CHEMICAL ENGINEERING TRANSACTIONS Volume 21, 2010
Editor J. J. Klemeš, H. L. Lam, P. S. Varbanov
 ISBN 978-88-95608-05-1 ISSN 1974-9791
DOI: 10.3303/CET1021202

Biomass Gasification Integrated With a Pulp and Paper Mill – The Need for Economic Policies Promoting Biofuels

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In this study we analyse economic policy support for biofuels, with the aim to determine the amount of support necessary to make investments in a gasification based biorefinery producing DME (dimethyl ether) profitable for a pulp and paper mill. As a case the integrated Swedish pulp and paper mill of Billerud Karlsborg is studied, using mixed integer linear programming and different future energy market scenarios. The results show that the required support is strongly connected to the price ratio of oil to biomass, with the support ranging from 10 EUR/MWh biofuel (lower than the present tax exemption of 14 EUR/MWh) to 61 EUR/MWh. The required support is shown to be sensitive to changes of the capital cost, but not to the pulp and paper production rate of the host mill. It is concluded that strong policy instruments will be required for forest industry based biorefineries to be desirable for the future.

1. Introduction

The pulp and paper industry faces several challenges, such as increased competition and rising energy prices. Biorefineries, producing for example biofuels (in this paper the term biofuels is used to denote renewable transportation fuels), chemicals or electricity in addition to the traditional core products, are currently being discussed as future opportunities for the forest industry; see e.g. (Van Heiningen, 2006; Consonni et al., 2009; Jönsson and Algehed, 2010). Thermal gasification enables the conversion of low-quality biomass into a synthesis gas that can be converted into higher value products, such as biofuels, and may constitute a key technology for future pulp and paper based biorefineries. The gasification based biofuel technology is however capital intensive and studies of biomass gasification integrated with district heating have shown that considerable economic policy support is required to reach profitability (Börjesson and Ahlgren, 2010; Wetterlund and Söderström, 2010). Today the main biofuel policy support instrument in Sweden is tax exemption. This causes substantial tax revenue losses and cannot be viewed as a long-term solution. Thus it can be assumed that in the future biofuels will be subject to the same level of energy tax as their fossil

Please cite this article as: Wetterlund E., Karlsson M. and Harvey S., (2010), Biomass gasification integrated with a pulp and paper mill – the need for economic policies promoting biofuels., Chemical Engineering Transactions, 21, 1207-1212 DOI: 10.3303/CET1021202

counterparts. Instead other support instruments, such as tradable green certificates in combination with a quota obligation, may be needed; see e.g. (Wiesenthal et al., 2009).
In this study a pulp and paper mill based biorefinery plant concept incorporating biomass gasification is studied. The main output from the biorefinery is DME (dimethyl ether) for use as a diesel substituting transportation fuel[1]. The BIGDME (biomass integrated gasification DME) process has a steam surplus that can be utilised in the pulp and paper mill. As a case the integrated pulp and paper mill of Billerud Karlsborg is used. The mill can be considered representative for pulp and paper mills with a steam deficit. The aim is to investigate the level of economic policy support needed to make investments in biorefinery technology profitable for a pulp and paper mill, under various energy market conditions for the medium-term future, when bioenergy is likely to be subject to competition. The results can provide policy makers with important information if the promotion of forest industry based biorefineries is a desirable route of development, and demonstrate possible biorefinery opportunities for the forest industry.

2. Method and input data

This work uses an optimisation model of the studied system to evaluate the profitability of biorefinery investments. Four energy market scenarios for around the year 2030 are used to represent different possible future energy market conditions. For each of the scenarios multiple optimisation runs are made while varying the level of the biofuel policy support, in order to find the support required to make investments profitable.

2.1 Studied system

The Billerud Karlsborg integrated pulp and paper mill is situated outside Kalix in northern Sweden. At the mill bleached kraft pulp and sack and kraft paper is produced. The annual production capacity, as used in this study, amounts to 320,000 ADt (air dried t) pulp and 165,000 t paper. The mill incorporates batch digesters, but has for this study been approximated as continuous. High pressure (HP) steam is produced in the recovery boiler and in a power boiler, fired mainly with falling bark and purchased wood fuel. A small amount of oil (~2 %) is used in the boilers. As fuel for the lime kiln internally produced tar oil is used. Electricity is produced in a backpressure turbine (44 MW maximum power output) with intermediate extraction of steam at two levels. Excess low pressure (LP) steam can be vented. The in-house electricity production covers approximately 70 % of the mill's electricity demand (2009). Figure 1 shows an overview of the studied mill, with the biorefinery alternative included.

2.2 Investment options

The mill management is interested in options for transforming the mill into a biorefinery. In this study a biorefinery incorporating DME production is evaluated. In the BIGDME process wood fuel is dried and gasified in a pressurised, oxygen-blown fluidised bed gasifier, followed by gas cleaning and upgrading, and synthesis to DME. Since the BIGDME process requires high quality fuel, a maximum amount of 10% bark is allowed to the gasifier. Excess bark from the pulp production can be sold. The main steam consumers are fuel dryer, distillation, gasifier, reformer and acid gas removal.

[1] Other possible fuel outputs include e.g. Fischer-Tropsch diesel or methanol. DME was chosen because interest in DME production from forest resources is considerable in the studied region.

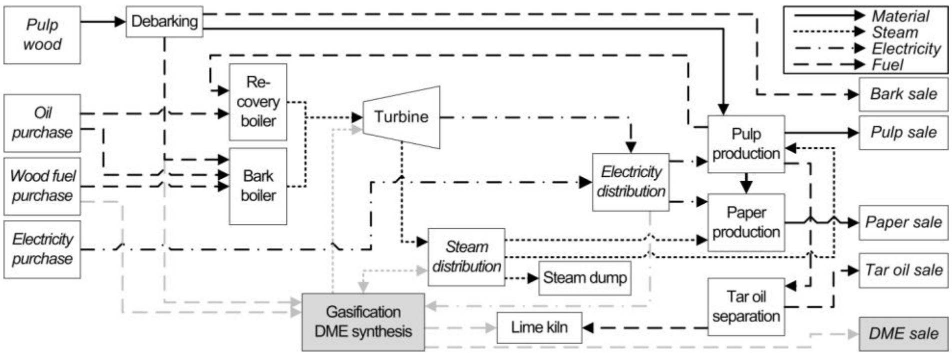

Figure 1: Overview of the studied system. Grey processes and flows indicate options for new investments.

Steam is produced mainly by heat recovery in the gas cooling section. The process has a steam surplus that can be utilised by the mill. HP steam from the BIGDME is superheated in an external superheater fired with offgas from the DME synthesis and directed to the mill's steam turbine. Excess offgas is assumed to replace tar oil in the lime kiln. Low grade heat (~90-150 °C) is assumed to be used in the mill's secondary heat system and for production of LP steam via very low pressure steam compression. Steam levels and process equipment size have been modified to fit the mill considered here. For example, the fuel dryer is assumed to operate at 12 instead of 15 bar, which entails a need for larger equipment. Key data is given in Table 1.

Table 1 Input data for the BIGDME (Ekbom et al., 2005; CEC, 2007; Börjesson and Ahlgren, 2010). The investment cost has been adjusted using the Chemical Engineering Plant Cost Index (CEPCI).

Investment cost	$7.5P^{0.7}$ MEUR/$MW_{biomass}$ (*P* refers to the biomass input)
Investment range	50-400 $MW_{biomass}$
O&M costs (variable/fixed)	3.3 EUR/$MWh_{biomass}$ /3.5% of inv. cost/year
Efficiency (DME/heat/electricity)	0.65/0.11/-0.11 MW/$MW_{biomass}$

2.3 Optimisation model

A model of the pulp and paper mill was constructed using the MIND method (Method for analysis of INDustrial energy systems), which is a method for optimisation of dynamic energy systems, based on mixed integer linear programming. The model includes existing boilers, turbine, steam and electricity users, fuel and electricity purchases, and the possibility to invest in the BIGDME biorefinery. The model is run for one year, where the year is divided into 12 time steps to visualise seasonal variations in process steam demand. The objective of the model is to minimise the annual system cost by choosing the best alternatives regarding operation and new investments, while meeting the specified demand for pulp and paper. The system cost includes fuel, electricity and maintenance costs, as well as revenues for sold biofuel and capital costs. The investment cost is discounted using the annuity method using a capital recovery factor of 0.1, which represents a rather strategic view on the investment.

2.4 Energy market scenarios

Four price scenarios for around 2030 with interdependent parameters are used. The scenarios are based on assumptions about future fossil fuel prices and CO_2 charge levels, using two different fuel price levels and two CO_2 charge levels. The wood fuel price is assumed to be determined by the high volume users' willingness-to-pay, here coal power plants co-firing biomass. This makes coal (including CO_2 charge) price-setting. The electricity price (base load market) is determined by the lowest generation cost for new fossil fuel fired base load plants and the DME price by the price of diesel. The charge for emitting fossil CO_2 is assumed equal in all sectors, including the transport sector. For a full description of the scenarios, see Axelsson et al. (2009) and Axelsson and Harvey (2010). In addition to the scenarios for 2030, market prices for 2009 are also considered, as a reference case. The resulting scenarios are shown in Table 2.

Table 2 Energy market scenario data.

Scenario		**1**	**2**	**3**	**4**	**2009**
Fossil fuel price/CO_2 charge level		low/low	low/high	high/low	high/high	
Wood fuel	EUR/MWh	31	57	34	60	17
Electricity	EUR/MWh	68	90	74	98	20
Heavy fuel oil (incl. CO_2 charge)	EUR/MWh	45	67	67	89	38
Tar oil (selling price)	EUR/MWh	35	35	57	57	22
DME (gate selling price)	EUR/MWh	57	77	88	109	58[a]
CO_2 charge	EUR/t CO_2	35	109	35	109	15[a]

[a] The 2009 scenario includes the current Swedish CO_2 tax, which varies depending on fuel and application. For diesel in the transport sector the CO_2 tax amounts to 119 EUR/t CO_2.

2.5 Sensitivity analysis

The scenarios constitute a sensitivity analysis of energy prices. Additional sensitivity analysis is performed to account for other uncertainties. The annual capital cost naturally has a large impact on the DME production cost. In the sensitivity analysis the capital recovery factor is increased from 0.1 to 0.2, which represents either a less long-term view on new investments, or a higher investment cost. To account for case study specific assumptions, the sensitivity analysis also considers the cases where offgas from the BIGDME process cannot be used in the lime kiln, and where bark cannot be used in the BIGDME process. The impact of the assumed future production level is analysed by considering the case where the annual pulp and paper production is reduced by 20 %.

3. Results

Table 3 shows the biofuel policy support levels necessary in order for investments in the BIGDME biorefinery to be profitable for the mill, for the base case and for the case with increased capital recovery factor. As can be seen the required support for biofuel is highly sensitive to assumed energy market parameters. Of particular importance is the price relation between the DME selling price and the biomass price. As biomass is assumed to be a replacement fuel for coal the biomass price is highly affected by the cost of CO_2, while the DME selling price is mainly determined by the oil price. In scenario 3 and in the 2009 scenario the oil price is high and the biomass price low, which creates strong incentives for investments in biorefinery technology, and makes the BIGDME profitable already with low additional support. In the 2009 scenario the high CO_2 tax imposed on diesel creates additional incentive for biofuel production.

Table 3 Level of biofuel support required to make investment in BIGDME profitable.

Scenario		1	2	3	4	2009
Base case	EUR/MWh	37	61	10	33	10
Capital recovery factor 0.2	EUR/MWh	59	84	33	58	32

The required support can be compared to the present Swedish subsidy for biofuels substituting diesel, which is exemption from the energy tax imposed on diesel of 14 EUR/MWh. As the table shows, the required support level is in general considerably higher than the present tax exemption, with the exception of scenario 3 and the 2009 scenario, where the required support is comparable to the present exemption.

Table 3 also shows that the required support is very sensitive to changes in capital cost (higher capital recovery factor or increased investment cost). The sensitivity analysis of the more case study specific assumptions (not shown in Table 3) shows that the required support levels are unaffected by the possibilities to use offgas from the BIGDME process in the lime kiln and bark from the pulp production in the BIGDME process. Neither does the production volume affect the required support.

4. Concluding Discussion

In this study support for biofuels has been analysed. The support could for example be in the form of tradable green certificates, the cost of which would burden the consumer, or, as is common today, in the form of tax reduction or exemption. The required support was found to range from lower than the present tax exemption, to more than four times the exemption, depending mainly on the price relation between oil and biomass. In this study future energy market scenarios with interdependent parameters have been used. The scenarios should not be viewed as attempts to accurately predict the future, but rather as a sensitivity analysis of a wide span of possible future market conditions. Core assumptions are that the future biomass price will be affected by the cost of emitting CO_2 due to the demand from for example coal power plants, and that the CO_2 charge will increase considerably. Today the price of emission permits within the EU is around 15 EUR/t CO_2. The prices used here are substantially higher. However, in 2006 the emission permit price reached 30 EUR/t CO_2, and the current Swedish CO_2 tax is in line with the higher CO_2 charge used here. The CO_2 prices used can thus not be regarded as unreasonable for the time frame considered. A higher CO_2 charge also affects the diesel price, and thus raises the DME selling price. This effect is however largely overshadowed by the increased biomass price. Unsurprisingly a high oil price reduces the necessary support level. In a market where demand for bioenergy as fossil fuel replacement increases the competition for the limited biomass resource, biomass prices are likely to soar, something that the forest sector is already experiencing. Transformation into biorefineries producing high-value products may provide the industry with a competitive way to meet increased feedstock costs. However, as this study shows, substantial policy support will likely be a requirement for profitability in biofuel production integrated with pulp and paper production.

In this study the Billerud Karlsborg pulp and paper mill has been used as case study. One main uncertainty in the study is that the mill incorporates batch digesters that have out of necessity for the time resolution employed in this study been approximated as continuous. On an aggregated monthly level this gives good correspondence to actual operation data, but on an hourly level the steam balance will be different than modelled here. To some extent this can be handled by the mill's steam accumulator, but more thorough calculations on a considerably shorter time frame will nonetheless be needed.

The studied mill is situated in a region abundant in forest resources, which makes biorefineries an interesting option to study from both the industry's and the region's perspective. This first paper will be followed by further biorefinery studies of the case mill and the surrounding region, with extended analysis of for example how the biomass price is affected by increased demand due to investments in biorefinery technology.

Acknowledgements

This work was carried out under the auspices of The Energy Systems Programme, financed by the Swedish Energy Agency. The study is part of the project "Development of regional-economic process integration model for Billerud Karlsborg", financed by Billerud Karlsborg and the Swedish Energy Agency. The authors would like to thank Karin Lundstedt and her colleagues at Billerud Karlsborg for invaluable support.

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