Original article

Options for the conversion of pulp and paper mill by-products in Western Canada

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ABSTRACT

The pulp and paper industry, one of Canada’s largest and most important industries, produces many by-products, some of which are used to produce electricity and steam for mill operations; however, the by-products are not used economically. The industry has been facing financial challenges and, therefore, an appropriate means of converting by-products to value-added products is highly desired. In this study, we explore nine pathways for the conversion of black liquor, the major by-product of the industry, to different value-added final products. These include steam, electricity, dimethyl ether, Fischer-Tropsch liquids, mixed alcohols, methanol, acetone, butanol, ethanol, and lignin. The most economical conversion pathway is selected based on the internal rate of return (IRR) calculated through a techno-economic assessment. Lignin production through the fractionation of black liquor is the most attractive scenario. Sensitivity and uncertainty analyses were performed on the IRR for the lignin production scenario to evaluate the effect of different parameters on overall performance and assess the accuracy of the results. The sensitivity analysis shows that lignin price and operating costs are the most influential parameters on IRR. This study offers insights into options of revenue generation for the pulp and paper industry through the innovative use of its by-products.

Introduction

The move toward electronic media from newsprint has led to a decline in pulp and paper industry revenue [1]. Globally, there has been a fall during recent years in the sale of forest and paper industry products, and pulp demand has decreased in all regions of the world except China [2]. In 2015, compared to 2014, EBITDA (earnings before interest, taxes, depreciation, and amortization) remained steady for Europe and the US, but a fall in EBITDA was observed in Canada [3]. For all regions, sales decreased between 2014 and 2015 except for the US, which showed a small increase; likewise, net income fell for all regions except Europe. The only region with negative net income or loss in 2015 was Canada [3].

As the second largest producer after the US and the largest exporter, the Canadian pulp and paper industry has worldwide importance [4]. As one of the largest industries in Canada, the pulp and paper industry would need to remain competitive in the global market because every economic downfall in the industry will affect Canada’s wellbeing [4].

In order to reposition the pulp and paper industry to survive, new practices and technologies should be applied. One of these is to generate revenue by using the by-products from pulp and paper mills to produce clean energy and chemicals [5]. During the pulping process, significant amounts of by-products are generated, most of which are not used or are underused [6]. There is no extra environmental concern in producing these by-products since they are produced during the pulping process from materials that are otherwise discarded as waste [6]. Unlike the use of fossil fuels, using these by-products for energy production lowers CO2 emissions because trees, as the source of these by-products, absorb CO2 during their growth [7,8].

In Alberta, the forest industry has contributed significantly to the revenue generated by the province, and its products are sold in Asia, Europe, and the Americas [9]. But the industry has faced very challenging economic conditions recently [5]. There are seven pulp mills currently operating and producing abundant by-products in Alberta. Table 1 shows the pulp mills with their facility type and Fig. 1 shows their location in Alberta on the map.

In this study, kraft pulp mills are considered for two reasons. First, because of their abundance in Alberta and second, because of the higher quantity and variety of the by-products they produce.

In Alberta, there are limited data on volume, potential use, and by-product conversion to a common intermediate that could be used in a bio-refinery to produce fuels and chemicals. So in the first step, we made estimates using the data provided by mills and from handbooks that can be applied to every pulp mill. Table 2 shows the total amount
of by-products produced in Alberta. There may be variations in the amount produced in consecutive months due to skimming efficiencies, chip age, and species variation. Alberta’s pulp mill black liquor production is high, but the use of black liquor is limited. Black liquor is a lignin-rich by-product stream resulting from the separation of cellulose from wood through the dissolving of lignin in white liquor [10]. Black liquor is currently burned in boilers to produce steam and electricity to supply the mills [11].

In this study, we studied different conversion routes for the use of black liquor (as the major by-product of kraft pulp mills in Alberta) to final high-value products.

There have been a number of studies on the gasification of black liquor. Fornell et al. investigated the gasification of kraft liquor residues to dimethyl ether (DME) from an energy and economic point of view [12]. Joellsson et al. explored two different routes for biofuel production, one with black liquor as the feedstock for gasifier-producing DME and the other with forest residues and small round wood from thinning for solid biomass gasifier-producing Fischer-Tropsch liquid (FTL) [13]. FTL is a mixture of straight-chain hydrocarbons (olefins or alkenes \((C_nH_{2n})\) and paraffins or alkanes \((C_nH_{2n+2})\) that can be used as a replacement for crude oil. The results of their analyses demonstrated that black liquor gasification to DME produces more motor biofuel than solid biomass gasification to FTLs [13]. Larson et al. studied the cogasification of biomass and black liquor for a reference mill in southeastern U.S. and compared air emissions, capital investment, and net present value (NPV) for all considered cases [14]. More precisely, they investigated the co-production of DME and electricity, FTL and electricity, mixed alcohols (MA) and electricity, electricity production in the case of installing new Tomlinson power boilers, and electricity production if a black liquor gasification combined cycle plant is installed. For MeOH production, Andersson et al. considered three system configurations: a stand-alone pressurised entrained flow biomass gasifier (PEBG), a PEBG unit to replace the bark boiler, and a parallel pressurised entrained flow black liquor gasifier (PEBLG) with a PEBG to replace the recovery boiler [15]. Svensson et al. [16] and Olsson et al. [17] studied lignin separation from black liquor by using CO\(_2\) in a precipitation process. Svensson et al. also studied increased power generation as another alternative for using surplus steam at a kraft pulp mill. According to their results, the profitability of lignin separation was dependent on the lignin price and the cost of the CO\(_2\) to precipitate the lignin. The results of their study show that the profitability for all considered cases was noticeably higher for power generation than for lignin separation at high electricity prices. Olsson et al. studied the effect of uncertainty in electricity and biofuel prices and CO\(_2\) emissions charges when deciding between possible scenarios to invest in [17]. Mesfun et al. explored a new way to convert the underused hemi-celluloses content of black liquor after the separation of the lignin by CO\(_2\) precipitation [18]. Lignin separation from black liquor is an essential step for debottlenecking the recovery boiler, and it increases pulp production. The resulting lignin separated liquor is then hydrolyzed and undergoes liming and fermentation to produce acetone, butanol, and ethanol (ABE).

While there are studies on the conversion of black liquor to useful products, few studies have comparatively analysed the technical and economic feasibility of producing various products from black liquor. Moreover, most studies considered black liquor use in Europe and usually with both biomass and black liquor as feedstock. The bioenergy outlook is expected to substantially influence the market and fundamental policy decisions, and the outlook in Europe is considerably different to Canada. The aim of this paper is to compare various economic pathways of black liquor conversion to added-value products in North America with a special focus on Canada and to conduct a case study for Alberta pulp mills. The products considered include electricity (via recovery boiler), electricity (via gasification), methanol (MeOH), DME, MA, FTL, ABE, and lignin.

The key specific objectives of this study are:

- To develop nine comprehensive techno-economic models for the conversion of black liquor to value-added products
- To compare the economic parameters of nine pathways (scenarios) of black liquor conversion including conversion to steam, electricity, DME, MeOH, MA, FTL, ABE, and lignin
- To select the most attractive scenario based on the estimated IRR
- To perform sensitivity and uncertainty analyses to determine the influential parameters on IRR for the most attractive scenario

The results of this study will help the industry reactivate pulp mills and reposition itself as a leading sector in the economy by generating revenue from the production of high value chemicals and fuels through the conversion of black liquor. The results will also help governments diversify federal policies by proposing new ones to help in this transition of the pulp and paper industry.

### Methodology

The reference pulp mill is a kraft pulp mill in Alberta, Canada that produces pulp as the main product and black liquor as one of the by-products. The mill produces about 474,807 air-dried tonne (adt) of pulp and 780,258 t/y of black liquor (dry basis) from both hardwood and softwood trees.

### Description of scenarios

Nine scenarios were developed here based on a wide range of published data [10,12,15,17,18] on electricity, motor fuels (DME, FTL,
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