HIGH EFFICIENT MOTOR FUEL PRODUCTION FROM BIOMASS VIA BLACK LIQUOR GASIFICATION

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ABSTRACT:

There is great promise in using kraft black liquor within the chemical pulp industry to produce motor fuels. This paper presents a highly cost-effective route for large-scale replacement of fossil based fuels by converting biomass via black liquor to high-quality energy products such as methanol, DME or Fischer-Tropsch Diesel (FTD). The new innovative concept, called BLGMF – Black Liquor Gasification with Motor Fuels production shows a biomass to methanol efficiency of 66%, when compared with a modern recovery boiler based on a 2000 ADt/day pulp mill. The production potential is 411,000 tons of methanol per year with a production cost of €10.2/GJ or $1.5 per gallon gasoline equivalent (€0.32 or SEK 3.0 per liter gasoline-equivalent). For Sweden, this cost would be competitive with current gasoline price, when including carbon dioxide tax and distribution costs, but excluding other taxes. The IRR is 35% with a payback of 3.1 years. DME shows similar good performances and FTP preliminary 26%, however, with low diesel yield as naphtha is co-produced. Estimated replacement share potential in Sweden and Finland with methanol as motor fuel is about 28% and 51%, respectively, or about 4.0 million tons each per year. In the whole European Union, the potential is 11 million tons per year and in USA potentially 28 million tons almost – almost equaling today's world methanol production. In conclusion, pulp mills are well suited for large-scale motor fuel production with substantial economic incentive for making plant investments and the studied concept could be a key in starting the transition to biorefinery production.
Keywords: methanol, DME, Fischer-Tropsch, black liquor, gasification.

1 INTRODUCTION

1.1 Increasing consumption of fossil fuels

There is a rapidly growing interest world-wide in finding ways to produce alternative renewable automotive fuels. Not only because they are CO_2-neutral to combat the global warming, but as *additional fuels* to meet the increased consumption of fossil fuels for road transport. In the European Union's transport sector, road transport generates 85% of total CO_2 emissions.

Furthermore, 98% of the European transport market is dependent upon oil which have become increasingly expensive and reached several all-time-highs this summer. This is viewed as economically and strategically unacceptable, especially from a security of supply point-of-view. The reasons behind this increase are two-fold. The transport sector is steadily increasing by 3% per year, and it is projected that by 2020 transportation will account for a third of EU's final energy carrier consumption. The other reason is that since 1970, the number of cars in the European Community has trebled from 62.5 million to nearly 175 million today and the number of private cars is still rising by more than 3 million every year [1].

The problems are bigger for the developing countries in Asia, e.g. China has today 16 million vehicles with an increase of two to three million annually. It has been estimated that from 2000 to 2020 there will be a 24-factor increase of cars in China while a three to four factor increase in India. Already 13 of the 15 dirtiest cities in the world with respect to air pollution are located in Asia. Consequently, there is also need for cleaner fuels, an opening for renewable fuels.

1.2 Swedish political initiatives and developments

The Swedish government, based on a Committee of inquiry on renewable fuels, has recently adopted a strategy to comply with European Union's Council Directive (2003/30/EC) on minimum 5.75% biofuels sold by 2010. Currently, the production capacity is only 1.1% (3.2 PJ), thus biofuel import have made up the difference to reach the national target of 3% by 2005 (highest set in EU) [2]. This has been supported with full tax exemption on biofuels to 2009.

The Committee also investigated a proposed Bill regarding obligation to supply biofuels at the gas stations. This was not preferred, however, but the government has sent the Bill for consideration nonetheless. Instead the Committee recommended replacing tax exemption with Green certificates by 2009 and increasing R&D&D with €16 million per year in developing second generation biofuels. This is vital as the most promising large-scale, low-cost alternative, as stated by four state agencies, to produce second generation biofuels is biomass gasification. Two demonstration plants for fuel production are partly in place (VVBGC in Växjö and Chemrec in Piteå) with a 30.000 tons methanol plant (or DME) planned by Chemrec for 2008.

1.3 New way of producing alternative fuels

Conversion of biomass feedstocks to renewable fuels has been investigated in a large number of studies, some of which discuss methanol production [3,4]. This paper presents a highly cost-effective route for large-scale replacement of fossil based fuels by converting low-grade renewable energy to high-quality energy products such as methanol, DME or Fischer-Tropsch Diesel (FTD). The new technology is based on spent cooking liquids (black liquor) in the pulp and paper industry, which is integrated with commercial synthesis technology, today used in the petrochemical industry. The new innovative concept is called BLGMF – Black Liquor Gasification with Motor Fuels production.

The results presented is a continuation from an earlier EU/Altener project in 2003 which studied the technical and economical feasibility of black liquor gasification integrated with bio-methanol/bio-DME production with an engineering study made for the plant with a ±30% cost estimate [5]. The objective of the new project is to study the feasibility of Fischer-Tropsch synthesis to diesel and compare with updated economic numbers, where this paper is a part of a coming report to the Swedish Energy Agency.

2 PULP & PAPER

2.1 Benefits of black liquor – a renewable resource

The European pulp and paper industry is a vital part of an economic cluster – the paper and forest cluster – that generates an annual turnover of more than €400 billion. In 2002, more than 1260 pulp and paper mills produced some 91 million tons of paper and board. The industry provides direct employment for about 250,000 people and indirect employment for 3.5 million people. World-wide, the black liquor production is about 175 million tons DS (Dry Solids) per year or 2160 PJ, with a steady increase following the growing demand for pulp & paper.

Today, all black liquor is used internally in the pulp mills, although with a low energy efficiency. Primary interest is therefore to maintain the important chemical recovery cycle in the mill and boost energy efficiency. Therefore, current interest and new possibility is to *additionally* produce "green" motor fuels from *added biomass* via black liquor gasification, in countries with a large pulp and paper industry such as Sweden and Finland, USA and Canada.

2.2 Kraft pulping process

The dominant route for production of pulp is by a century-old sulfur-based chemical process known as "kraft pulping". The digester is the main process unit and where wood chips are transformed into pulp by cooking at high temperature and pressure in a caustic solution called *white liquor* (mainly sodium hydroxide and sodium sulfide). The spent cooking liquor exiting the digester, known as *black liquor*, contains roughly 15% solids consisting of dissolved organics from the wood and spent pulping chemicals. In a recovery cycle, energy is recovered from the dissolved organic material and the cooking chemicals are regenerated from the intermediary *green liquor* back to *white liquor* (see Figure 1). Without the recovery cycle, the process would be both economically and environmentally impossible.

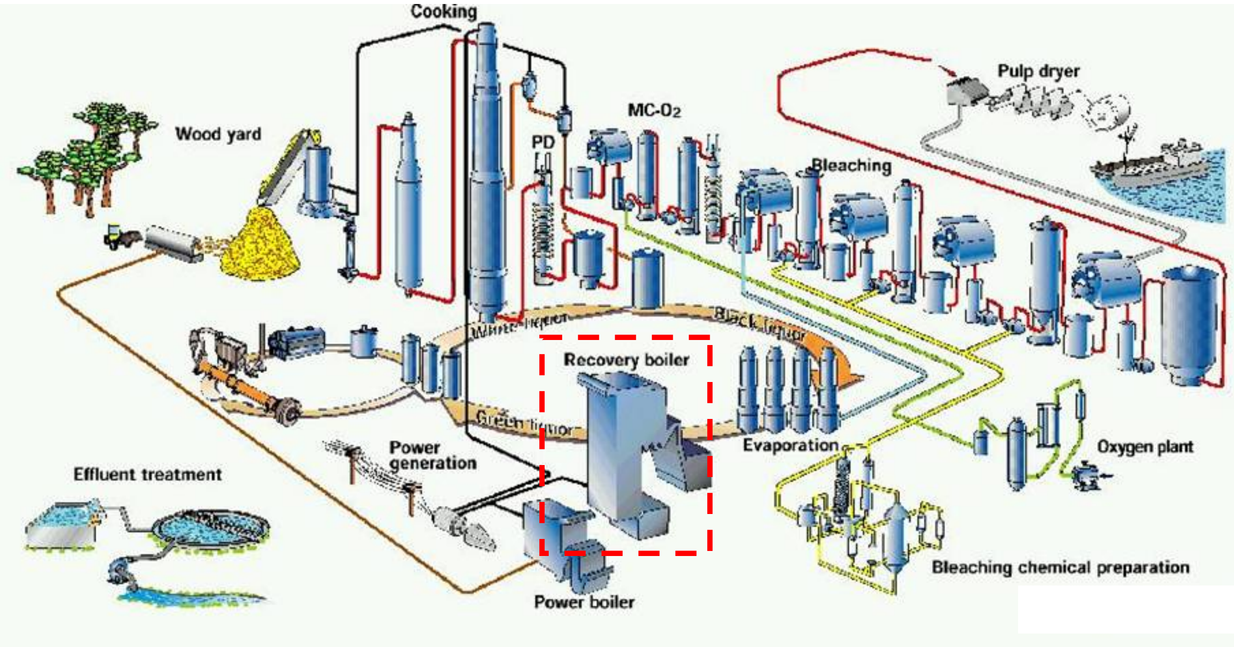

Figure 1. Schematic of a modern kraft pulp mill with its process units. In a BLGMF system only the recovery boiler (marked with red dotted box) has to be replaced.

A modern-sized pulp mill produces about 2000 AD tons/day (Air Dried) of pulp and thus generates 3400-3600 tons DS of black liquor or about 15 PJ/year, which is further processed in a Tomlinson recovery boiler. In comparison with other potential biomass sources for chemicals production, black liquor has great advantage that it is already partially processed and exists in a pumpable, liquid form. Using black liquor as a raw material for fuel production would have the following advantages:

- Biomass logistics are extremely simplified as the raw material for fuel making is handled within the ordinary operations of the pulp & paper plant
- The process is easily pressurized and the produced syngas has a low methane content, which enhances fuel production efficiency and lowers the capital cost
- Gasification capital cost is shared between chemical recovery, steam production and syngas production and pulp mill economics becomes less sensitive to pulp prices as the economics are diversified with another product.

3 PROCESS DESCRIPTION

3.1 Two cases: Recovery boiler and BLGMF concept

Simply said, the process of burning the black liquor in the recovery boiler producing power and heat in one case is compared with gasification in a gasifier reactor in an alternative case producing motor fuels. A schematic of the two cases is shown in Figure 2.

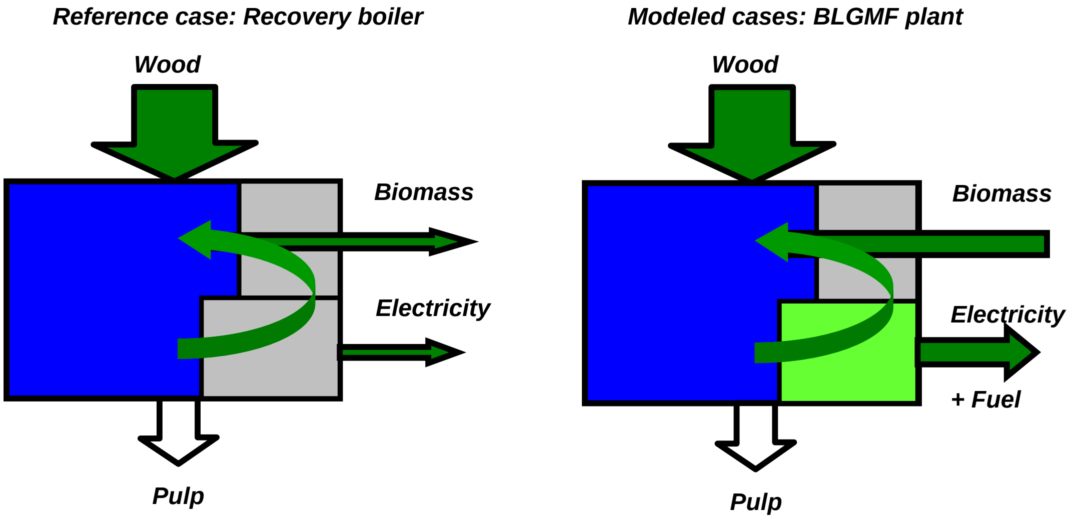

Figure 2. Comparison of the reference case and modeled BLGMF cases, where the fuel can be methanol, DME or Fischer-Tropsch diesel.

In the reference case (modeled as the Ecocyclic pulp mill, which is detailed in the KAM/FRAM program) there is surplus of biomass and electricity after the pulp mill has covered its own needs in term of steam and power. In the modeled cases additional biomass covers the deficit in power and the net result is additional fuel produced at equal electricity production. An important note is that pulp production and operation is not changed.

3.2 The BLGMF process concept

An overall block flow diagram of the system is shown in Figure 3 where a description is followed. Concentrated black liquor is sent to a CHEMREC® entrained flow gasification reactor, where it is gasified at 32 bar, 950°C with 99% oxygen. The process produces an energy-rich gas low in methane, which is cooled in a gas cooler from which the raw gas will be sent to a gas cleaning unit.

The gas cleaning unit selected here is a Rectisol® plant since there are stringent demands on a highly purified cleaned gas, free from H_2S, COS and low in CO_2. HCN and NH_3 will also be removed, as well as tar components such as benzene, toluene and naphthalene. The removed tars are recycled to the gasification reactor.

The sulfur rich gas from the regeneration column is sprayed with aqueous sodium hydroxide (white liquor from the mill) in a short-time contactor unit, which selectively absorbs all sulfur components. After CO-shifting, used to obtain a final stoichiometric H_2:CO ratio of 2.0-2.4, the gas stream is cooled down to ambient temperature via steam generation. The cleaned outlet synthesis gas is then synthesized to methanol, DME or FTD in a separate process similar to conventional natural gas based synthesis processes.

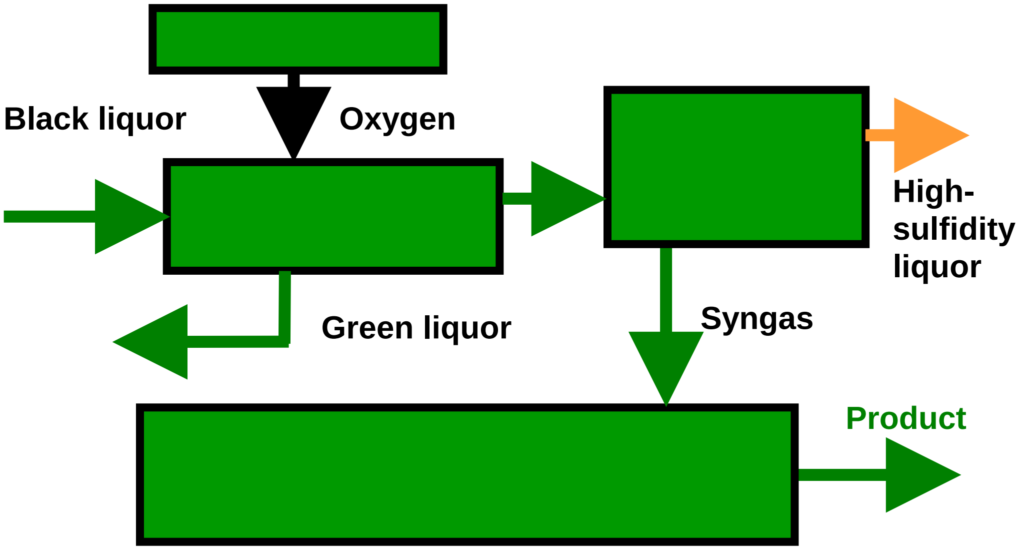

Figure 3. Block flow diagram of the BLGMF plant with its main process sections.

When synthesizing methanol the gas is compressed to about 60 bar in a centrifugal compressor prior to the methanol synthesis loop containing a conventional catalyst reactor protected from any remaining sulfur with a sulfur absorber. Direct DME manufacture is very similar to the methanol synthesis loop and both products are distilled to fuel quality for vehicle use.

Fischer-Tropsch synthesis is different to methanol in that the catalytic reaction is not selective and a wide range of hydrocarbons are produced. The Co-based catalyst is placed in a low-temperature slurry phase reactor that operates at 25 bar, 210°C, similar to Statoil's 1000 bpd plant in Mossel Bay, South Africa [6]. Light fractions C_1-C_4 are separated, partially oxidized to H_2 and CO and recycled to the FT-reactor. Part of the H_2 is separated in a Pressure Swing Adsorption (PSA) unit.

The heavy fractions, naphtha C_5-C_{11}, diesel C_{12}-C_{20} and waxes C_{21+} are sent to a Heavy Paraffin Cracker (HPC), where the long-chained waxes are hydrocracked selectively with the H_2

separated in the PSA unit, combined with isomerisation to increase the diesel share and to improve the cold-flow properties of the diesel. The fractions are then separated in a distillation column, with remaining waxes recycled to the HPC.

4 MATERIAL AND ENERGY BALANCE

4.1 Energy efficiency

The pulp and paper processing plant which forms the base for the BLGMF plant is essentially unchanged and has the same energy demand still in the form of power and heat. As the black liquor is withdrawn from the mill, additional biomass has to be added to a biomass boiler in order to provide the necessary energy. Based on the Ecocyclic pulp mill, where all energy and by-products are recovered with today's most efficient technology, a BLGMF concept was designed and calculated based on a 2000 ADt/day pulp mill, where the calculations for the FTD case is preliminary and not fully optimized.

The calculated production potential is 411,000 tons of methanol per year or 290,000 tons of DME or 150,000 tons of FTD and naphtha (total equivalent to 3,600 barrels per day), however naphtha, C_5-C_{11}, falls below the diesel C_{12}-C_{20}, specification and may only be used as very low gasoline blendstock. As the correct specifications of FTD and naphtha can not be obtained, it is assumed that with 95% syngas conversion the C_{5+} products follow the ASF relation with an α of 0.90. For the lower hydrocarbon fractions (C_1-C_4) the following was assumed: 10% of the converted C-atoms exit as methane, 10% as LPG + ethane, and 2% as CO_2. The FTD has also been calculated with assumed diesel physical properties and heating value of 41.3 MJ/kg [7]. The biomass to fuel efficiency, the ratio of produced fuel and consumed biomass is calculated as 66% for methanol, see Table 1 for main material and energy balances for all cases.

Table 1: Material and energy balances for BLGMF in a 2000 ADt/day market pulp mill with resulting biomass to fuel efficiency. Note in the FTD case naphtha is produced, however not considered a motor fuel.

Fuel options	**Methanol**	**DME**	**FT-diesel + Naphtha**
Biomass consumption	414 MW	408 MW	371 MW
Fuel production	273 MW	275 MW	103 MW + 112 MW
Fuel production	1183 t/d	824 t/d	215 t/d + 218 t/d
Biomass to fuel	**66%**	**67%**	**28% + 30% = 58%**

4.2 Transport fuel potential

Methanol has very good features as a future transport fuel in low-blend or as neat motor fuel. DME shares same technology and ease of production but need a separate infra-structure and dedicated vehicles. However, Volvo Truck has developed a DME prototype with a 9.0 liter heavy-duty engine that shows extremely good performance with ultra-low emissions thanks to virtually particle-free exhaust gases.

FTD is considerably more complicated to produce and the process yields a bi-product, naphtha with very low octane number thus lowering total yield of motor fuel products. However, the FTD is easy to distribute with conventional diesel fuel and is free from impurities and has very high cetane number that facilitates complete combustion and very low emissions.

The estimated black liquor production with projections to 2025 based on previous 35 years yearly production records shows a steady increase of 3.5% per annum. North America is the main world producer (1260 PJ) and Europe as second largest producer (432 PJ) with Sweden (139 PJ) and Finland (143 PJ) as main producers [8]. With additional biomass there are favorable conditions for large-scale production of studied motor fuels. Using above biomass to fuel efficiency, substantial amounts can be produced and a high replacement share of current fuel consumption obtained, see Table 2.

Table 2: Potential fuel production from biomass via black liquor gasification and methanol road transport fuel replacement share in selected countries. Note, in the FTD case additional naphtha with about equal amount of energy is produced, however not considered a motor fuel.

Country	**Gasoline/diesel consumption**	**Black liquor production**[a]	**Methanol repl. share**	**Methanol production**	**DME production**	**FT-diesel production**
Austria[b]	6.3 Mtoe	13.5 PJ	2.8%	0.38 Mton	0.26 Mton	0.068 Mtoe
Finland[b]	3.8 Mtoe	143.0 PJ	**50.6%**	4.03 Mton	2.81 Mton	0.72 Mtoe
Portugal[b]	6.2 Mtoe	33.2 PJ	7.2%	0.94 Mton	0.65 Mton	0.17 Mtoe
Spain[b]	28.1 Mtoe	32.3 PJ	1.6%	0.91 Mton	0.63 Mton	0.16 Mtoe
Sweden[b]	6.8 Mtoe	139.0 PJ	**27.6%**	3.92 Mton	2.73 Mton	0.70 Mtoe
Brazil[c]	48.1 Mtoe	106.0 PJ	3.0%	2.99 Mton	2.08 Mton	0.54 Mtoe
Indonesia[d]	19.5 Mtoe	73.4 PJ	9.0%	2.07 Mton	1.44 Mton	0.37 Mtoe
Japan[d]	342.0 Mtoe	192.4 PJ	1.4%	5.42 Mton	3.78 Mton	0.97 Mtoe
Canada[d]	48.1 Mtoe	252.0 PJ	7.1%	7.10 Mton	4.95 Mton	1.28 Mtoe
USA[e]	549.0 Mtoe	1007 PJ	2.5%	28.4 Mton	19.8 Mton	5.10 Mtoe

Notes:

[a] Black liquor production, FAOSTAT, 2001.

[b] Road transport consumption in 2002, EUROSTAT, 2004.

[c] Total road transport consumption 2000, IEA, 2004.

[d] Road transport consumption 2000, World Energy Outlook 2002.

[e] Road transport consumption 2003, Bureau of Transportation Statistics, 2004.

5 ECONOMICS

5.1 Investment cost estimates

To justify a replacement investment at a plant and replacing an existing process where the economic life has ended, we have decided to calculate an *incremental* investment cost with *additional* production costs. Thus, the investment decision would normally be based on a *comparison* between the two alternatives: a) reference mill with a recovery boiler and b) same type of mill with a BLGMF plant. It should therefore be noted that the results in this paper are based on a *comparison* and that the *incremental* investment cost and additional production costs are calculated. Key input financial variables have been a weighted average cost of capital, 8.0%, a project life-time of 25 years and annual operating hours, 8,330.

The investment costs have all been based on quotations from leading process suppliers with money value 3Q2003 and then updated to 3Q2005 with the Chemical Engineering Plant Cost Index. The index has shown a steady increase with approx. 0.6% per year from 389.5 (1998) to 395.6 (2002) with a small increase in 2003 to 402.0 and then an extraordinary 10% increase in 2004 to 444.2. Moreover, the latest available index is March 2005 with 468.3. This large increase compared with small changes previously is partly due to increase of the price of steel.

The incremental investment cost for the gasification plant integrated with methanol synthesis is estimated to be about €164 million, see Table 3. The cost includes a large biomass boiler and all extra balance of plant costs. The investment cost for the FTD case is somewhat more uncertain and is notably lower than for the others, due to simplified product upgrading and about half the volumetric output of the reactor although more process units needed.

Table 3: Summary of investment costs for three cases compared with a reference case, a modern recovery boiler. Note, the FT-synthesis and upgrading investment cost partly estimated.

Investment cost estimate, MEUR	**Reference mill, Recovery boiler**	**BLGMF Methanol**	**BLGMF DME**	**BLGMF FT-diesel**
Recovery boiler	105.0	N/A	N/A	N/A
ASU[a]	4.3	30.0	30.0	33.5
Gasification and gas cooling	N/A	68.5	68.5	68.5
Gas cleaning and sulfur handling[b]	N/A	37.6	37.6	37.6
Fuel synthesis and storage[c]	N/A	51.7	63.0	54.2
Power boiler with steam turbine[d]	23.0	64.8	67.1	23.7
Lime kiln and bark dryer	23.7	29.2	29.2	29.2
Balance of plant	N/A	6.2	6.2	6.2
Equipment and assembly	***156.1***	***287.9***	***301.5***	***252.8***
Site costs incl. owner's cost	0.8	5.3	5.3	5.3
Interest during construction	5.5	12.6	13.2	11.1
Unspecified costs[e]	7.8	28.8	30.2	25.3
Total investment cost	**170.2**	**334.6**	**350.2**	**294.4**
Incremental BLGMF investment	**N/A**	**164.4**	**180.0**	**124.2**

Notes:

[a] The Air Separation Unit, ASU is 17% larger than for the methanol and DME cases.

[b] Includes pre-wash, CO-shift and a Rectisol® unit.

[c] Includes compressor, catalytic reactor and distillation column, for FT-diesel case POX-reactor with PSA and HPC.

[d] Includes wood yard and fuel handling. The FTD case handles much smaller biomass quantity than the other cases.

[e] Includes engineering, spare parts, licensing fees, start-up etc.

5.2 Production costs

The net production cost has been calculated as the incremental capital cost with the difference between the operating benefit of the reference case and the operating cost of the BLGMF cases. The prices have been based on the 2004 Swedish averages, biomass price of €3.7/GJ and electricity price of €51/MWh that includes a "green" electricity certificate of €23.5/MWh. The net methanol production cost is €10.2/GJ or $1.5 per gallon gasoline equivalent (€0.32 or SEK 3.0 per liter gasoline-equivalent). Note, in the FTD case, only the energy share of FTD to the total output including naphtha has been used to calculate the production cost, see Table 4.

Table 4: Summary of production cost for three cases compared with a reference case, a modern recovery boiler. Negative costs for the reference mill refer to revenues.

Additional production cost	**Unit**	**Ref mill, Rec. boiler**	**BLGMF Methanol**	**BLGMF DME**	**BLGMF FT-diesel**
Incremental capital cost	**MEUR/year**	**N/A**	**15.4**	**16.9**	**11.6**
Biomass[a]	MEUR/year	-2.8	14.4	13.9	2.8
Electricity[b]	MEUR/year	-19.1	24.1	23.8	34.5
Chemicals, water etc.	MEUR/year	N/A	2.9	3.0	2.5
Operation & maintenance	MEUR/year	3.9	8.6	8.9	6.4
Total cost	***MEUR/year***	***-18.1***	***49.9***	***49.6***	***46.2***
Addition. operating cost	**MEUR/year**	**N/A**	**67.9**	**67.7**	**64.3**
Total production cost	**EUR/GJ**	**N/A**	**10.2**	**10.3**	**12.1**[d]
Total production cost	**EUR/ton**	**N/A**	**203**	**296**	**499**[d]
Total production cost[c]	**EUR¢/equiv. liter**	**N/A**	**32.0**	**35.4**	**41.6**[d]
Total production cost[c]	**SEK/equival. liter**	**N/A**	**3.0**	**3.3**	**3.9**[d]
Total production cost[c]	**USD/equiv. gallon**	**N/A**	**1.5**	**1.7**	**2.0**[d]

Notes:

[a] Based on the amount needed to balance the energy need of the mill.

[b] Based on the amount needed to equal the electricity production as for the ref case.

[c] The production cost is based on gasoline and diesel equivalents, 11.63 MWh/ton, 750 kg/m^3 and 11.75 MWh/ton, 815 kg/m^3, respectively.

[d] Costs are given only as the energy share of the FT-diesel to the total output including naphtha.

The net production costs are shown in Figure 4, where the additional operating cost and the full capital cost have been included. The distribution costs have been calculated with Rotterdam as base for equal distance and not including the cost for building the infrastructure. However in reality the cost would be lower as the plant would be located in Sweden closer to the depots.

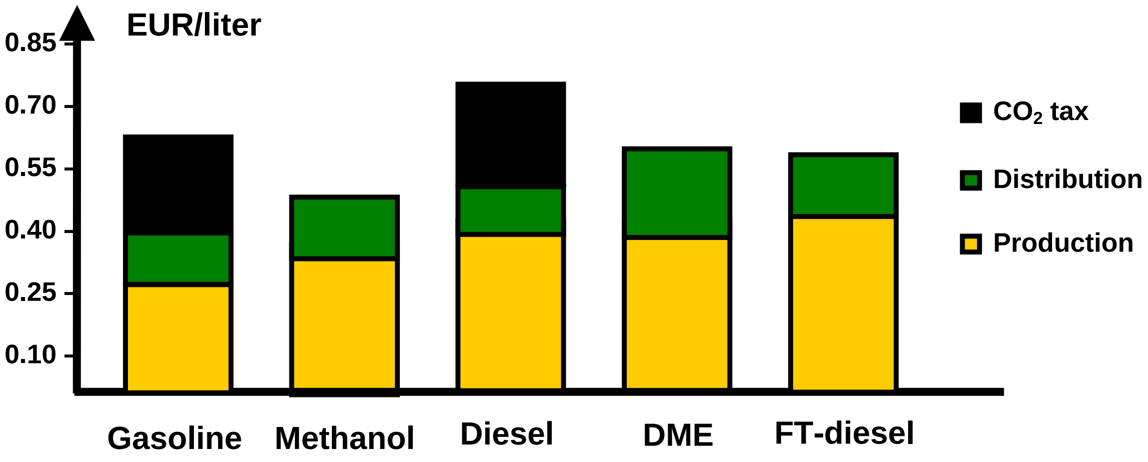

Figure 4. Summary of production costs compared with gasoline and diesel which are taken as average Swedish fuel costs during Jan-July 2005 in energy-equivalent liters. Note, the FTD cost assumes offset of large quantity naphtha covering its own costs.

5.3 Return on investment results

The potential fuel product revenues at the mill gate are based on assumed same cost on an energy basis for the consumer on gasoline (methanol) and diesel (DME, FTD). Because DME and FTD can not replace gasoline in an otto engine, DME and FTD are priced as diesel fuels and related to current diesel price. It should be noted however, that the gasoline and diesel consumer prices differ from country to country in taxes, distribution costs and markets share. The following are based for a Swedish setting, however can be recalculated for other countries with respective local taxes and prices.

Naphtha is highly paraffinic (primarily straight chains, low octane number) and low in aromatics making neither good gasoline blendstock nor a suitable refinery catalytic reformer feed. Rather, it is an excellent feed for steam crackers to produce ethylene and other olefins. In fact, due to its paraffinicity and purity naphtha yields more ethylene than does refinery naphtha. Naphtha falls outside diesel specification and this study assumed that “green” naphtha covers its production costs by generating a netback including “green” premium equal to Swedish CO_2 tax.

The estimated netback/selling price of the fuel products was calculated as the average 2005 prices of gasoline and diesel consumer price at pump, subtracted for the taxes and estimated distribution costs, shown in Figure 5 below [9].

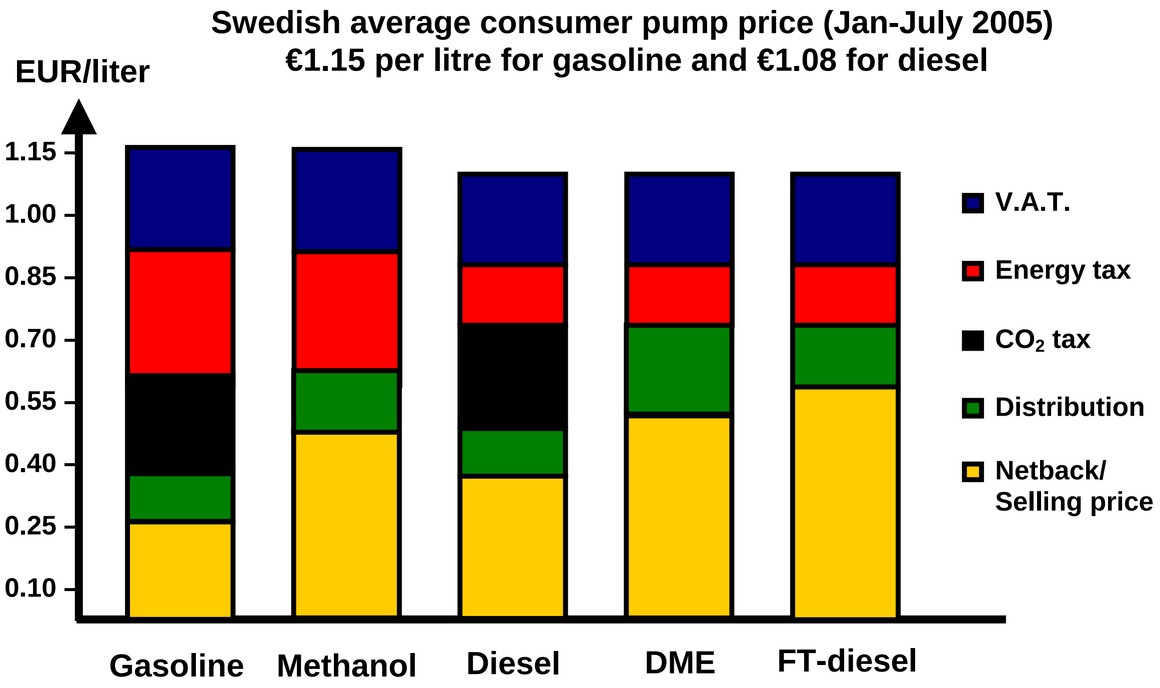

Figure 5. Breakdown of the average 2005 prices for gasoline and diesel showing estimated netback/selling prices for methanol, DME and FT-diesel products in energy-equivalent liters, including applicable taxes and distribution costs.

With current remarkable increase in crude oil prices fuel prices have increased as well. The average Brent crude oil price for 2002 was $25 per barrel which was close to a 20 year average. This increased to $29 for 2003 and further to $38 for 2004. Today, August 2005, several all-time-highs have been recorded above $65.

There are many factors behind this high level such as war and speculation, however there has been a rapid increase in world oil consumption and according to ASPO global oil production is peaking as reserves of light oil are getting depleted and new discoveries does not make up for the current consumption of 84 million barrels per day [10].

A cash flow IRR analysis was carried out for all cases, considering the incremental investment and operating costs for the BLGMF system relative to a new recovery boiler investment. The cash flow analysis did not take into account any yearly differences in consumption, production, depreciation, financing other than stated above, and furthermore rest value of the investment or any levelized prices.

The capital costs in this study have an accuracy of ±30% due to the level of detail included in the cost estimates and to inherent uncertainties in projecting "Nth plant" costs given the pre-commercial status of the BLGMF technology today. Future energy price levels are also uncertain and prices can vary considerably between regions. The incremental investment of €164 million gave an IRR of 35% for methanol with a pay-back of 3.1 years (see Table 5).

Table 5: Results on return on investment, where the FTD and naphtha are added.

Results	**Unit**	**BLGMF Methanol**	**BLGMF DME**	**BLGMF FT-diesel**	**BLGMF FT-naphtha**
Netback/Selling price	€/liter	0.48	0.54	0.63	0.38
Production cost	€/liter	0.32	0.35	0.42	0.38
Capital part of prod. cost	€/liter	+0.06	+0.07	+0.06	+0.06
Margin	€/liter	0.22	0.26	0.27	0.06
Yearly production volume[a]	m^3	260,600	238,900	89,500	107,200
Yearly margin	MEUR	54	62	24	6.4
Total investment	MEUR	164	180	124	
Payback time[b]	years	3.1	2.9	4.1	
Real return on total capital	%	29%	30%	23%	
IRR	**%**	**35%**	**36%**	**26%**	

Notes:

[a] Gasoline/diesel equivalent m^3 where methanol and naphtha are gasoline fuels and the others diesel fuels.

[b] Payback time calculated excluding inflation.

6 CONCLUSIONS

There is a need for introduction of large-scale low cost alternative fuel production as global warming and increased fossil fuel consumption becomes more evident. The pulp plants show several advantages for the implementation of efficient fuel production by black liquor gasification. The studied BLGMF concept shows very high biomass to methanol efficiency of 66% and flexibility to produce also DME or Fischer-Tropsch diesel. Based on a 2000 ADt/day pulp mill, the production potential is 411,000 tons of methanol per year with a production cost of €10.2/GJ or $1.5 per gallon gasoline equivalent (€0.32 or SEK 3.0 per liter g.-equivalent). For Sweden, this cost would be competitive with current gasoline price, when including carbon dioxide tax and distribution costs, but excluding other taxes. The IRR is 35% with a payback of 3.1 years. DME shows similar good performances and FTP preliminary 26%, however, with low diesel yield as naphtha is co-produced and on shared production cost conditions.

Estimated replacement share potential in Sweden and Finland with methanol as motor fuel is about 28% and 51%, respectively, or about 4.0 million tons each per year. In the whole EU, the potential is 11 million tons and in USA potentially 28 million tons – *almost equaling today's world methanol production*. For FTD production it is essential that the produced naphtha finds a market possibly as feed for ethylene production or as very low gasoline blendstock. The calculations for the FTD case are somewhat uncertain as several assumptions have been used and the FT-technology is not widely commercial. However, there are great potential for improvements, e.g. in the catalyst selectivity and option of relocating the upgrading to a refinery where distribution could also be handled, thus lowering the capital cost significantly.

In conclusion, there are necessary resources and potential for large-scale methanol (or DME, FTD) production and substantial economic incentive for making plant investments and achieving competitive product revenues. A schematic vision for recycling of carbon in a future BLGMF concept in a biorefinery pulp mill is shown in Figure 6.

Figure 6. Vision of carbon recycling with a pulp mill biorefinery for future plants.

7 ACKNOWLEDGEMENTS

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