IEA Bioenergy

Task 38

Greenhouse Gas Balances of Biomass and Bioenergy Systems

Reductions in greenhouse gas emissions and oil use through di-methyl ether and Fischer-Tropsch diesel production in Swedish chemical pulp mills

Leif Gustavsson[1]* and Jonas Joelsson[2]

[1] Department of Building and Energy Technology, Linnaeus University, SE-351 95 Växjö, Sweden

[2] Processum Biorefinery Initiative AB, Box 70, SE-891 22 Örnsköldsvik, Sweden

* Contact: Leif Gustavsson (leif.gustavsson@lnu.se)

Summary

In this study, we analyse the resource efficiency and the reductions in CO2 emissions and oil use when motor biofuels are produced in an integrated pulp and paper mill, under Swedish conditions, and used to replace fossil motor fuels. In addition, di-methyl ether production through black liquor gasification (BLG-DME) is compared with Fischer-Tropsch fuel production through solid biomass gasification (BIG-FT). In order to allow comparison, stand-alone production of biomass-based electricity and motor fuel is added so that both systems yield the same amounts of motor fuel, electricity and pulp. More motor biofuel can be produced in integration with the studied mills using BLG-DME than with BIG-FT because the black liquor flow is large and the integration potential for BIG-FT is limited by the mill's heat demand. When both systems are required to produce the same output, the BLG-DME system achieves larger reductions in CO_2 emissions and oil use per unit of biomass consumed. Integration of motor biofuel production with a pulp mill is more efficient than stand-alone motor biofuel production, but larger reductions in CO_2 emissions or oil use can be achieved if biomass replaces coal or oil directly in stationary energy applications.

Scope

The use of motor biofuels is increasing and has been promoted in many areas with the goals of reducing greenhouse gas (GHG) emissions and securing the energy supply. In Sweden, the pulp and paper industry processes large amounts of forest biomass and produces large amounts of by-products that are mainly used for energy purposes. The integration of motor biofuel production with existing pulp and paper mills has therefore achieved special attention.

In 2007 Swedish pulp mills used 48 Mm^3 of wood (corresponding to about 380 PJ of energy, at a moisture content of 40%) to produce 12.4 million tonnes (Mt) of pulp. The mills use large amounts of steam, which is commonly cogenerated with electricity. About 220 PJ of fuel was used for steam production in 2007, which was 10% of the total Swedish primary energy use.

Figure 1: Piteå di-methyl ether (DME) plant
Photo: Chemrec

The single largest fuel source was black liquor – a lignin-containing pulp mill by-product – accounting for more than 60% of the total fuel use in the Swedish pulp and paper sector.

Bark and other wood residues accounted for most of the remainder, while fossil fuels represented about 8% of the fuel used. Motor biofuel production based on gasification technology could be integrated into pulp mills, with recovery of surplus heat in the motor fuel production to be used for process steam in the mills. The heat sink of the mill processes is a precondition for efficient integration of motor biofuel production.

Figure 2: Varkaus Fischer-Tropsch (FT) plant
Photo: Stora Enso

Description

In this study, we analyse the resource efficiency and the reductions in CO_2 emissions and oil use when motor biofuels are produced in integrated pulp and paper mills, under Swedish conditions, and used to replace fossil motor fuels. We compared a concept based on black liquor gasification (BLG) to a concept based on solid biomass gasification (BIG). The BLG alternative produces dimethyl ether (DME) and is being developed in Sweden by the company Chemrec. The technology has been demonstrated in a pilot plant at a pulp mill in Piteå, Sweden (Figure 1).

The BIG alternative produces Fischer-Tropsch (FT) fuel and has been demonstrated at a mill in Varkaus, Finland, by Stora Enso and Neste Oil (Figure 2). Both technologies are being considered for larger-scale demonstration plants.

Biomass is a limited resource that should be used efficiently. Replacement of coal with biomass in large-scale, stationary applications is an efficient and potential large-volume use of biomass as CO_2 emission constraints become increasingly important. If biomass is instead used to replace oil, Gustavsson et al. [1] showed that larger oil use reductions per unit of biomass can be achieved by replacing fuel oil with biomass in stationary applications than if biomass is converted into motor fuel that replaces fossil motor fuels. In 2006, 11 000 PJ of oil products were used outside the transportation sector in Europe, which is a large amount compared with the available biomass. Long-distance transport of biomass is plausible with respect to primary energy efficiency and CO_2 balance, albeit at an increased transportation cost. Large-scale production of motor biofuel in a mill requires an input of additional biomass and may divert resources from their current use or from other potential uses. The benefits of mill-integrated motor biofuel production were therefore compared with the alternative benefits that could be achieved if biomass was used to replace coal or oil in stationary applications.

The BLG-DME alternative is limited by the amount of black liquor available while the BIG-FT alternative is limited by the steam demand of the mill. The black liquor recovery boiler provides most of the steam demanded by a typical chemical pulp mill. Hence, there is little demand for additional steam and consequently a small potential for integration of the BIG-FT alternative. The potential for the BLG-DME alternative will typically be larger, since it utilises the black liquor flow, thereby replacing the recovery boiler. In general, the use for waste heat is limited and demand for motor fuel, beyond amounts produced in integrated plants, has to be met with stand-alone production of fuels. This is the case in the system under consideration.

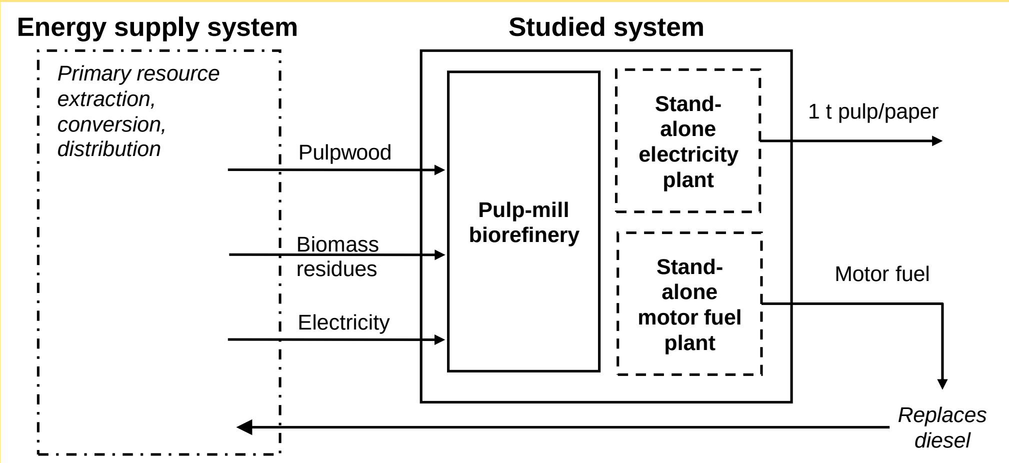

Figure 3: Study system

Table 1: Reference system data

	CO_2 emissions, kg/GJ		Oil use, GJ/GJ	
	End-use	upstream	End-use	Upstream
Coal	96.3	8.2	0.0	0.04
Diesel	73.2	14.2	1.0	0.16
Fuel oil	73.2	14.2	1.0	0.16
Biomass residues	0	1.3	0	0.02

The studied system components are shown Figure 3. The system includes the pulp-mill, the integrated motor fuel plant, and stand alone plants for motor fuel and electricity production from biomass. It interacts with a reference energy supply system through energy inputs and outputs. Bioenergy produced in the mill biorefineries is assumed to replace fossil-based reference energy carriers, and thereby reduce CO_2 emissions. Energy use and emissions associated with the construction or maintenance of buildings, vehicles, infrastructure, etc., were not considered.

Energy use in the main upstream processes, such as extraction, transportation and conversion of biomass, fossil fuels, and other primary energy sources, was taken into account in the calculations, both for the biomass system and the reference system. The biomass used in addition to internal mill residues is assumed to be logging residues.

The Swedish productive forest is managed in such a way that the forest biomass and hence the carbon stock is increasing over time. The CO_2 emitted from forest biomass combustion, decay etc. is therefore more than balanced by CO_2 uptake by growing forest on a landscape level. Furthermore, more intensive use of forest biomass for motor biofuel production could be accompanied by more intensive forest management that would further increase biomass production levels and standing carbon stock [e.g. 2]. These carbon stock implications were not included in this study. Instead we assumed conservatively that Swedish forest management, including the use of internal mill residues and logging residue, would not change the forest carbon stock on a landscape level.

Functional unit

The integration potential for fuel production is limited by the pulp and paper production. The functional unit of the case study is therefore based on 1 tonne of pulp/paper product.

Reference energy system

The supply of fossil gas is considered less secure than the supply of coal, and based on the driving forces of CO_2 emission reduction and energy supply security we assumed that a change in electricity demand or supply in Sweden will, in the longer term, mainly affect electricity production in coal-based condensing plants. Diesel was used as the reference fossil motor fuel. Selected reference system data are presented in Table 1

Method

The results from published GHG balance assessments of motor biofuels vary significantly. The reasons for the variations could be many, for example, differences in the setting of system boundaries, selection of reference system, assumptions on carbon stock changes, and allocation methods. To compare biorefinery configurations we applied system expansion, where stand-alone production of motor fuel from biomass was added so that the compared systems produced the same outputs in terms of pulp/paper product and motor fuel. Stand-alone production of electricity from biomass was added to compensate for the lost cogeneration potential and increased electricity demand when the motor fuel production is integrated into the mill. The data for the

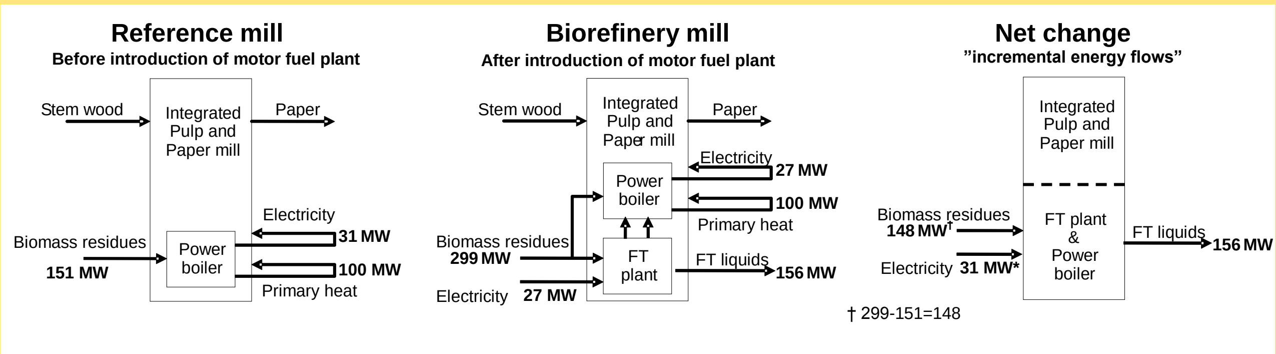

Figure 4: Incremental flows exemplified for the Fischer-Tropsch (FT) case

BLG-DME alternative were based on Pettersson and Harvey [3] and Ekbom et al. [4] while data for the BIG-FT alternative were based on McKeough and Kurkela[5].

A state-of the-art conventional chemical pulp mill integrated with a paper mill, without motor fuel production, was used as reference case. We considered a pulp mill scale corresponding to a fuel demand (excluding black liquor) of 100 MW. Results were also calculated for variations in the steam demand of the mill and for variations in the mill type including a chemical market pulp mill and a liner mill that uses both internally produced and bought pulp. The difference in energy and material flows between a mill with motor fuel production and the reference mill is termed incremental (Figure 4). The incremental flows were used to calculate CO_2 emission and oil use balances.

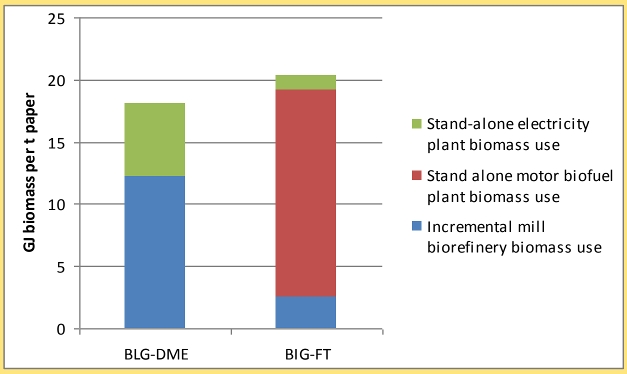

Figure 5: Incremental biomass use to produce the functional unit.

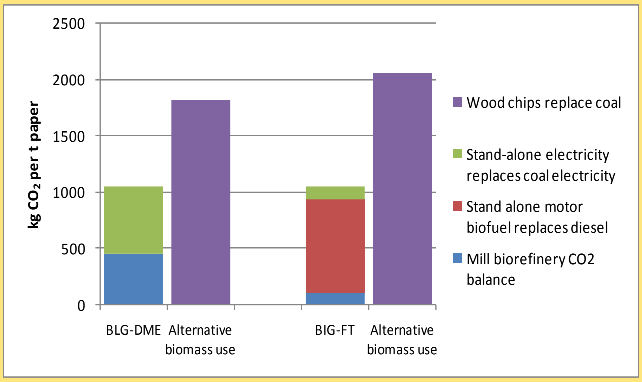

Figure 6: Reduction in fossil CO2 emissions

Reductions in CO_2 emissions and oil use will depend on the energy balance of the studied motor biofuel production system and on the reference energy system. The reference energy system defines which energy carriers will be replaced by energy exported from the mill and how energy inputs to the mill are supplied. When expanded with stand-alone production, all pulp mill systems produce the same output, with biomass as the only input. Here, the functional unit is 1 tonne of pulp/paper product, 0 GJ of electricity and X GJ of motor fuel. Hence, the same amount of fossil motor fuel is therefore replaced, but the biomass demand may be different for the different biorefineries. The reductions in CO_2 emissions and oil use per unit of biomass use therefore vary between the systems.

We defined the system efficiency to be the amount of motor fuel produced per unit of biomass used – including the incremental biomass use of the integrated mill/motor fuel plant and the biomass used for stand-alone production of motor fuel and electricity. As a base case, the efficiency for stand-alone motor fuel production was assumed to be 56%, and for stand-alone electricity production to be 47%. Gasification based technologies were assumed to be used for both motor fuel and electricity production.

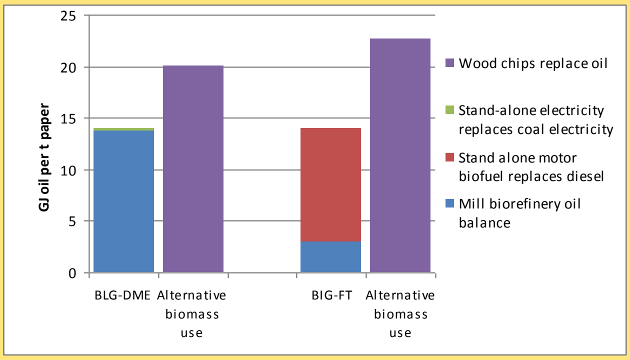

Figure 7: Reduction in oil use

Results

The calculated biomass requirement was higher for the BIG-FT alternative than for the BLG-DME alternative, when the systems were expanded with stand-alone production so that they produced the same amount of motor biofuel (Figure 5). In the BLG-DME mill, most of the biomass was used in the mill, to cover the steam deficit when a large part of the black liquor energy was exported as motor biofuel. Biomass was also used for stand-alone electricity generation to compensate for the lost cogeneration of electricity and the increased electricity demand of the DME plant. For the BIG-FT alternative, a large amount of biomass was used for stand-alone production of motor biofuel to achieve the same amount of motor biofuel production as for the BLG-DME mill. Stand-alone production is less efficient than integrated production, which is why the biomass use was higher for the BIG-FT alternative.

As both systems were balanced to yield the same output, they achieved the same CO_2 emission and oil use reduction (Figure 6 and Figure 7) assuming that the net contribution of CO_2 from the biomass carbon cycle to the atmosphere is zero. However, the BIG-FT alternative required a larger biomass input, and hence has lower system efficiency. Larger CO_2 emission reduction could be achieved if biomass was instead used to replace coal in stationary applications, and larger oil use reduction could be achieved if oil was replaced in stationary applications.

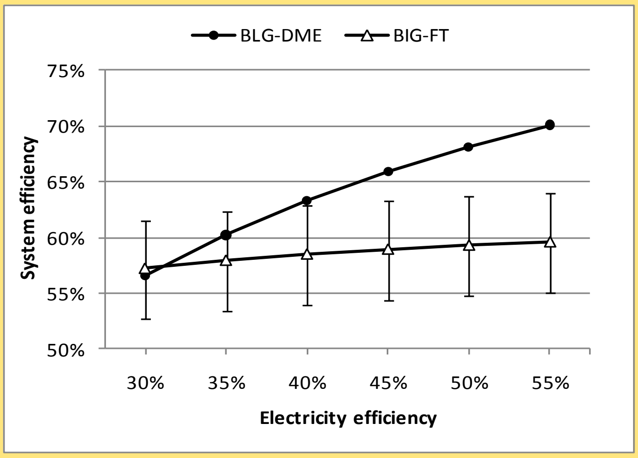

Figure 8: System efficiency of the BLG-DME and BIG-FT biorefineries as a function of the stand-alone electricity generation efficiency. Error bars denote the variation in system efficiency as the stand-alone motor biofuel generation efficiency is varied by +/- 5 %-units. The variation applies only to the BIG-FT case, because no stand-alone motor biofuel generation is required in the BLG-DME case.

Factors that influence the results

The results are affected by many factors, besides the technical performance of the integrated motor biofuel plants themselves. Figure 8 shows the system efficiency for the BLG-DME and BIG-FT systems as a function of the stand-alone electricity efficiency. The results were also calculated for a +/- 5 %-units change in the efficiency of the stand-alone motor biofuel generation. The corresponding change in system efficiency is illustrated by error bars in Figure 8. Lower stand-alone electricity efficiency and higher stand-alone motor biofuel efficiency favoured the BIG-FT alternative. The amount of motor biofuel that can be produced in the integrated mill influences the result. The BLG-DME alternative is limited by the available black liquor, while the BIG-FT alternative is limited by the demand for additional fuel to meet the steam demand of the mill. In the reference mill, the ratio of additional fuel to black liquor is 0.12. In a less efficient mill more additional fuel is needed, and the ratio is higher. It is roughly approximated that in a mill identical to the reference mill but with the performance of today's average mills, the ratio would be 0.2. Also, the type of mill will influence the ratio. Based on data for a modern liner mill, the ratio is calculated to approximately 0.16, while a modern market pulp mill may meet all of its steam demand with black liquor alone, i.e. an additional fuel to black liquor ratio of 0. Figure 9 shows the relative system efficiency of the BIG-FT option compared to the BLG-DME option for each of these alternative mills.

Discussion

In a conventional chemical pulp and paper mill, the power boiler serves the purpose to supply steam to the mill processes, and to co-produce electricity. The recovery boiler has the additional purpose of recovering the pulping chemicals. We conclude that, by substituting conventional technologies with gasification technologies that produce motor biofuels and at the same time fulfil the services of the conventional technologies, motor biofuels can be produced more efficiently than in stand-alone motor

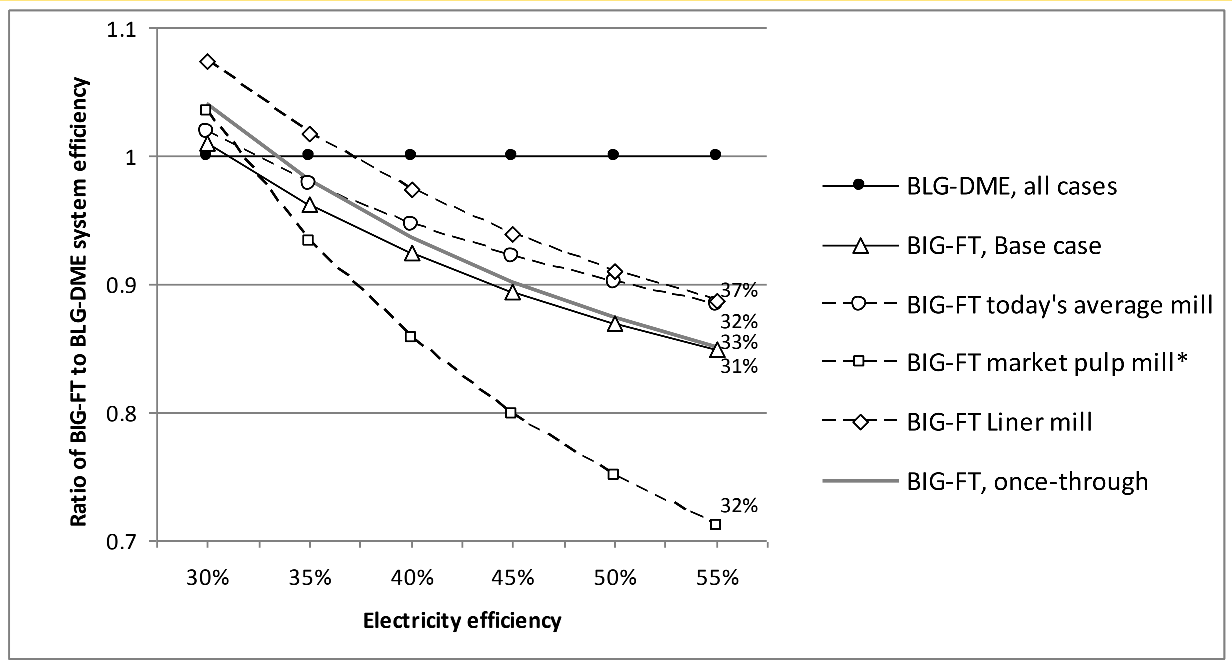

Figure 9: Ratio of the BIG-FT system efficiency to the BLG-DME system efficiency for variations types of mills and steam demands, as a function of the stand-alone electricity generation efficiency. The stand-alone electricity efficiencies at which the BLG-DME and BIG-FT alternatives achieve the same system efficiency are given for each mill type and steam demand variation.

** In the market pulp mill there is no potential for integration of BIG-FT, hence in this alternative all motor fuel is produced in a stand-alone plant.*

biofuel plants. However, the integration potential for solid biomass gasification is limited in a modern mill with low steam demand. When the studied systems are required to produce the same amount of motor biofuel per tonne pulp, the BLG-DME system has higher system efficiency due to the larger integration potential per tonne pulp. Our results also show that there are other uses for biomass that can reduce oil use and CO_2 emissions more than motor biofuel production. For example, the total oil use reduction is larger if biomass is used as a replacement for fuel oil in stationary applications instead of being used for motor biofuel production. If CO_2 emission reduction is the priority, gasification with increased electricity generation may be a better choice, for the pulp mill, than motor biofuel production. This alternative was not included here. To compare different alternative biofuel production technologies, it is important to carefully choose system boundaries and functional units so that all relevant aspects are taken into account. For the pulp mill biorefineries studied here, it is important to consider that different amounts of auxiliary electricity are used, that the integration potential per unit of pulp/paper product varies, and that the amount of pulp/paper product limits the co-production of biofuels.

In summary, we conclude that:

1. Pulp mill integrated production of motor biofuels is more efficient than stand-alone biofuel production.
2. The integration potential in pulp mills is smaller for BIG-FT than for BLG-DME. Hence, to produce the same amount of motor biofuel, more biofuel needs to be produced in stand-alone plants, giving lower motor biofuel efficiency for the BIG-FT alternative.
3. Reductions in CO_2 emissions and oil use are achieved more efficiently if biomass replaces oil in stationary applications. Even larger CO_2 emission reductions can be achieved if biomass replaces coal in stationary applications.

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