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Transportation fuel production from gasified biomass integrated with a pulp and paper mill - Part B: Analysis of economic performance and greenhouse gas emissions

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ABSTRACT

This paper presents a comparison between four gasification-based biorefineries integrated with a pulp and paper mill. It is a continuation of 'Transportation fuel production from gasified biomass integrated with a pulp and paper mill - Part A: Heat integration and system performance'. Synthesis into methanol, Fischer-Tropsch crude or synthetic natural gas, or electricity generation in a gas turbine combined cycle, were evaluated. The concepts were assessed in terms of GHG (greenhouse gas) emissions and economic performance. Net annual profits were positive for all biofuel cases for an annuity factor of 0.1 in the year 2030; however, the results are sensitive to biofuel selling prices and $CO_{2,eq}$ charge. Additionally, GHG emissions from grid electricity are highly influential on the results since all biofuel processes require external power. Credits for stored CO_2 might be necessary for processes to be competitive, i.e. storage of separated CO_2 from the syngas conditioning has an important role to play. Without CO_2 storage, the gas turbine case is better than, or equal to, biofuels regarding GHG emissions. Efficiency measures at the host mill prior to heat integration of a gasification process are beneficial from the perspective of GHG emissions, while having a negative impact on the economy.

1. Introduction

Production of transportation fuels from biomass (here referred to as biofuels) has been suggested as a way of introducing renewable alternatives in the transportation system to hinder the build-up of GHG (greenhouse gases) in the atmosphere. Biomass can be converted to fuels through gasification into gases rich in CO and H_2, which can be used as building blocks for synthesis of virtually any hydrocarbon. Such processes have limited conversion efficiency and the remaining energy leaves the process as heat. Efficient utilisation of this heat should facilitate more efficient use of biomass resources and improved economic competitiveness. By co-locating a gasification process with a heat demanding industry, the excess heat can be consumed throughout the year. Additionally, if woody biomass has been the source of energy to provide heat for that industry, that biomass can possibly be redistributed to the gasifier. The host process could be, for example, a PP (pulp and paper) mill which has the benefit of having the infrastructure and knowledge in place to handle large amounts of biomass, apart from having a heat deficit. Some mill owners also own their own forest, which further ensures supply. These processes would together form a biorefinery, producing multiple products from a bio-based raw material.

Previous works concerning GHG emissions and economics for biorefineries integrated with existing industry and with kraft PP mills in particular have been performed before. GHG emission consequences have been studied by for example Ljungstedt et al. [1], Larson et al. [2] and Tunå et al. [3], using different methodologies. The studies by Ljungstedt et al. and Larson et al. also include economic assessments. GHG emission consequences of integrating gasification-based biofuel production with a mechanical PP mill were investigated in a previous paper by Isaksson et al. [4]. This type of gasification-based industrial symbiosis is not restricted to PP mills, but has been studied also for, e.g., oil refineries [5], district heating systems [6] and sugar mills [7]. Earlier work within the

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Nomenclature

ADt	air dry tonnes (90% dry solids content in the pulp)
BECCS	bio-energy with carbon capture and storage
BGCC	biomass gasification combined cycle
CCS	carbon capture and storage
CFB	circulating fluidised bed
EM	efficiency measures
ENPAC	Energy Price and Carbon Balance Scenarios tool
FT	Fischer-Tropsch
GHG	greenhouse gas
HRSG	heat recovery steam generator
IEA	International energy agency
IRR	internal rate of return
NPS	new policies scenario
NAP	net annual profit
PP	pulp and paper
SNG	synthetic natural gas
t	tonne = metric ton
WEO	world energy outlook
450	450 ppm scenario

field of PP mill integrated gasification-based biorefineries concerning heat integration aspects, GHG emission consequences and economics is further discussed in the first part of this study [8]. The economic performance and the net GHG emission consequences of the proposed processes in that paper are assessed here.

2. Objective

The objective of this study was to compare the economic performance and GHG emission consequences of four gasification-based biorefineries integrated with an existing chemical PP mill. The economic and environmental performances were evaluated under two different consistent sets of fuel prices and $CO_{2,eq}$ charge in a future energy market, for two different time periods. A comparison between end-products from solid biomass gasification in a PP mill with respect to economic performance and GHG emissions, such as the one presented in this paper, has not been found in the literature.

3. Studied processes

For a detailed description of the studied PP mill and the four gasification processes, including choices of different modelling parameters and flowsheets, the reader is referred to the first part of this study [8]. A summary of the results from that paper is provided in Section 4. The host process is a PP mill producing 2000 ADt d^{-1} of unbleached pulp, which is used together with purchased bleached chemical pulp, recycled fibres and fillers to produce kraftliner (cardboard). The recovery boiler covers the heat demands of the processes together with a boiler with 75 MW bark input. About half of the bark boiler feed is the on-site falling bark, while the remaining part has to be purchased. The onsite back-pressure steam turbine is large enough to avoid by-pass expansion [9].

The studied end-products from the gasification-based systems are methanol, FT (Fischer-Tropsch) crude, SNG (synthetic natural gas); and electricity production in a gas turbine combined cycle (biomass gasification combined cycle – BGCC). The systems were simulated in Aspen Plus [10] to retrieve mass and energy balances. The front-ends of all four gasification processes are essentially the same, and consists of an air-dryer, able to utilise low temperature heat to dry the biomass before the gasifier, followed by a CFB (circulating fluidised bed) gasifier operated at 5 bar. The gas is cleaned in a hot gas candle filter before being sent through a catalytic reformer, water-gas-shift for H_2/CO adjustment, scrubber for final removal of impurities, and finally, removal of sulphur and CO_2 in a methanol-based process before synthesis into methanol, FT crude or SNG. The reformer is operated differently depending on whether methane needs to be preserved. Generation of fuel gas for the gas turbine takes place in an air-blown CFB gasifier followed by a hot gas filter, while oxygen is used as an oxidising agent for the three biofuel cases. A HRSG (heat recovery steam generator) is used to utilise the energy content of the exhaust gases from the gas turbine to raise steam, which is sent through a steam turbine for electricity generation.

The sizing constraint of the gasification processes is either to exactly replace the present bark boiler with excess heat from the gasification process, or to design the new biorefinery processes with a fixed size in terms of biomass input. A size of 400 MW was considered large enough to benefit from economy of scale and to result in a steam surplus at the studied PP mill. The steam excess can be utilised in a condensing steam turbine for additional electricity generation. A certain degree of energy efficiency measures at the PP mill in connection with biorefinery integration were proposed in Ref. [8].

4. Results from part A

Part A [8] of this study focuses on the integration potential between the PP mill and various novel biorefinery concepts for two different sizing constraints, as described in Section 3. The integration potential was also evaluated when certain efficiency measures were performed at the PP mill. Additionally, a more generalised case was included in the study where 70% of the theoretical heat savings potential of the PP mill was to be realised. It was found that the end-product of a gasification-based biorefinery can have significant impact on the heat integration potential with a PP mill. End-products with high conversion efficiency will require a larger process throughput if the heat demand from the PP mill is to be met because less excess heat is generated per unit of product. Furthermore, it was found that the efficiency measures implemented in the mill can increase the biomass resource efficiency by up to 3 percentage points. The different efficiency measures can reduce the necessary size of the biorefinery by 50% if the sizing constraint is to replace the bark boiler with excess heat from the biorefinery. A large fixed biomass input to the gasifier (400 MW here) was found to be beneficial in terms of biomass efficiency for a marginal electrical efficiency of 30% or below. Because marginal electricity should be possible to be produced more efficiently than that, a large system with a condensing turbine will not be feasible from that perspective. Table 1 summarises some key results from Part A of this study.

5. Methodology

The evaluation of the studied biorefinery concepts was performed systematically through a three step approach. As large scale biomass gasification for biofuel production is not established, the mass and energy balances have to be estimated using process simulation. Heat integration potential between the host PP mill and the gasification based system is consecutively evaluated using pinch analysis methodology. These first two steps are described in detail in the first part of this study [8]. Thirdly, the systems are evaluated in terms of biomass efficiency, included in Part A, and in terms of GHG emission consequences and economic performance,