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Bio-SNG Production in a TMP Mill in Comparison with BIGCC

Jie He, Per Engstrand and Wennan Zhang
Mid Sweden University, Sundsvall, SE-85170, Sweden

Jie He (jie.he@miun.se)
Per Engstrand (Per.Engstrand@miun.se)
Wennan Zhang (wennan.zhang@miun.se)

Abstract
Biorefinery as a concept for polygeneration of various bio-based materials, fuels and chemicals has been more and more attractive. This concept is applied to the thermomechanical pulp (TMP) and paper industry in the present study to evaluate the possibility of co-production of substitute natural gas (SNG), electricity and district heating (DH) in addition to mechanical pulp and paper. In TMP mills, wood and biomass residues are commonly utilized for electricity and steam production through an associated combined heat and power (CHP) plant. This CHP plant is designed to be replaced by a biomass-to-SNG (BtSNG) plant including an associated heat and power centre. Implementing BtSNG in a mechanical pulp production line might improve the profitability of a TMP mill and also help to commercialize the BtSNG technology by taking into account of some key issues such as, biomass availability, heat utilization etc.. A TMP+BtSNG mathematical model is developed with ASPEN Plus.

Keywords:
Biomass, Gasification, Methane, TMP, Electricity

Introduction
The present transport biofuels in the market are produced mainly from food crops, referred to as the 1st generation biofuels, which are not encouraged any longer. From the viewpoint of economics, environment, land use, water use, chemical fertilizer use, etc., however, there is a strong preference for the 2nd generation biofuels that are produced from woody, grassy materials as well as agricultural residues, municipal wastes and industrial wastes as the feedstock. Thus, the production of the synthetic transport fuels such as methanol, ethanol, dimethyl-ether (DME), Fischer-Tropsch (FT) fuel and synthetic natural gas (SNG) via gasification and synthesis is promising (Zhang 2010). Production of these fuels from coal and natural gas has been well commercialized e.g., by Sasol and Mobil (Dry 2002). For biomass, however, the technology has not been established mainly due to the high production cost against a limited scale of biomass-based plant.

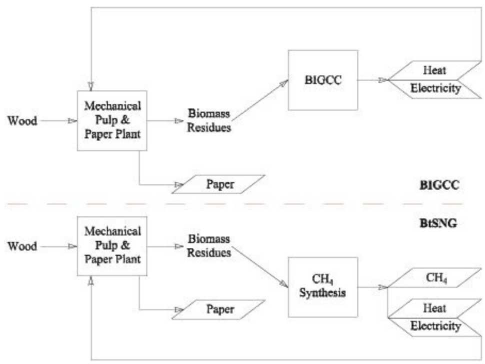

Figure 1: Two designed systems integrated with a mechanical pulp mill respectively

Among the above mentioned fuels, bio-SNG can be produced easily since the once-through methanation conversion efficiency is high even at a moderate condition, and a sophisticated upgrading of products is not needed. Thus, biomass to SNG (BtSNG) can be realized commercially with a small & medium scale of around 100 MW.

The thermo-mechanical pulping (TMP) process is electrical energy-intensive in pulp & paper industry. A previous

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study has investigated the profitability of a TMP mill integrated with a biomass integrated gasification combined cycle (BIGCC) for electricity generation (He, Engstrand et al. 2013). In the present study, the feasibility ofbiomass gasification-based technology to produce CH_4, in a TMP mill is evaluated and compared with TMP+BIGCC in terms of the technical and economic aspects. Fig. 1 schematically shows two designed systems integrated with a TMP mill.

Results and Discussion

The TMP+BtSNG block flow diagram with an outline of mass and energy input and output is shown in Fig. 2. About 100 MW of biomass residues including bark, bio-sludge, reject fibres from TMP and logging residues from pulpwood harvesting in forest are available for bio-SNG production in the TMP+PM mill with a paper production capacity of 250,000 t/yr. 63 MW of bio-SNG can be produced as the bio-SNG yield of BtSNG is estimated to be 63%. The remaining energy of 37 MW of biomass feedstock is carried by flue gas from the combustor, product gas from the gasifier, the cooling medium from methanation etc. in the form of heat at different temperatures. This heat energy is recovered to generate 31 MW steam going to the steam cycle in the heat & power (H&P) centre with 6 MW heat loss. The H&P centre subsequently supplies TMP+PM with 9.5 MW steam, BtSNG itself with 6.0 MW electricity, and DH with 4.5 MW low temperature heat.

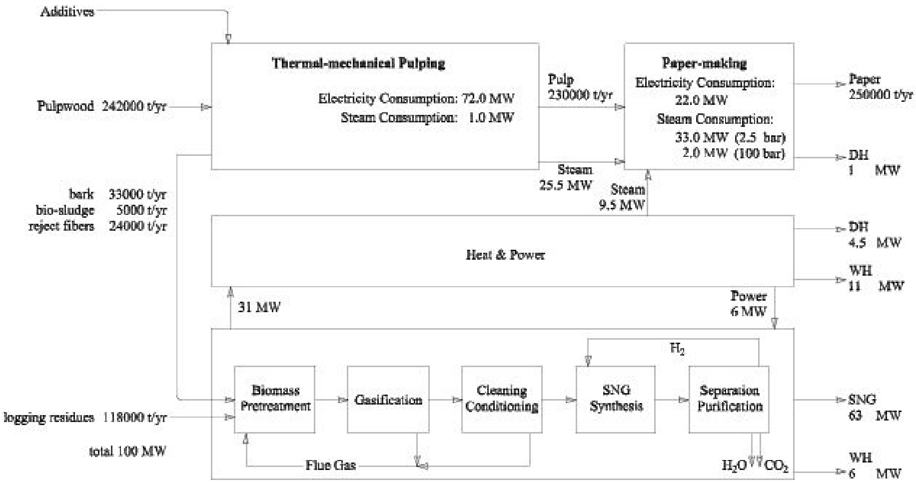

Figure 2: A TMP+BtSNG block flow diagram with the major mass and energy inputs and outputs

The steam cycle in the H&P centre has a generation efficiency of 20% and produces 6 MW electricity to meet the demand of BtSNG for the compression of syngas and bio-SNG, syngas cleaning, CO_2 removal, gasifier operation etc.. Little excess electricity is available for the TMP+PM mill. On the other hand, the H&P centre can supply TMP+PM with enough steam, 9.5 MW, and 4.5 MW low grade heat energy can be recovered as DH. As a result, the H&P centre has a total efficiency of about 65%, and BtSNG has an overall efficiency of 83%.

The energy balance over the TMP+BtSNG mill is studied by applying the model, in comparison with other two cases of TMP+BIGCC and TMP+ Boiler studied previously (He, Engstrand et al. 2013), as seen in Fig. 3. For the TMP+PM mill studied, the TMP SEC is 2.5 MWh/bdt pulp, the PM SEC is 0.75 MWh/bdt pulp, and the steam consumption in the PM is 1.38 MWh/bdt pulp (see Table 1). The total steam demand is kept constant because of the constant paper throughput, and is provided from the steam energy recovered mainly from the TMP refining process and also from the BtSNG process to a minor degree. The enhancement of refining efficiency lowers the steam yield from TMP. Moving out the reject fibres makes the TMP more energy-efficient, ***i.e.,*** the TMP SEC is reduced, and the steam yield from TMP is also reduced. A decrease in the steam generation from TMP is compensated for from the BtSNG plant so that the bio-SNG yield may be reduced. The model is designed to ensure that the steam consumption is sufficiently satisfied, as the results indicate in Fig. 3. The residual low-grade energy is utilized in DH. The heat energy for DH is from both TMP and BtSNG.

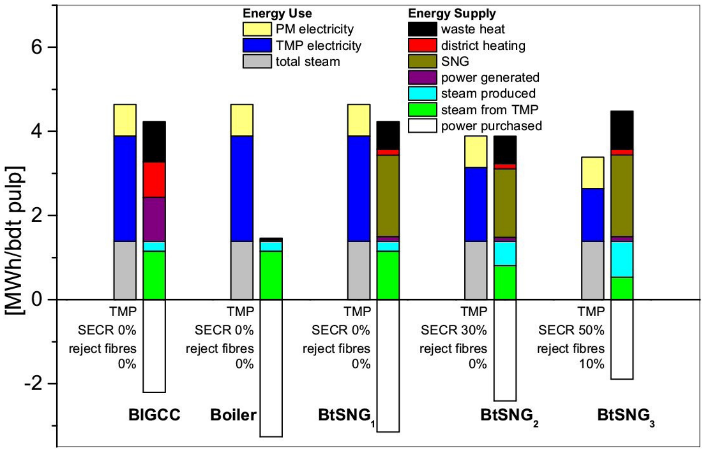

Figure 3: Poly-generation of SNG, electricity, and heat in a TMP mill

In the case of Boiler, which is common for present TMP mills, The TMP biomass residues such as bark, reject fibres are burned to produce the steam needed by PM. No poly-generation is considered by utilizing the large amount of logging residues as seen in Fig. 3.

Compared with the case of BIGCC, $BtSNG_1$ gives almost double product yield in energy content and much less DH and WH, so that the overall energy efficiency is high, but more electricity will need to be purchased.

In the case of $BtSNG_2$ when the SECR is raised from 0 to 30%, the steam generated from TMP refining is reduced, and more steam production from BtSNG is required. The steam demand exceeds the steam provided by BtSNG under normal operation condition of maximizing bio-SNG production. Thus a part of syngas will be burned to provide steam, which gives rise to a lower bio-SNG yield.

In the case of $BtSNG_3$ when the SECR is raised to 50% by 10% fibre rejection, the bio-SNG yield is increased back to the level of the BtSNG1 case in spite of more syngas going to steam production. This is attributed to the 10% reject fibres leading to twofold impacts, 1) direct addition of 10% reject fibres as feedstock to BtSNG and 2) indirect addition of total biomass residues to the gasifier. The usable biomass, about 3.1 MWh/bdt pulp, includes the logging residues, bark, and bio-sludge, and is about 3.9 MWh/bdt pulp, further including the reject fibres (10 wt.%). The paper yield will be kept by adding more pulpwood, though the reject fibres are moved out.

The above analysis of energy balance over the TMP+BtSNG mill is based on a typical scale of TMP+PM mills with a paper production capacity of 250,000 t/yr. The corresponding scale of the BtSNG plant is 100 MW of biomass thermal input. The scale of the BtSNG will be taken to represent the whole scale of the TMP+BtSNG mill for economical analysis as shown in Fig. 4.

As seen in Fig. 4(a), the bio-SNG production per tonne of pulp holds constant against the scale, which indicates a linear relationship between the bio-SNG production and the TMP pulp output. The steam produced from the H&P centre associated to the BtSNG plant is fairly limited in comparison with the BIGCC plant, but still can meet the demand of the TMP+PM mill as shown in Fig. 4(b). Very little heat energy is available for DH, which can also be observed from Fig. 3.

The economic profitability is also sensitive to both the SNG price and the pulpwood price as seen in Figs. 4(c) and 4(d). When the SNG price is doubled, the IRR increases from about 2% to about 16%. When the pulpwood price is doubled, the IRR decreases from about 2% down to about -13%.

Compared to the results of the case of TMP+BIGCC, represented by the dashed curves in Figs. 4(c) and 4(d), the NR and IRR of TMP+BtSNG are much lower. This is attributed to 3 reasons, 1) the specific investment cost is much higher for BtSNG, 2) the electricity certificate instrument in Sweden has added a credit to the electricity production, and 3) much more DH is produced by BIGCC, and DH has a price unusually high (higher than electricity) in Sweden.

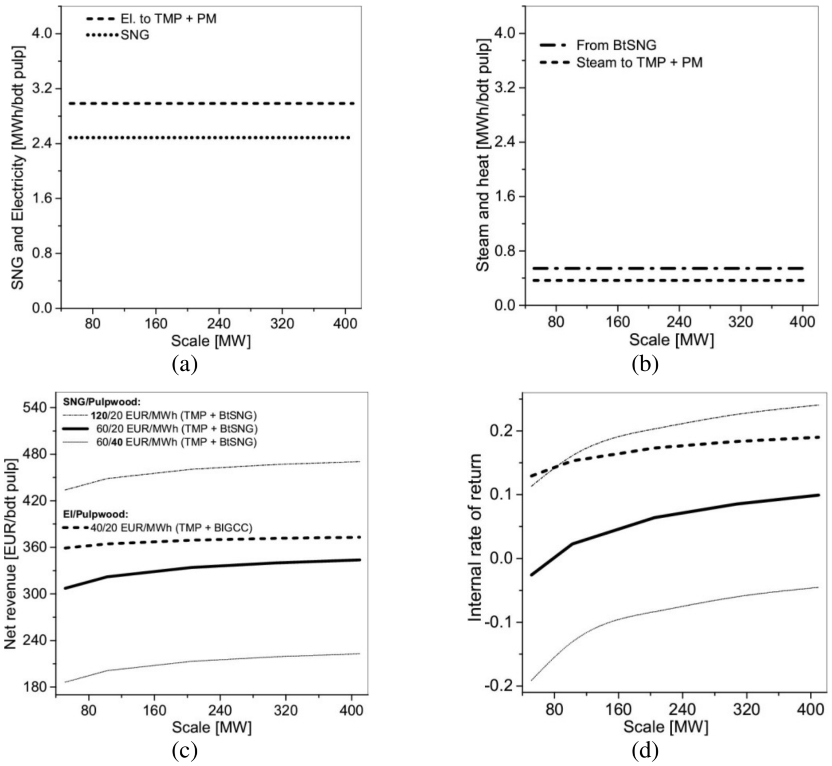

Figure 4: Effect of the scale of TMP+Mill represented by the biomass thermal input to the BtSNG plant

1. Conclusions

A TMP+BtSNG mathematical model is developed based on the economical conditions in Sweden. The profitability of the TMP+BtSNG mill is evaluated in comparison with the TMP+BIGCC mill. The model prediction can be concluded below:

The scale of the TMP+BtSNG mill and SNG price are two strong factors for the implementation of BtSNG in a TMP mill. A BtSNG plant associated to a TMP mill should be built at a scale above 100 MW of biomass thermal input. Compared to the case of TMP+BIGCC, the NR and IRR of TMP+BtSNG are much lower. This is attributed to 3 reasons, 1) the specific investment cost is much higher for BtSNG, 2) The electricity certificate instrument in Sweden has added a credit to the electricity production, and 3) Much more DH is produced by BIGCC, which has a price unusually high (higher than electricity), in Sweden. Political instruments to support commercialization of bio-transport fuel are necessary.

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