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RENEW

Renewable fuels for advanced powertrains

Integrated Project

Sustainable energy systems

D3.8.5 SP3 Final Report

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SP3 Final Report

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1 OBJECTIVES AND MAIN RESULTS IN SP3

The objective of subproject (SP) three within the Renew project is to show the technical and commercial impact of locating a black liquor gasification plant producing DME/methanol at the Södra Cell pulp mill in Mörrum, Sweden. The capacity corresponds to the production of nearly 100 tonnes of methanol equivalents per day, treating roughly 14% of the total black liquor capacity of the mill. Thus, the gasification plant relieves the present recovery cycle process and frees production capacity for future expansion.

Involved in the work is Södra Cell, a market pulp mill operator that produces kraft pulp for sales, STFI-Packforsk, a research institute that develops novel cooking processes to increase the paper yield and improve characteristics of pulp and paper products, Volvo through Volvo Technology Corporation, a heavy truck manufacturer, Ecotraffic ERD[3], a consultant company with long experience within transport and energy related issues and the SP leader, Chemrec, a leading technology developer of the Chemrec high-temperature black liquor gasification process.

__Figure 1.__ The Södra Cell host pulp mill, located in Mörrum, Sweden © Södra Cell AB 2004

In principally 8 work packages SP3 will make a complete assessment of the impact on a modern market pulp mill from integrating a black liquor gasification plant with motor fuel production (BLGMF) with the host pulp mill. The beginning of the project was focussing on the present situation at the mill and the effect from altering the cooking process chemicals. By introducing gasification new cooking processes, e.g. polysulphide cooking, can be used, which when implemented increase the pulp yield by 1.9% on wood with the same wood consumption, a figure confirmed in laboratory trials within the project. Pulp characteristics are principally unchanged in terms of bleachability, better beatability and slightly lower tear strength.

During 2005-2006 the Chemrec BLGMF process was studied in detail and a prefeasibility study was carried out involving the subcontractors Linde, Thyssen Krupp and Haldor Topose. Technical performance of the demonstration plant was found to confirm the results from a full-scale BLGMF plant previously calculated in a prefeasibility study. Existing differences are explained by the smaller scale which affects primarily the energy efficiency of the air separation unit and the Rectisol wash due to the relatively higher heat losses. In 2007 an update of the preliminary engineering work was made with the input from an alternative DME process supplier, JFE, which offers a one-stage process that is seemingly simpler and more efficient. The results show efficiencies from biomass (wood) to DME for the conventional and the one-stage process respectively of 69% and 74%, including the internal electricity consumption in the BLGMF plant. The conventional process is designed for a flexible production ratio, ranging from 20% to 100% DME (on energy basis).

In a parallel work package the BLGMF process in demonstration as well as full-scale was simulated in an integrated pulp mill and black liquor gasification simulation software, developed by STFI-Packforsk. The simulation results are validated using data from subcontractors in the engineering work. The simulation software also includes the changes occurring at the mill site, e.g. resulting from the new cooking cycle, which also visualises bottlenecks limiting the overall pulping capacity. When implementing the BLGMF plant, the simulation showed a biomass requirement for the conventional and one-stage processes of 21 MW and 17 MW respectively. This biomass covers the steam requirement at the mill as well as the internal electricity demand of the BLGMF plant. To improve the model, results from the development plant for pressurised black liquor gasification in Piteå have been incorporated. Primarily the operation in 2006-2007 has provided results on gas composition, efficiency and general performance at high pressure and load and stable operating conditions. In December 31 2007 the plant had successfully accumulated more than 3,695 operating hours.

The resulting production from the demonstration plant amounts to 69.9 (or 79.9 tonnes of methanol) and 66.9 tonnes of DME per day for the conventional and the one-stage processes respectively. The higher efficiency for the one-stage process is a result from a higher steam production capability and hence a lower biomass requirement. Ecotraffic has proposed a distribution strategy for the products from the Mörrum demonstration plant, i.e. methanol and DME for use as automotive fuel components. The flexible production process can start with 100% methanol production, shifting to DME when the market develops. The recommendation is to use the produced methanol to replace fossil methanol in FAME and MTBE to subsequently use it as low-blend component in petrol. The simultaneous use of ethanol as low-blend component, normal in many European countries, will eliminate the risk of phase separation. The use of DME as automotive fuel is initially restricted to fleets of vehicles.

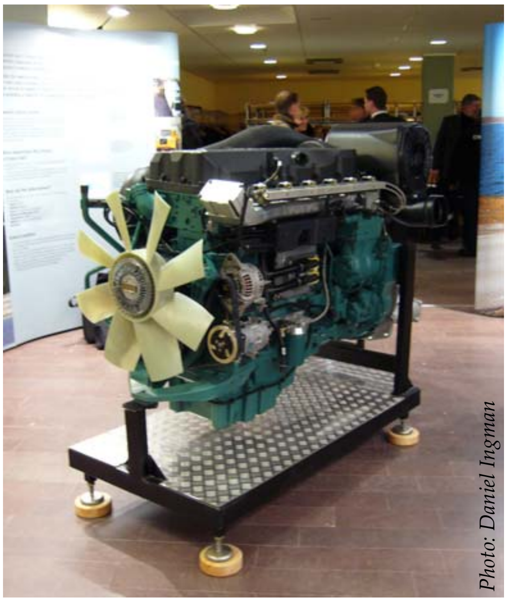

***Figure 2.** The 9.4 litre DME engine from Volvo.*

Finally, the use of DME in dedicated diesel engines has been investigated by Volvo in laboratory tests and field tests with a 9 litre engine based truck. The truck was first presented at the Synbios conference in 2005 and has since then accumulated mileage during test campaigns. Laboratory tests have been carried out 2006-2007 with different DME fuel compositions including contaminants such as water and methanol in different amounts for fuel specification optimisation. Tests have been made in laboratory with designed fuel qualities, using contaminant levels much higher than expected in a real process. With up to 3.3 %wt water and 6.6 %wt of methanol emission levels were basically unchanged compared to the very low emissions from using neat DME.

2 PILOT DATA AND MODELLING (WP3.1)

The objectives of WP3.1 was to develop a simulation model and simulate a demo as well as a full-scale BLGMF plant, including the results and evaluation from the pressurised Skoghall plant in Sweden. The model is to be updated with results from the new development plant installed in Piteå Sweden. The pressurised demo plant in Sweden is state-of-the-art of pressurised black liquor gasification.

Chemrec has coordinated the work and evaluated the results and taken part in the validation of the model against results from the development plant in Piteå, the pilot plant in Skoghall operated in the 1990'ies, as well as the engineering work in WP3.2.

2.1 TASK 3.1.1 EVALUATION OF PILOT PLANT OPERATION DATA

The Chemrec pressurized pilot plant for gasification of black liquor in Skoghall, Sweden, was in operation between 1994 and 2000. It was located at StoraEnso's Skoghall mill near Karlstad, Sweden. It was started as air-blown and was rebuilt to become oxygen-blown during 1997. The plant was built to test the technical feasibility of black liquor gasification under pressurized conditions, specially focusing the ability to achieve high carbon conversion.

In 1994 the original plant had a capacity of 6 tpd of black liquor, operated at 1.5 MPa pressure and 975°C and comprised an entrained-flow gasification reactor, gas quenching and green liquor production system, gas cooler, green or white liquor scrubbing-based sulfur removal system and flare. The development efforts at that time focused on improving operability and reliability through design modifications. Operation of the plant revealed no problems with carbon conversion, and sulfate reduction was good.
When the pilot plant was modified to be oxygen-blown, it resulted in a capacity increase to 10 tds/day. The calorific value of the fuel gas also increased correspondingly, as a result of removing the dead load of nitrogen in the syngas.

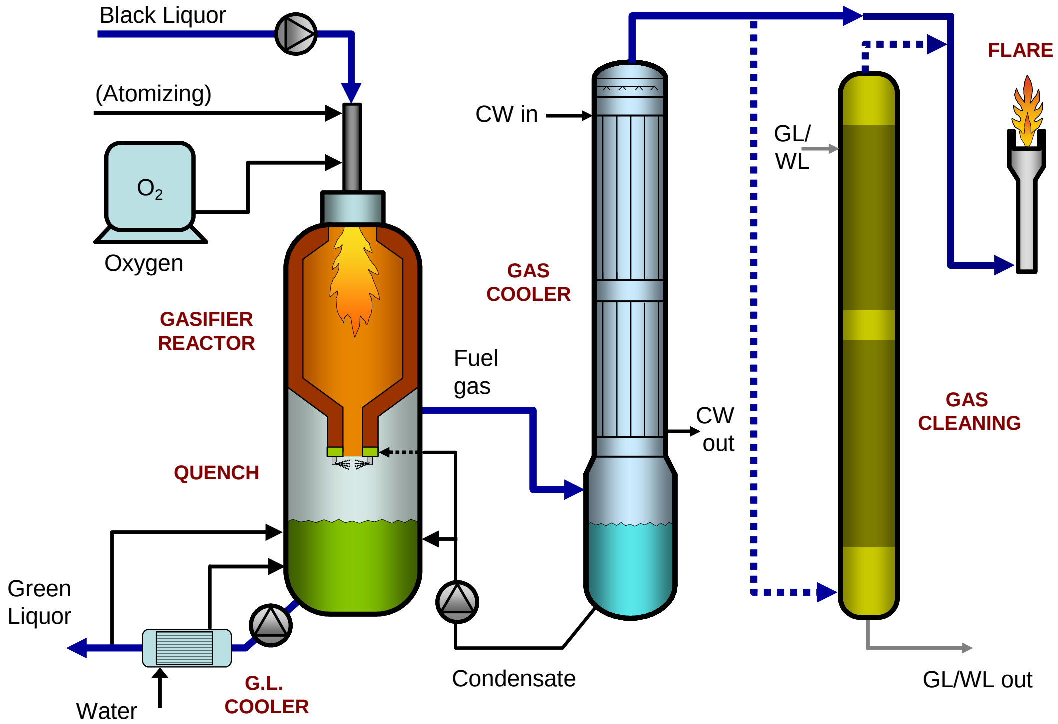

__Figure 3.__ The Chemrec Skoghall pilot plant for pressurized gasification of black liquor.

The pilot system was in operation on black liquor totally almost 2400 hours until the shut-down in febr 2000. The on-stream time as oxygen-blown was totally more than 600 hours. On two occasions, multi-day operation was attempted and the longest run lasted almost 72 hours. However, the pilot system was not fully capable of such sustained operation. The problems encountered were primarily related to problems with the burner. In the design used in the pilot the black liquor passages in the burner are quite narrow. Such plugging problems are expected to go away for larger systems.

Conversion of the black liquor was acceptable during normal operation. Carbon conversions were generally above 98%, with 99% being more typical of steady-state operation. During particularly stable runs, carbon conversions higher than 99.5% were achieved.

The sulfate reduction was good. Of the sulfur entering the system, roughly 2% exited as sulfate and 45% exited as sulfide in the green liquor, with the remainder of the sulfur being present as H2S in the gas.

The Skoghall pilot plant was decommissioned in early 2000, having served its purpose to prove that pressurized black liquor gasification is technically feasible. Several critical design issues were solved in the pilot plant, and valuable data on gasification behavior was obtained.

The Skoghall pilot did have a number of shortcomings, one being that it operated at only half the pressure designated for the full-scale system. Also, due to its initial designation as a proof-of-concept plant it was not built for detailed research and development, and lacked efficient means for sampling within the process.

The new development plant, DP-1 in Piteå in northern Sweden (Figure 7) which will be mechanically complete within short is being built and equipped to be able to accomplish those tasks that the previous plant was unable to do.

2.2 TASK 3.1.2 DEVELOPMENT OF A COMPUTER SIMULATION MODEL

The effects on a pulp mill of using black liquor for motor fuels production have been evaluated, as part of the RENEW project that aims to evaluate and develop processes for the production of motor fuels from biomass.

The balances are based on a set of simulation models for gasification, gas cooling, gas cleaning, synthesis and upgrading that have been developed by STFI-Packforsk in the process simulation tool Hysys. The model can use input such as black liquor composition, reactor temperatures, etc., to give information about product composition, flows, steam balances, etc. The model has primarily been used to study the production of dimethyl ether (DME) from gasified black liquor via BLG (i.e. Black Liquor Gasification).

Material and energy balances have been calculated for a theoretical kraft market pulp mill integrated with a plant for black liquor gasification and subsequent production of DME. The results show that up to 0.41 tonnes of DME per tonne of pulp can be produced, i.e. about 800 tonnes per day in the reference 2000 ADt/d mill. Calculations have also been made for a possible demonstration plant at an existing Swedish mill (pulp production 1400 ADt/d), where it has been assumed that up to 15 % of the black liquor could be used for DME production. The corresponding production of DME is about 70 tonnes per day.

To compensate for the decrease in steam production from black liquor an amount of biomass needs to be purchased to maintain the steam balance. The amount of purchased biomass is smaller than the amount of black liquor withdrawn, however, since the exothermic synthesis can be well integrated with the pulp mill. In the full scale case a new biomass boiler is required that is also partly fired with residual gas from the synthesis. In the demonstration case the existing bark boiler has sufficient capacity. The major differences in the energy balance are shown in the table below.

		Theoretical full scale case		Mörrum demo case	
		RB	BLG	RB	RB/BLG
Black liquor (BL)	tDS/d	3400	3400	2300	1970/330
(BL, LHV)	MW	475	475	314	269/45
DME sold	t/d	-	824	-	70
(DME sold, LHV)	MW	-	275	-	23
Biomass sold	MW	32	-125	0	-20
Power sold	MW	45	-56	3	-5

The change from electricity generation (recovery boiler case) to fuels production (BLGMF case) results in the mill becoming a net buyer instead of a net seller of electricity. To indicate a correct system efficiency, the whole decrease in electricity generation is accounted for (including the surplus previously sold in the recovery boiler case). For the full scale case the biomass-to-DME efficiency is approximately 65 %.

2.3 TASK 3.1.3 ADAPT SIMU MODEL TO PILOT RESULTS

This task was included in the above activities. The start-up of the BLG development plant in Piteå, Sweden, was delayed and steady-state values that were representative for the normal operation caused a shift in timeplan for this specific activity.

The results were however, incorporated in the model as well as input from the engineering package in WP3.2. This resulted in a validation of the simulation model and that predicted performance reflects empirical data.

3 PLANT DEVELOPMENT ENGINEERING (WP3.2)

The objectives of WP3.2 was to perform a preliminary engineering for a 45 MWth BLG plant for production of methanol and DME, including also an investment cost estimate to an accuracy of +/-30% of the planned demo scale BLGMF plant.

Chemrec has performed the preliminary engineering work together with subcontractors for separate process units. Together with subcontractors, flexibility in the production was discussed versus additional investment cost. Apart from coordinating the work made by subcontractors, the technical work was focusing on the integration aspects and the Chemrec gasifier itself.

3.1 TASK 3.2.1 PRELIMINARY ENGINEERING OF 45 MW DEMO PLANT

WP3.2 will show the technical and commercial impact of locating a gasification plant producing DME/methanol via gasification of black liquor at a market pulp mill. The host pulp mill is situated in Mörrum, southern part of Sweden, and is operated by Södra Cell AB. In the lead of SP 3 is Chemrec AB, a gasification technology developer and the licenser of the Chemrec® high-temperature black liquor gasification process.

Black liquor is formed when wood chips are boiled with cooking chemicals in the digester. The fibre is separated and used for paper production and the residue, an energy-rich chemical is utilised to cover the mill's internal needs of steam. A modern market pulp mill often has a surplus of black liquor energy relative to what is needed in the process. The gasification plant studied for the mill in Mörrum will increase the black liquor processing capacity of the mill with around 12%, having a capacity of 45 MWth or 330-370 tDS/24 h.

The withdrawal of black liquor energy implies a reduction in high pressure steam production, which has to be compensated by importing biomass for steam production. The use of black liquor gasification will produce a raw gas, with high sulphur content. After gas clean-up in a Rectisol wash unit and gas conditioning, the gas is used for methanol and DME synthesis. The production ratio can be shifted from 19% (LHV) DME to 100%, to follow the development of the DME fuel market.

The process design is shown in the below block flow diagram. The diagram shows the interaction with the host pulp mill and the internal process units included. Important units include the Rectisol wash unit and the air separation unit respectively, which both are large power consumers and influence the overall balances. The methanol and DME synthesis unit is designed for a flexible production which is indicated in the figure.

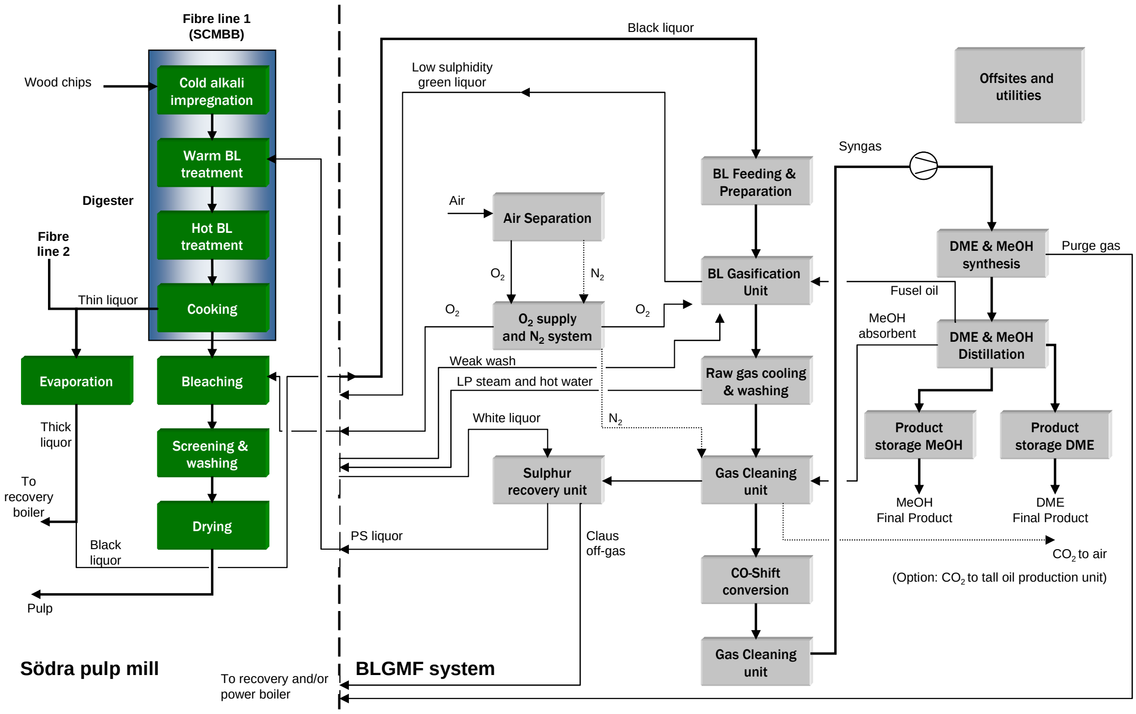

Figure 4 The BLGMF plant and its connections to the SCM pulp mill

The sulphur is recovered from the Rectisol wash regeneration column, via a Claus unit, as polysulphide liquor. Polysulphide liquor improves the cooking process and increases the pulp yield. The gasification and synthesis plant also result in a steam surplus, exported to the host mill as low pressure steam for use in the pulping process.

The net loss in high pressure steam production in the recovery boiler corresponds to the LP steam delivery to SCM, i.e. 17.5-20.9 tph. The mill has to import 18-21 MW biofuel for steam production. The produced amount of methanol plus DME at the 19/81% production point totals 22.7 MW, whereas the 100% DME production generates 23.3 MW. The product output is hence higher for DME production, but the net steam export is lower and the resulting biomass to fuel efficiency is lower compared to methanol production. Seen from the netback of DME production as diesel substitute, the DME output should be maximised.

The engineering work carried out is tightly connected to the mill site and to provide input to the work in WP3.3 practical issues and area requirements had to be considered in detail. The plot plan considered is shown in the below figure.

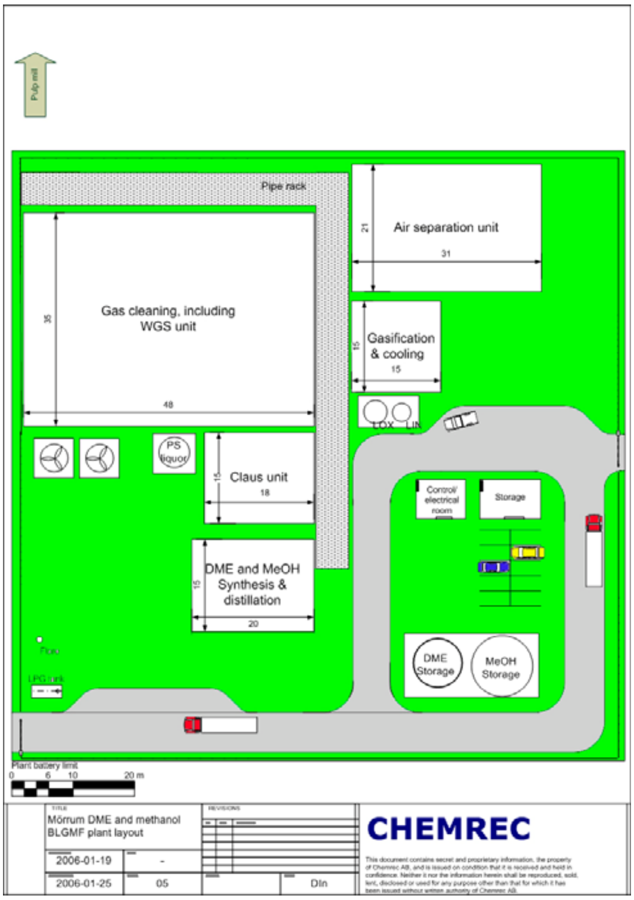

Figure 5 *The BLGMF plant and its connections to the SCM pulp mill*

3.2 TASK 3.2.2 INVESTMENT COST ESTIMATE FOR DEMO PLANT

Supplementing the above engineering work, the cost estimate was established based on formal quotations from a number of subcontractors covering each of the process units. The gasifier and gas cooling island was calculated by Chemrec.

The basis for calculating the overall investment cost thus includes the cost for the discrete BLGMF plant with the internal process units such as gasifier, gas clean-up, gas conditioning and synthesis etc, as well as the cost associated with SCM and the integration with the mill site.

The investment cost stated includes the following scope of supply and services, without being exhaustive in the description:

- Itemised equipment, included as package units as stated in Chapter 5.1 in deliverable D3.2.1.
- Bulk material such as piping, electrical equipment, instrumentation, tracing and insulation, pipe racks and steel structures, painting
- Engineering
- Procurement and license fees
- Civil works and erection

- Access roads and biomass handling area
- Spare parts for key equipment
- Freight to the building site

The overall investment cost, including the balance of plant, i.e. the integration between the host mill and the BLGMF plant, as calculated by Södra, is 98 MEUR. The relatively small scale demo plant increases the specific investment cost significantly for some process units. The relative cost fraction for each of the process islands is shown in the below figure.

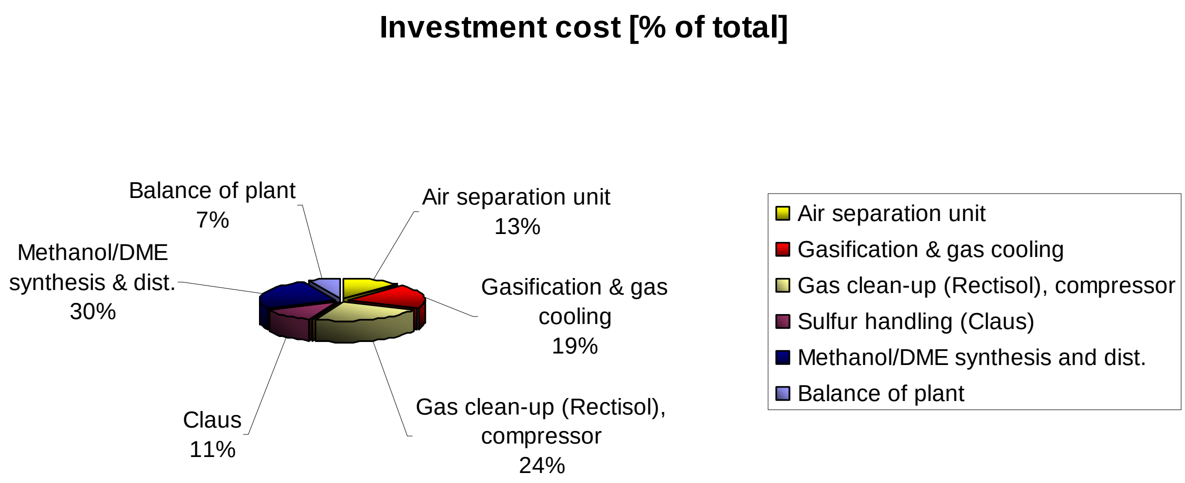

Figure 6 *Investment cost break-down on process units of the BLGMF plant.*

4 BALANCE OF PLANT (WP3.3)

The objectives of WP3.3 were to investigate the integration of te BLGMF plant on the specific Mörrum site in south Sweden, including preliminary engineering and an investment cost estimate for the balance of plant, which connects the demo plant to the host mill. The goal is to find an optimum level of integration, thereby minimising the total CAPEX and OPEX of the plant.

WP3.3 and the integration aspects for the planned development plant and the pulp mill were assessed by the Södra mill with Chemrec providing data on the required connections and the desired stream specifications as pressure levels, composition etc. Media streams were discussed in terms of max/min values for start-up and steady-state conditions.

4.1 TASK 3.3.1 INTEGRATION IMPACT ON THE HOST PULP MILL

In WP3.3 the impact on the energy and mass balances by implementation of a Black Liquor Gasification Motor Fuel (BLGMF) unit at a pulp mill is studied. The basis for the study is the implementation of a 45 MWth BLGMF demonstration plant for DME/methanol production at the Södra Cell Mörrum mill in Sweden. The present report is focused on the influence on the mill while the preliminary engineering of the BLGMF plant itself is studied within WP 3.2 (Ingman, 2006). To attain the total situation, both reports have to be studied.

The implementation of the BLGMF unit will affect many of the mills main and sub systems such as steam, liquor, water, off-gases and electricity. Furthermore, in order to maintain the mill energy balance additional biofuel has to be imported and fired in the existing power boiler. The consequential process integration systems are identified and specified in the report and conceptual and basic design work of these systems is made.

The green liquor produced in the gasifier has a lower concentration of sulphur and a higher concentration of carbonate compared to the green liquor produced in the recovery boiler. A negative consequence of this is that the additional carbonate has to be converted to hydroxide (OH) in the causticising unit. Since the causticising unit at the Mörrum mill is a bottle-neck, the impact on this is of special interest. In order to study the mass balance of the associated chemicals in the causticising unit, a process simulations model developed in the software Extend is used.

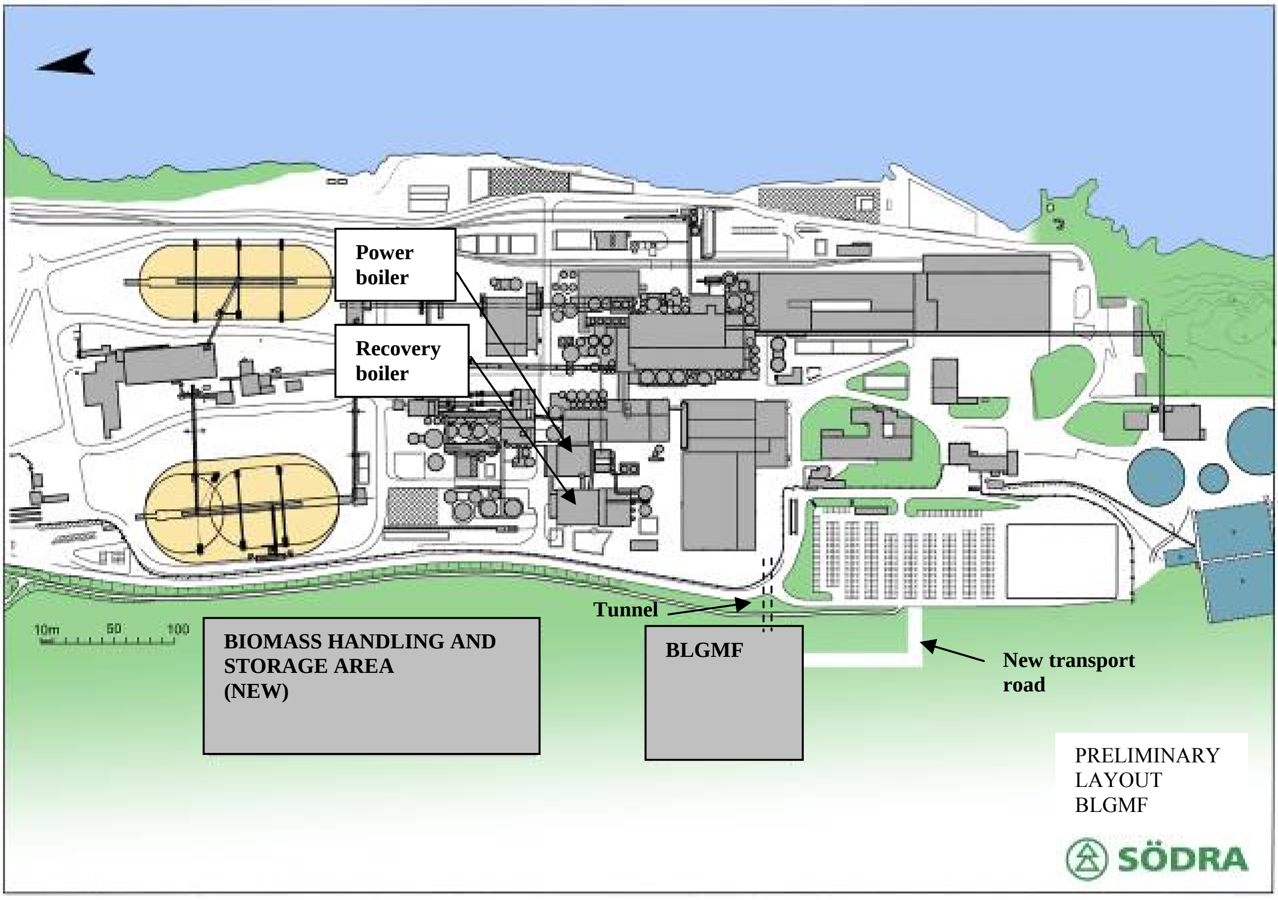

Figure 7. *Preliminary location of BLGMF unit at the Mörrum pulp mill.*

4.2 TASK 3.3.2 PREL ENGINEERING OF DEMO PLANT INTEGRATION TO PULP MILL

A total of 25 process streams are engineered with respect to connection points, design capacity and required pump work. Process streams include black liquor (BL) feed, other liquor streams, steam, instrument air, town water electricity connections, etc. In every aspect required incremental investments on the mill site are considered. The Södra mill site in Mörrum is shown in Figure 6.

The results from engineering work and simulations as in Figure 7, show that approximately 5 % more burned lime mud must be added in the lime slaker. The simulations were made in the software Extend® used by the mill to easily calculate overall balances. The software can withdraw on-line process data to get an up-to-date view of the process and its effect on other processes. The simulation was extended to include the BLGMF system with overall ins and outs. The increase in lime consumption in turn will lead to a corresponding increase of the load in the lime kiln were the lime mud is re-burnt. A higher lime mud load in the lime kiln will also result in a higher fuel consumption which in turn will generate a larger amount of flue gas.

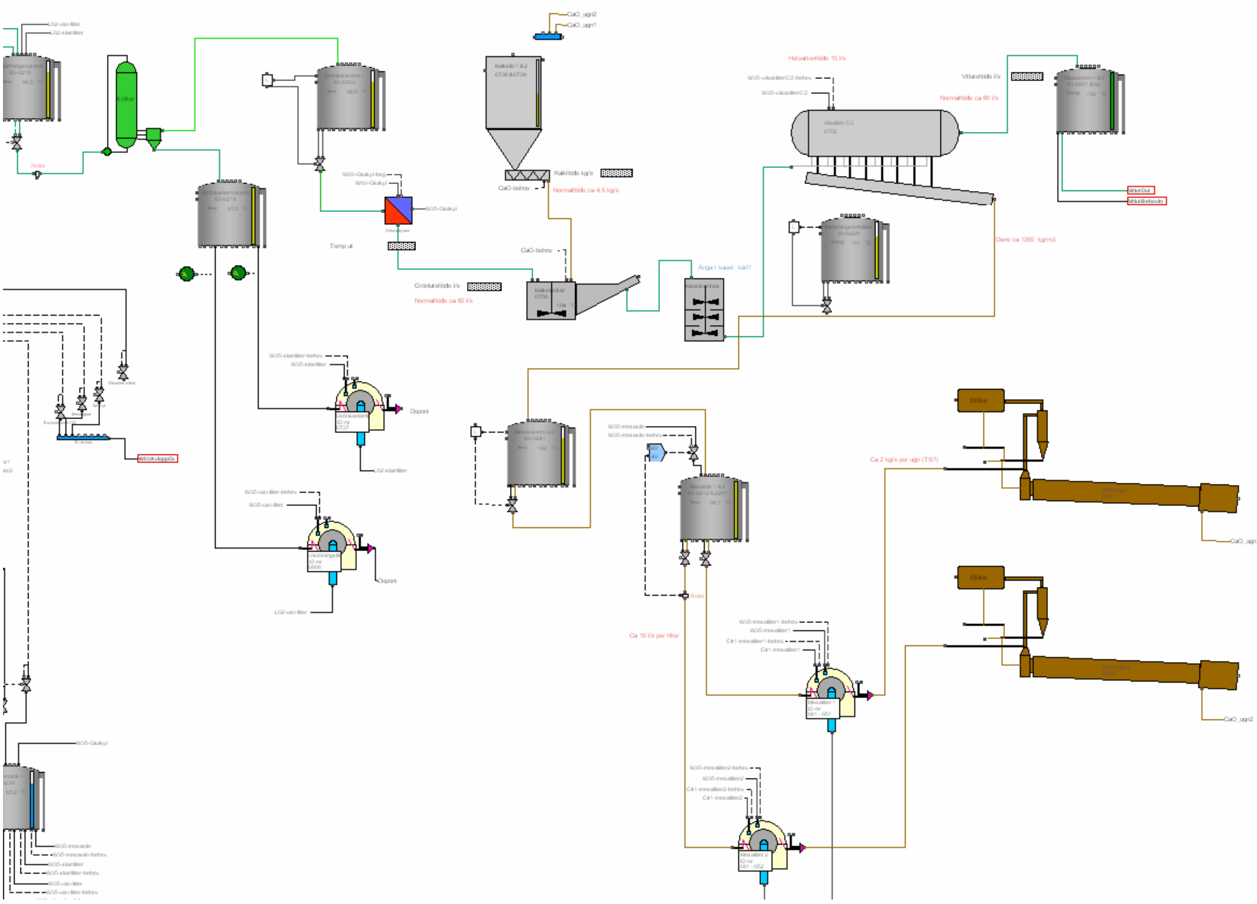

Figure 8. *Extend® process model of causticising plant*

In order to compensate for or to reduce the increased load on the causticising process some measures to be further investigated are suggested:

- Increase the sulphidity in the recovery boiler. Preliminary calculations (Berglin, 2005) show that the reduced sulhidity in the green liquor from the gasifier can be compensated for by increasing the sulphidity in the recovery boiler to approximately 42 %. However, the sulphidity in the recovery boiler at Mörrum is approximately 36 % at present and such a large increase is probably not realistic. Preliminary estimations (Arnesson, 2005) suggest an increase of the sulphidity to 38 %, i.e., 2 percent units above current sulphidity.

- Introduction of supplemental oxygen into the kiln burner. By this the capacity of the lime kilns can be increased and, additionally, fuel consumption and sulphur emissions can be reduced.

- External drying of lime mud. Makes it possible to increase capacity in lime kilns since only heating, calcination and sintering occurs in the kiln.

Analogous to the preliminary engineering in WP3.2, the engineering in WP3.3 was supplementing with a cost estimate for the integration. The integration also includes some de-bottlenecking costs for being able to use some of the incremental capacity boost added by the demo plant. This for instance includes a new bark fuel handling site as indicated in Figure 6. The investment cost was included in the engineering package.

The overall investment cost for the integration work is estimated to 13 MEUR, including a large cost for the new biomass handling site. The biomass boiler is sufficient to handle the biomass, but since today all bark is consumed at the mill additional fuel needs to be imported. Not included is the cost for possible rebuild of the caustizising plant.

5 NEW COOKING LIQUOR TESTS (WP3.4)

The objectives of WP3.4 is to establish the potential for improvements in pulp yield that can be attained through the use of cooking liquors obtained with the BLG demo plant, in particular in combination with alkali-free pre-treatment. The so produced alternative pulps produced will be evaluated in terms of paper making properties.

The work has been carried out by STFI-PF and Södra.

WP3.4 was divided into 4 separate tasks as shown below, resulting in a single deliverable in 2005 in the early phase of the project.

- ***TASK 3.4.1 DESIGN OF EXPERIMENTAL PLAN***
- ***TASK 3.4.2 PRODUCE PULP SAMPLES FOR TESTING***
- ***TASK 3.4.3 EVALUATE PROPERTIES – UNBLEACHED PULP***
- ***TASK 3.4.4 PREPARE BLEACHED PULPS***
- ***TASK 3.4.5 EVALUATE PAPER MAKING PROPERTIES***

A very important result is the fact that the alternative cooking processes result in an increased pulp yield as shown below. The ZAP-Kraft-AQ cooking, made possible with the BLGMF plant, results in a 3% increase of pulp. Considering that the gasifier only processes a fraction of the black liquor produced, this is a significant figure.

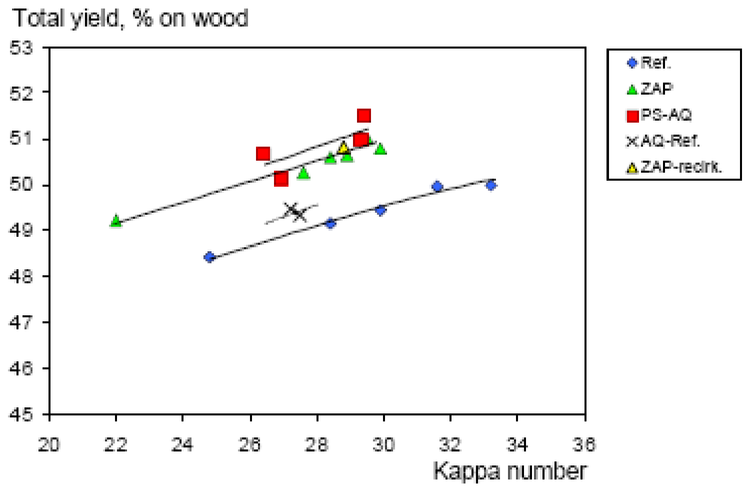

Figure 9. *Total yield versus Kappa number for different cooking processes.*

In this study the improvement of pulp yield and the effects on the bleachability and strength properties of fully bleached pulps that can be attained through the use of cooking liquors obtained with a black liquor gasification (BLG) system have been evaluated. The focus has been on what can be obtained specifically at the Mörrum mill (in Sweden) owned by Södra Cell AB, if the 45 MW BLG demonstration plant studied within RENEW SP3 is built.

The reference Kraft cooking was batch cooking of RDH (Rapid Displacement Heating)-type, applied at the Mörrum Pulp Mill, the host mill for the prospective BLG demo plant. The studied cooking processes were: (1) polysulphide-anthraquinone (PS-AQ) cooking and (2) "ZAP" Kraft-AQ cooking. "ZAP" Kraft-AQ cooking means cooking in two stages with pre-treatment liquor containing mainly HS^- and AQ. In the case of a BLG system the pre-treatment liquor also contains small amounts of hydroxide and carbonate ions. The studied cooking processes (PS-AQ and "ZAP" Kraft-AQ) were based on the RDH-type of Kraft cooking.

The results showed that the PS-AQ-pulp had the highest yield after cooking; about 2 % higher compared to the reference Kraft pulp. Cooking according to "ZAP" Kraft-AQ resulted in 1.5 % higher yield compared to the reference Kraft pulp. Yield improvement of one percentage unit on wood can be directly attributed to the "ZAP" pre-treatment stage and "ZAP" liquor produced by the BLG system and remaining 0.5 % to AQ. After two oxygen stages, the difference in pulp yield was about the same indicating that the yield gain compared to the reference remains also after bleaching (D-EOP-Q-PO-sequence).

"ZAP" Kraft-AQ cooking resulted in a somewhat brighter pulp after cook. To reach 89 % ISO brightness about 1.5 % less hydrogen peroxide was needed for the "ZAP" Kraft-AQ pulp. The PS-AQ pulp needed slightly more bleaching chemicals than the reference Kraft pulp.

The PS-AQ pulp was easiest to beat and reached the highest tensile index at a given beating degree. The other strength properties were comparable with the reference pulp except tear index, which was highest for the reference pulp, followed by "ZAP" Kraft-AQ pulp and was lowest for PS-AQ pulp.

6 DISTRIBUTION STRATEGY (WP3.5)

The objective of WP3.5 is to develop a strategy for handling and distributing the BLGMF plant fuel products (DME and methanol) from the demo plant at the pulp mill site to consumers.

The distribution strategy proposed by Ecotraffic was discussed by Chemrec which provided volume fractions of methanol and DME to be distributed from the development plant. The strategy and selection of products were also discussed, also considering the flexible production ratio between the two products.

6.1 TASK 3.5.1 PRODUCT MIXTURE OF DME/METHANOL

This task considers the market demand and proposes a production ratio between DME and methanol from this. The task also considers the European legislation, biofuel directives and the national demand on renewable fuels in the automotive fuel pools. Considering the allowed blend-in of methanol in gasoline all the methanol produced in the demo BLGMF plant can be supplied as low-blend constituent to the Swedish market. The production ratio is hence determined by the expanding DME fuel market. The demo plant can produce methanol until test fleets for DME fuel develop and then gradually shift to DME production.

6.2 TASK 3.5.2 PLAN DISTRIBUTION STRATEGY OF DME AND METHANOL

In short, the conclusions in this study are the following:

- Methanol was one of the first alternative fuels to be considered for a large scale introduction in the 1980's. However, since the 1990's, most stakeholders have lost interest in this option. In contrast, DME is a relatively "new" alternative fuel on the market.
- The fire and explosion safety hazards with methanol have been investigated. In general, methanol should be considered safer than or at least as safe as petrol in this respect. DME has some safety issues to be taken into consideration. DME distribution has many similarities to the distribution of LPG, an established technology today.
- Material compatibility must be addressed for methanol, since methanol is corrosive and degrades some polymers and elastomers. However, there are suitable materials available on the market and test methods for material selection (e.g. SAE J1681) have been developed. Methanol is a chemical commodity today and is handled in large quantities on the world market without any apparent problems.
- DME, as a new fuel, has several material compatibility problems that must be overcome until DME could be introduced on a larger scale. Much development work is going on in this field.
- Phase separation with methanol/petrol blends is an issue to consider. In low-level blending a stabilising agent must be used. This stabiliser could be ethanol. Some options of fuel distribution must be avoided to prevent phase separation.

- The health effects of methanol exposure have been thoroughly investigated in the past. Methanol is more toxic than petrol when ingested. On the other hand, methanol is neither mutagenic nor carcinogenic, as in contrast to petrol. Normal exposures of methanol to humans give concentrations that are far below the level of health effects. Human body metabolism and ingestion of diet beverages and fruit generally cause higher concentrations.
- Methanol spill to land and water does generally have lower environmental impact than petrol and diesel fuel spills. Below a certain concentration, methanol is not toxic, is metabolised by micro-organisms and consequently, the impact is only local.
- Engine wear is the most severe of all potential show-stoppers for methanol that have been identified in this study. The increased engine wear was investigated in the 1980's and the mechanisms are fairly well-understood. However, these results are not directly applicable on modern engines. It is hypothesized by these authors that advanced engine technology such as, e.g. direct injection, might overcome those problems.
- DME cannot be used in fuel-flexible vehicles so it would have to be used in dedicated fleets during an introductory phase. In the first production plants, where both DME and methanol could be produced, the share of DME would have to scale with these fleets. Since DME seems to be favoured over methanol by oil and auto industry, DME should be given highest priority.
- On the short term horizon, the use of methanol in low-level blending would have the greatest potential. Cost calculations show that methanol would be cost competitive with ethanol and it is not likely that ethanol could be produced in sufficient quantities in the EU to meet the demand. However, neither the oil nor the auto industries favour the blending option. Therefore, the "safest" and most conservative route of introducing methanol would initially be to use it as a substitute for fossil methanol in FAME and MTBE production.
- On a longer term horizon, the use of fuel-flexible and dedicated light-duty vehicles is the most favoured option. The use of direct injection would greatly enhance the cold start properties and enable a significant increase in engine efficiency. Furthermore, M100 could be used instead of M85. Dedicated heavy-duty M100 vehicles could be introduced at a later stage.
- An introduction strategy based on the distribution of anhydrous M100 and the use of blending pumps to make other fuel qualities (e.g. M85) available is proposed. In the discussion with oil and auto industries it has been found that they are currently not particularly interested in methanol as a motor fuel. However, it has been very difficult to pinpoint any particular reason as to why these negative attitudes have been formed. Ecotraffic welcomes a debate of the pros and cons of methanol as a motor fuel of the future.

7 FUEL PURITY OPTIMISATION ENGINE TESTS (WP3.6)

The objectives of WP3.6 are to test a designated heavy-duty auto ignition engine in an engine test bench, using DME as a fuel, and to determine the impact of methanol and water on engine parameters such as regulated and non-regulated emissions, torque and power. The base engine is a 9.4 litre, 6 cylinder in-line VTEC engine using a designated fuel injection system developed for the use of DME. The research will provide a baseline for a tentative fuel specification of engine-grade DME.

Fuel specifications for DME and the laboratory tests have been determined outgoing from DME fuel composition from the demo plant. The work done by VTEC in the single activity was presented in three deliverables.

7.1 TASK 3.6.1 DME FUEL SPECIFICATION – ENGINE PERFORMANCE VERSUS FUEL PRODUCTION OPTIMISATION

Engine performance for a heavy duty six-cylinder diesel engine, fuelled with DME which was mixed with small amounts of methanol and/or water, has been investigated experimentally.

These impurities had very limited effect on emissions but affected the combustion in such a way that more energy was released during the initial combustion phase. The conclusion is therefore that fuel grade DME may contain a rather large fraction of methanol and/or water. Other potential impurity effects, such as long term effects on fuel system, have however not been considered.

The thermodynamic and fuel characteristics of DME, water and methanol are shown in the below table.

Table 1 Selected chemical and physical properties of DME, methanol and water.

Property	DME	Methanol	Water
Chemical formula	CH_3-O-CH_3	CH_3-OH	H_2O
Lower Heating Value, [MJ/kg]	28.8	19.8	-
Density, 15°C, [kg/m^3]	671	791	999
Viscosity, 40°C, [m^2/s]x10^{-6}	0.18	0.6	0.66
Critical Point [bar];[K]	53;400	81;513	647;221
Cetane number	>55	-	-
Octane number, RON	-	106	-

Considering several parameters such as e.g. solubility limits, a test matrix was established. Based on these considerations and with safety margins to solubility limits following specifications were mainly studied

- 0 wt%, i.e. chemical grade DME with lube additive,
- 10 wt% of a mixture containing two parts of methanol and one part water (6.6 wt% methanol and 3.3 wt% water),
- 6.6 wt% methanol and
- 3.3 wt% water.

Injection timing and EGR were varied for every operating point and mixture.

It may be further concluded that number of particles from a diesel engine fuelled with DME is low and the particle size is well below the soot size range and not in greater number than from a diesel engine in that size range. In addition, most of the unregulated emissions were negligible. Methane was e.g. detected as EGR reached higher levels.

Carbon monoxide is the most noticeable species of a DME engine, with a diesel combustion system. In order to reduce CO emissions and improve engine efficiency a DME specific combustion and fuel injection systems are therefore required.

It can consequently be stated that a DME engine may give very low emissions after the combustion and fuel injection system have been developed for DME.

8 SP 3 DATA TO LIFE CYCLE ANALYSIS STUDIES SP 5 (WP3.7)

In parallel to the technical work, Chemrec has provided SP5 with input to the LCA work in principle according to agreed agendas between the involved partners.

The input also forms the SP 3 base for the technical and economic assessment of the six different technology which has been carried out within SP 5. Deliverables covering this and the LCA analysis are IEE, VW and others.

9 S&T COORDINATION MANAGEMENT (WP3.8)

In WP3.8 Chemrec has been in charge of the updates of the description of work and the detailed implementation plan to the Renew coordinator.

Progress monitoring forms have been prepared using input from the active WP:s within SP3 and reported to the project coordinator. The work has been carried out during the full project time.

10 DME SYNTHESIS INVESTIGATION & OPTIMISATION (WP3.9)

The objective of WP3.9 is to find an optimum DME synthesis for black liquor derived syngas.

In WP3.9 and 3.10 Chemrec has performed engineering work for the alternative one-stage DME process, a process suitable for the raw gas composition produced in black liquor gasification. During 2006, contacts with alternative synthesis process suppliers were taken for further investigation of the technical details and performance of this process in relation to the process already included and examined in WP3.2.

In 2006 a report was disseminated for a 45 MW(NHV) demonstration BLGMF plant with a flexible DME and methanol process. The present report includes a novel DME process which is compared to the previous report. The novel DME process is based on a slurry bed DME synthesis process where DME is formed in one stage without producing methanol as an intermediate. Other general improvements in the BLGMF plant requires close contact with subcontractors and process suppliers. It is likely that the relatively big utility consumptions in the gas treatment unit can be lowered.

The one-stage DME process requires a H_2:CO ratio of 1 and a part of this report has been to optimise the reforming of the original raw gas from black liquor gasification with a ratio of 1.3-1.4 to 1. In a sensitivity analysis, it was found that around 17% of the carbon coming in with the black liquor, corresponding to 31% of the outgoing CO_2, needed to be recycled to the gasifier. The exiting gas is close to 1 in stoichiometry and there is no shift reactor in the plant, in contrast to the conventional DME process where the H_2:CO ratio requirement is above 2 and the raw gas needs to be conditioned. The overall process is shown in the below block flow diagram, which should be compared to the conventional methanol/DME process shown in

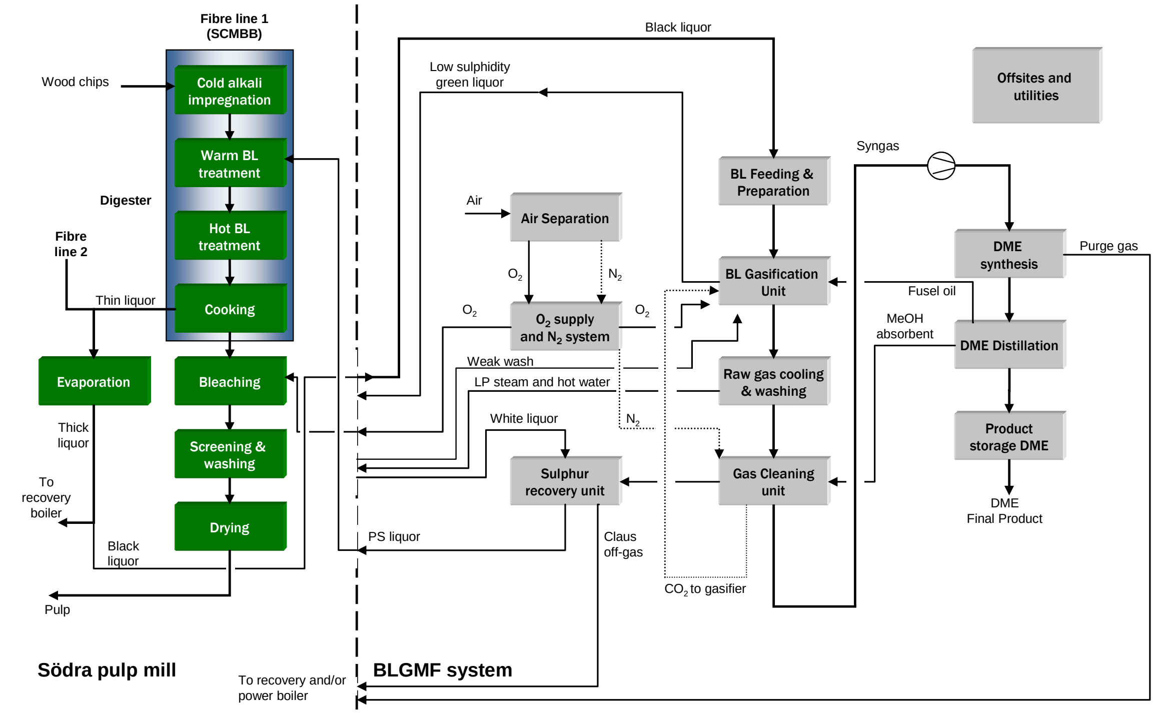

Figure 10 The BLGMF plant including the one-stage and simplified DME synthesis process

Results show that the one-stage process is not more efficient than the conventional DME process. Efficiencies from biomass to DME, including the BLGMF plant's internal power consumption, is 69% and 74% for the conventional and one-stage processes respectively. The results are shown in the table below in more detail, presenting both the results from WP3.2 and the results for the one-stage process respectively, as comparison.

Table 10.1 *Overall energy balance and efficiencies, in MW (LHV) or tph.*

	Ref (MW, LHV)	One-stage (MW, LHV)
Production		
DME production	23.3	22.3
Synthesis purge gas to SCM	2.6	2.6
Net steam delivery to SCM (LP)	10.8	13.9
District heating	1.2	1.4
Consumption		
Black liquor consumption	45.0 MW (NHV) 51.7 MW (LHV) 1)	
Additional biomass consumption at SCM2)	21	17
Electric power consumption (gross)	5.2	5.2
Energy efficiencies (LHV)		
Biomass to fuel (excl. biomass for power)	110%	130%
Biomass to fuel (incl. biomass for power)	69%	74%

The higher efficiency results from a higher steam production in the counter-current-condenser and no steam needed for the gas shift unit step and hence a lower biomass requirement at the mill site. The production in the one-stage DME process is 66.9 tpd of DME and for the conventional process 69.9 tpd is produced. Data are taken from two different suppliers of technology and there is a need to further investigate the one stage process as result of development trials.

Although less product is formed in the one-stage process, there are likely benefits such as lower investment cost for the overall BLGMF plant and the negligible production of waste water etc. The findings in this report should therefore be verified in more detailed simulations and in semi-empirical testing to validate the calculated effect on the raw gas composition from recycling of CO_2 and the actual energy loss during reforming in the gasifier. More work is also required to optimise the gasifier and determine the best solution for introducing the CO_2.

11 BLGMF PLANT PROCESS & UTILITY OPTIMISATION (WP3.10)

The objective of WP3.10 was to optimize process and utility systems for the Mörrum application of the BLGMF technology. Most subsystems as steam, feed water, electricity etc had to be recalculated with the new DME process selected in WP3.9. One of the most important issues is to arrive at a suitable stoichiometry for the DME synthesis, which is different from the one in the conventional process examined in WP3.2. Hence a lot of work was put into the separation and recycling of CO_2 back to the gasifier and the effect on the syngas composition.

Optimisation work was carried out for the BLGMF plant in general and different ways to separate CO_2, which is separated to the gasifier, was evaluated. Calculations with different CO_2 recycling rates to the gasifier were made to achieve the required H_2:CO ratio in the resulting syngas. The effect from recycling CO_2 is shown in the below figure, from which it is apparent that 17% of the incoming carbon (3 tph) in the black liquor should be recycled in order to lower the H2:CO ratio in the syngas to approximately 1.0.

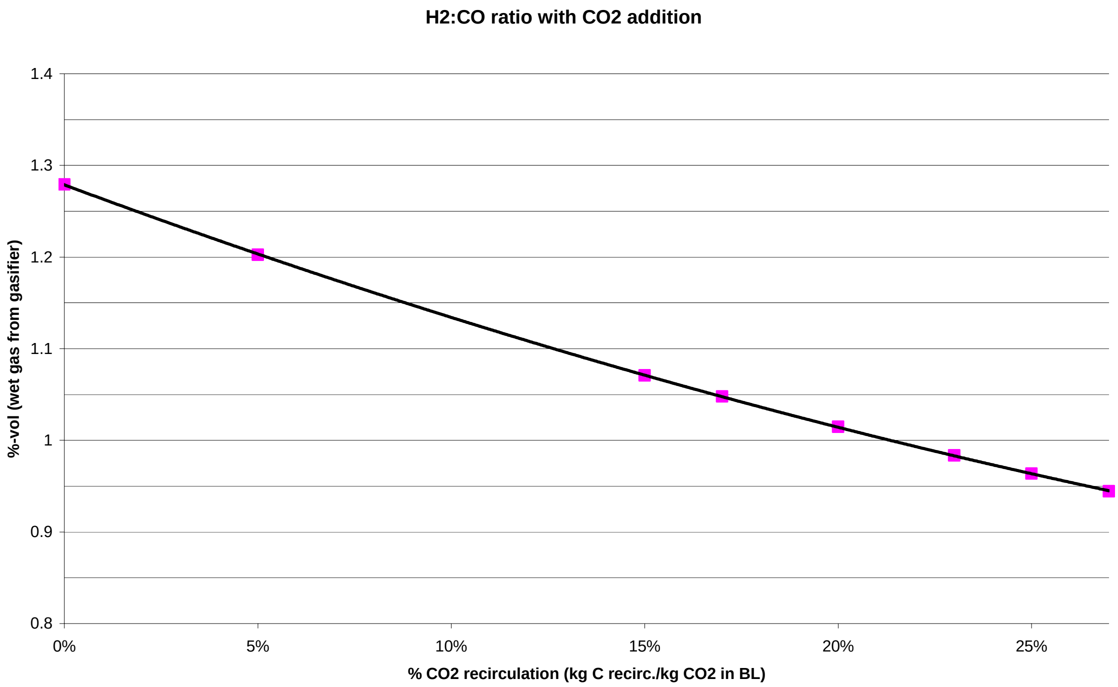

Figure 11 *Effect on H_2:CO ratio from recirculating CO_2 to the gasifier.*

The work in WP3.10 is tightly related to the synthesis selection in WP3.9 and the findings were presented in a single deliverable.