8,17]; gasification of black liquor or wood residues has been evaluated as a mean to produce liquid fuels and chemicals. The focus of those studies was either the techno-economic feasibility [13] or the environmental benefit of developing an integrated forest-based complex [5,29]. In most of the studies, the opportunities for material and energy integration between the receptor mill and the biorefinery unit have not been taken into account.

An important feature of the integrated complex is its ability to become energy self-sufficient. The addition of a biorefinery unit to a P&P mill impacts the water and steam consumption of the overall facility. To avoid the possibility of using fossil fuel to satisfy the energy requirement, energy integration and optimization measures are proposed [21,28]. Energy efficiency projects to maximize heat recovery, to minimize utility consumption and to enhance condensate recovery and water system closure are sometimes implemented in P&P mills. Those projects generally consist of performing either thermal or water Pinch Analysis [3,18]. The interaction of the energy and water systems in P&P mills has motivated the development of combined optimization methods. Savulescu et al. [36,37], have developed a two stage methodology to identify system network design with minimum water and energy consumption. Mateos-Espejel et al. [25], and more recently Keshtkar [16], have proposed methodologies for combined energy and water analysis taking into consideration different measures (internal heat recovery, water reutilization, condensates return, energy upgrading and conversion, elimination of non-isothermal mixing) to improve the overall thermal energy efficiency of the Kraft process. The technique was applied to Canadian Kraft mills to evaluate the possibility to liberate enough steam to satisfy the demand of a biorefinery [22,23].

Most of the work done in the area of integrating biomass conversion technology into pulp mills for producing bioproducts focuses either on the energy aspect of the integrated facility [9,27,28] or on the economic requirements [10].

Forest biorefinery has been studied extensively over the last years. However, there has been no biorefinery concept proposal including specific bioprocesses targeted toward the development of an integrated facility with lower fossil fuel usage. In this paper, the problematic has been addressed by introducing a new concept, the Green Integrated Forest Biorefinery (GIFBR), a fossil fuel free integrated facility.

The aim of a zero fossil fuel consumption is of particular interest from and environmental and economic point of view but the development of such a facility is complex. Biorefinery processes to be implemented have to be carefully selected, the level of mass and energy integration between them has to be assessed to optimize the overall energy requirement and guarantee no fossil fuel usage. A strategy has to be proposed to mitigate the technical, economic and financial risks and uncertainties of developing an IFBR and assess its economic and environmental advantages. The novelty of such biorefinery concept lies in the way to consider the components of a GIFBR and how they should be interconnected to satisfy technical, economic and environmental requirements. In this work, the GIFBR concept is first described, and its feasibility is subsequently illustrated by a case study. A methodology to develop a GIFBR based on an existing Canadian Kraft pulping mill is proposed.

2. The Green Integrated Forest Biorefinery

2.1. Concept definition

The GIFBR is a multi-revenue generating complex composed of four units: a P&P receptor mill, which is the core of the complex, a biorefinery unit manufacturing value-added bioproducts, a woody biomass gasification plant producing syngas and, a polygeneration unit generating green power and supplying cooling and heating to the integrated facility. A GIFBR is characterized by a zero fossil fuel consumption, minimum fresh water and energy demand, reduced amounts of water effluents and greenhouse gases emissions. An overview of this concept is presented on Fig. 1.

Multiple integration levels exist between the main units of the GIFBR. The receptor mill uses wood chips as a feedstock to produce either paper pulp or specialty pulp from which cellulose-based products are manufactured such as intelligent paper, biosensitive paper, nanocrystalline cellulose, etc. Part of a process stream from the pulp mill is diverted as feedstock to the biorefinery plant. Typically it is hemicellulosic pre-hydrolyzate or partially concentrated black liquor. The pulp mill also provides the utilities required by the biorefinery unit. Biomass residues from the pulping process and from external sources feed the gasifier unit. The produced syngas can replace the natural gas used on site to fire the lime kiln of the Kraft process and to initiate the boiler combustion in the steam plant; it can also be used to feed a turbine or a polygeneration unit for heat and power production, or be sold as a precursor for biochemicals production. The additional cooling and heating required by the integrated facility are supplied by the polygeneration unit. The higher level of integration between the different components is crucial for the development of an economically viable GIFBR. Several challenges, such as the site location or the level of potential integration between the units should be addressed to develop a sustainable GIFBR.

2.2. Implementation strategy

For the successful development of the GIFBR, a progressive implementation strategy is recommended and it involves five different phases, as illustrated on Fig. 2.

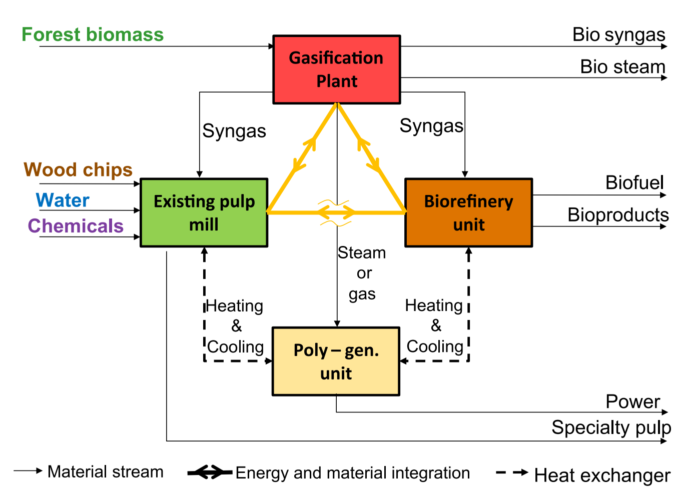

Fig. 1. Overview of the Green Integrated Forest Biorefinery concept.