

Black Liquor Gasification

Summary and Conclusions from the IEA Bioenergy ExCo54 Workshop

This publication provides the record of a workshop organised by IEA Bioenergy. Black liquor gasification is an interesting option for production of synthesis gas that can subsequently be converted to a variety of motor fuels. The technology can be integrated into modern, ecocyclic, kraft pulp mill biorefineries. USA and Sweden lead developments in this field. It is of interest primarily among countries with strong pulp and paper industries and national policies which promote substitution of petrol and diesel by biofuels.



INTRODUCTION

This publication provides a summary and the conclusions from a workshop organised by IEA Bioenergy. It was held in conjunction with the 54th meeting of the Executive Committee in Ottawa on 6 October 2004. The purpose of the workshop was to present the developments of black liquor gasification for the production of energy and/or biofuels for transport and discuss the remaining barriers, either technical or strategic, that need to be overcome in order to accelerate the successful demonstration of black liquor gasification technologies and subsequently their penetration in the market.

There is a growing interest in finding cheap and efficient ways to produce CO₂-neutral automotive fuels by using biomass as the raw material, as CO₂ is the main gas responsible for climate change. However, the consumption of fossil fuels by all economic sectors is decreasing with the exception of road transport; that continues to increase and there is a need to cut down on CO₂ emissions. There is therefore an urgent need to develop not only alternative but also additional fuels.

Emissions from the transport sector are growing at an alarming rate. Road transport in particular generates 85% of the European Union transport sector's emissions. Furthermore, 98% of the European transport market is dependent upon oil. The external energy dependence has passed 50% and will increase to more than 70% and 90%, for oil in particular, in 20-30 years if nothing is done. This is viewed as economically and strategically unacceptable.

Black Liquor Gasification (BLG) is an interesting alternative to produce synthesis gas that can subsequently be converted to a variety of motor fuels such as Fischer-Tropsch, DME, methanol, and hydrogen. BLG can be integrated in a future modern, ecocyclic, pulp mill biorefinery for the production of renewable energy sources in the form of CO₂-neutral fuels for automotive uses.

BACKGROUND

The Pulp and Paper Industry

The pulp and paper industry is a vital part of the global economic cluster – the paper and forest cluster – that in Europe alone generates an annual turnover of more than €400 billion. In 2002, more than 1260 pulp and paper mills produced a total of some 91 million tonnes of paper and board. The industry provides direct employment for about 250,000 people, and indirect employment – through the paper and forest sectors – for a total of 3.5 million people.

A pulp mill that produces bleached kraft pulp generates 1.7-1.8 tonnes of black liquor (measured as dry content) per tonne of pulp. Black liquor thus represents a potential energy source of 250-500 MW per mill. As modern kraft pulp mills have a surplus of energy, they could become key suppliers of renewable fuels in the future energy system. Today, black liquor is the most important source of energy from biomass in countries such as Sweden and Finland with

a large pulp and paper industry. It is thus of great interest to convert the primary energy in the black liquor to an energy carrier of high value.

Worldwide, the pulp and paper industry currently processes about 170 million tonnes of black liquor (measured as dry solids) per year, with a total energy content of about 2EJ, making black liquor a very significant biomass source (see Figure 1). In comparison with other potential biomass sources for chemicals production, black liquor has the great advantage that it is already partially processed and exists in a pumpable, liquid form. Using black liquor as a raw material for liquid or gaseous biofuel production in a biorefinery would have the following advantages:

- Biomass logistics are extremely simplified as the raw material for fuel production is handled within the boundaries of the pulp and paper plant.
- The process is easily pressurised, which enhances fuel production efficiency.
- Due to the processing of wood to pulp, the produced syngas has a low methane content, which optimises fuel yield.
- Pulp mill economics become less sensitive to pulp prices when diversified with another product.
- Gasification capital cost is shared between recovery of inorganic chemicals, steam production, and syngas production.

Overall, if the global production of black liquor were to be used for transport biofuel production, then this would correspond to about 48 million tonnes of methanol, compared with current world production from fossil fuels of about 32 million tonnes, a significant impact.

Pulp and Paper Making

Most of the pulp and paper produced today (90%) originates from wood. The major components of softwoods (e.g., pine, spruce) as well as hardwoods (e.g., birch, aspen, eucalypts) are cellulose (40-50%), hemicellulose (25-30%), and lignin (25-30%). Extractives constitute a minor part.

Pulp for paper production is obtained via two classes of processes that differ greatly in principle:

- Mechanical pulping, in which the fibres are separated mainly through mechanical treatment in refiners. Most of the wood thus becomes pulp, including the lignin.
- Chemical pulping, in which the fibres are separated mainly through chemical treatment in either acidic or caustic solutions. These processes aim to separate the lignin from the cellulose fibres.

Due to their high lignin content, mechanical pulps quickly become yellow. They are therefore used mostly for products with a short life span, such as newsprint and magazine paper. Another reason why mechanical pulps are used in these products is because they contain large fractions of relatively short fibres and fibre fragments; therefore they make dense and opaque sheets that are suitable for printing paper. Approximately one-third of the pulp produced in the European Union is mechanical pulp.

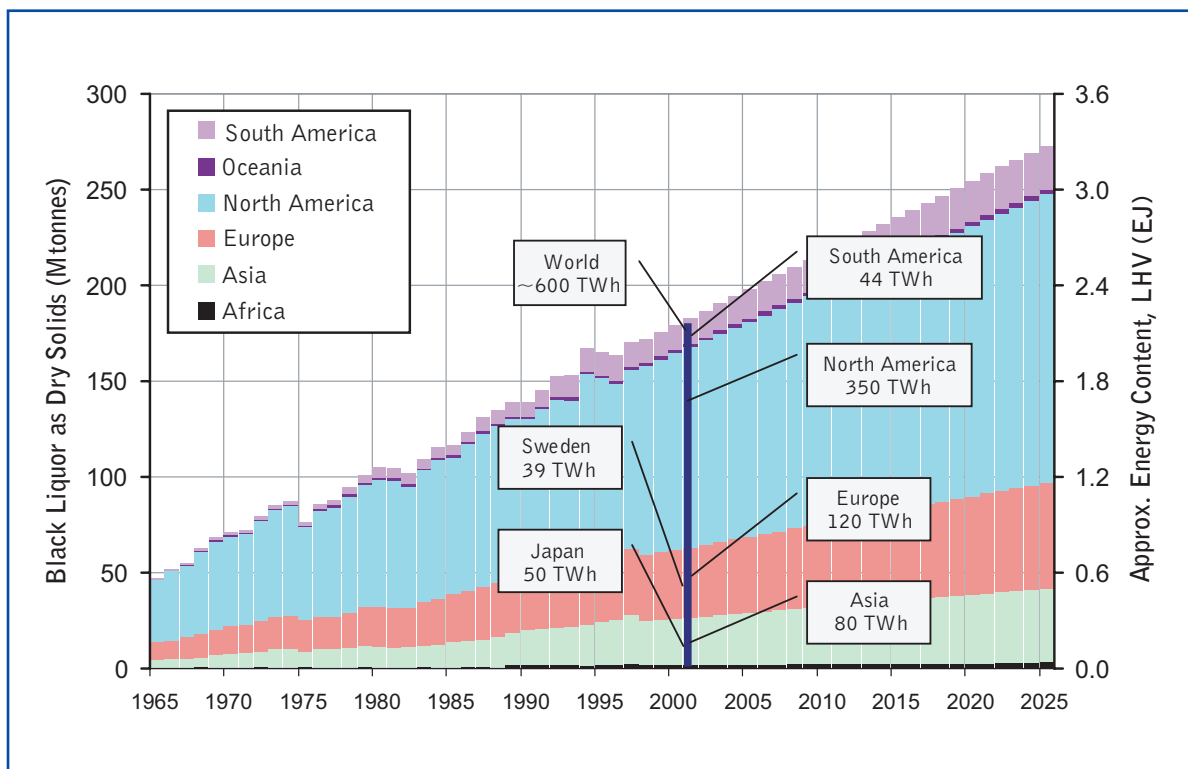


Figure 1: Estimated Black Liquor World production (FAOSTAT, 2001).

Chemical pulps constitute the other two-thirds of the pulp production. These pulps are characterised by high strength and, if bleached, by high brightness and long-term brightness stability. Typical products made from bleached chemical pulp include fine paper, tissue, and a number of board grades. Unbleached chemical pulp is mostly used to produce corrugated board and sack paper.

Out of the total fibre furnish used for papermaking in Europe, about half the pulp is supplied directly from the processes above as 'virgin fibre'. Recovered paper makes up the remaining fraction, which increased from 40% in 1990 to 54% in 2002 (FAOSTAT, 2003).

From an energy point-of-view the two processes differ greatly. Mechanical pulping consumes electrical energy, which to some extent is recovered as steam and usable low-grade heat. Only a small fraction of the wood is dissolved in the process. In contrast, about 50% of the wood is dissolved in chemical pulping. The processing of this dissolved organic substance can make a mill self-sufficient in energy and, depending on the type of product, even generate a surplus of steam or electricity. It is this dissolution of the energy-rich lignin fraction from the pulp fibres that makes chemical pulping an interesting candidate for the production of liquid fuels from biomass.

The dominant process for chemical pulping (at about 90%) is the kraft process, sometimes called the sulphate process.

Kraft Pulping Process

Nearly all of today's paper is manufactured by a century-old sulphur-based chemical process known as the 'kraft pulping' process. In Figure 2 a schematic is shown of a modern kraft mill that produces bleached market pulp. Many mills have integrated pulp and paper production where only a part of the pulp production, or none at all, is sold on the market. In principle, in an integrated mill, the pulp dryer in Figure 2 is replaced by a paper machine.

The process starts in the wood yard where logs are debarked and cut into wood chips a few centimetres in length. It is also common for mills to use a fraction of purchased sawmill chips. The wood chips are impregnated with cooking liquor and then fed to the digester, commonly of the continuous type, although there are many mills that use batch digesters as well. The residence time in the digester is several hours, during which the chips are cooked at a temperature of 150-170°C under strongly alkaline conditions and in the presence of sulphide. The main objective is to dissolve as much of the lignin as possible while minimising the simultaneous dissolution of the carbohydrates.

Sulphide has two positive effects; it both reduces the reaction rate for carbohydrate dissolution and increases the delignification rate. The drawback is that small amounts of sulphide react to produce organic sulphur compounds such as methyl mercaptan and dimethyl sulphide. The odour threshold for these compounds is very low, and despite the efficiency of modern collection systems for odorous gases there is always a characteristic smell from a kraft pulp

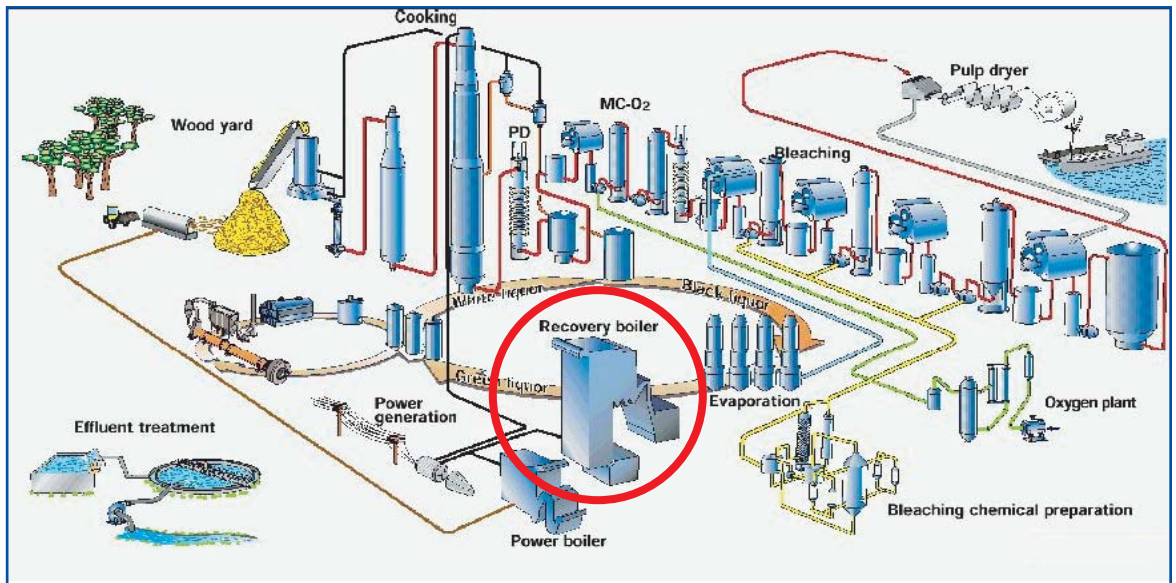


Figure 2: Schematic of a modern kraft pulp mill with its process units. In a BLG system only the recovery boiler (marked with red circle) has to be replaced.

mill, which may be almost negligible under continuous trouble-free operation, but becomes evident during upsets or accidental spills.

The pulp produced in the digester is washed to recover the cooking liquor and reduce the carryover of dissolved organic material to the oxygen delignification stage. This stage is more selective than cooking, i.e., the yield loss is smaller per unit of lignin removed. After further washing, the pulp goes to the bleach plant. Final bleaching is still more selective than oxygen delignification and is usually done in a sequence of acidic and alkaline stages with washing between the stages. The most common bleaching chemicals used today are chlorine dioxide and hydrogen peroxide. After final bleaching the lignin content is very low, giving the pulp high brightness stability.

In a market pulp mill, the bleached pulp is dried with hot air in a pulp dryer before it is baled and shipped to the customers (paper mills). In an integrated mill the pulp is not dried but pumped to the paper machine, where it can be mixed with other pulps and additives to give the paper its desired properties. Even integrated mills sometimes produce market pulp, since the optimal size of a pulp mill is larger than that of a paper machine.

Recovery Cycle

An extremely important part of the pulp mill is the recovery cycle, which is shown in the circle in the centre of Figure 2. In this cycle, energy is recovered from the dissolved organic material and the cooking chemicals are regenerated. Without the recovery cycle, the process would be both economically and environmentally impossible. A more detailed drawing is shown in Figure 3. The raw material for the recovery cycle is the cooking liquor that has been displaced during washing of the pulp. Due to its colour, it is called **black liquor**. It contains approximately half of the organic material that was originally in the wood and almost all of the inorganic chemicals that were used for delignification. The solids content of the black liquor is relatively low when it is withdrawn from the digester, and to produce a combustible

material the black liquor is evaporated to high dryness in a multi-stage evaporation plant.

After evaporation, the black liquor is burned in the recovery boiler, often referred to as a Tomlinson boiler after its inventor. By employing a staged combustion process, the conditions in the furnace can be reducing at the bottom and oxidising at the top. In this way, the sodium and sulphur can be recovered as molten sodium sulphide and sodium carbonate – called **smelt** – that is tapped from the bottom of the boiler. Meanwhile, the organic material is completely oxidised in the upper parts of the furnace to provide heat for high pressure steam generation.

After the smelt has been dissolved in weak wash it is known as green liquor. Before it can be reused in the cooking process, the carbonate ions in the liquor need to be replaced by hydroxide ions. This is done through a process called causticising where the green liquor reacts with quick lime to produce calcium carbonate and sodium hydroxide. The result is called white liquor, which is the cooking liquor needed to start the delignification process again.

The calcium carbonate formed in the causticising vessels is washed (giving weak wash) and then burned in the lime

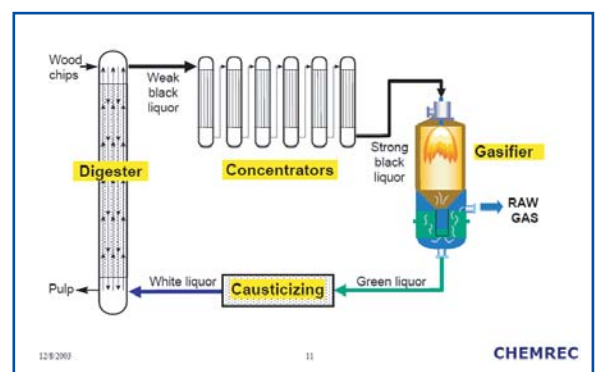


Figure 3: Simplified flow diagram of the chemical recovery cycle in the kraft pulping process.

kiln to regenerate the quick lime. The kraft process is thus nearly self-sufficient in the production of the major chemicals used for cooking. Small amounts of sodium and sulphur must sometimes be added to compensate for losses. The most common make-up chemical is sodium sulphate, which has given the process its alternative name. Due to steadily increasing closure of the process the natural losses are diminishing, and it is therefore necessary in some mills to purge sodium and sulphur rather than supplying them as make-up.

Modern Mills

A modern kraft pulp mill is energy self-sufficient; it can produce all the steam and power that is needed for the process as well as a surplus. The major part of the energy comes from the combustion of black liquor in the recovery boiler. The second boiler on site (power boiler in Figure 2) is used to burn the bark and sometimes biosludge from the effluent treatment. In older, less energy-efficient, pulp mills and in most integrated mills, purchased fuels are also burned in the power boiler. These are mostly wood fuels, but some oil is also used. The lime kiln is then usually fired with oil or natural gas, but in modern market pulp mills the surplus of biofuels is used to provide heat also for the lime kiln. Available methods include bark gasification and direct-firing of pulverised bark.

High-pressure steam is generated in both boilers, and electric power is generated in one or two back-pressure steam turbines. The heat demand of the mill is usually split between two steam levels, medium pressure at 10-12 bar(a) and low pressure at 4-5 bar(a).

The logistics of handling biomass feedstock are well developed around a pulp mill. Large mills that produce in the order of 2000 tonnes of pulp per day handle 3-4 million cubic metres of wood per year. In energy terms, the wood that is processed corresponds to 800-900 MW.

Black Liquor

As it exits in the digester, the black liquor contains 15-17% solids, consisting of dissolved organics from the wood and spent pulping chemicals. A typical pulp mill uses several hundred tonnes of inorganic chemicals per day. For both environmental and economic reasons, it is desirable to recover and recycle these chemicals. Black liquor has a high organic content from the dissolved lignin and carbohydrates, and in concentrated form (>60% solids) it burns in a manner similar to heavy oil. In a modern pulp mill, the black liquor is usually concentrated to 70-80% dry solids.

A typical black liquor composition is shown in Table 1. The inorganic content is high – about 45% of the black liquor exits the recovery boiler as smelt. The heating value per tonne of black liquor solids is thus relatively low, despite the fact that black liquor is rich in lignin, which has a higher heating value than the other major components of wood.

A mill that produces bleached kraft pulp generates 1.7-1.8 tonnes of black liquor (measured as dry content) per tonne of pulp. Black liquor thus represents a potential energy source of 250-500 MW per mill. As modern kraft pulp mills have a surplus of energy, they could become key suppliers of renewable fuels in the future energy system. Today, black liquor is the most important source of energy from biomass

Table 1: Typical elemental analysis and heating value of black liquor solids

Component	% Mass	
C	35.7	
H	3.7	
S	4.4	
O	35.8	
Na	19	
K	1.1	
Cl	0.3	
N	<0.1	
Total (%)	100	
Combustible Characteristics		
BL, Dry Solids	% Mass	80%
HHV	MJ/kg, DS	14.50
NHV	MJ/kg, DS	12.29

in countries such as Sweden and Finland with a large pulp and paper industry. It is thus of great interest to convert the primary energy in the black liquor to an energy carrier of high value such as electricity and transport biofuels. Given the continuous significant global increase in transport fuel demand, it is of strategic importance that black liquor be converted to transport biofuels wherever the local or national conditions promote this with appropriate and enabling policies.

Black Liquor Gasification (BLG)

Gasification of black liquor is an alternative recovery technology that has gone through a step-wise development since its early predecessor was developed in the 1960s. The currently most commercially advanced BLG technology is the Chemrec technology, which is based on entrained-flow gasification of the black liquor at temperatures above the melting point of the inorganic chemicals.

In a BLG system the recovery boiler is replaced with a gasification plant. The evaporated black liquor is gasified in a pressurised reactor under reducing conditions. The generated gas is separated from the inorganic smelt and ash. The gas and smelt are cooled and separated in the quench zone below the gasifier. The smelt falls into the quench bath where it dissolves to form green liquor in a manner similar to the dissolving tank of a recovery boiler.

The raw fuel gas exits the quench and is further cooled in a counter-current condenser. Water vapour in the fuel gas is condensed, and this heat release is used to generate steam. Hydrogen sulphide is removed from the cool, dry fuel gas in a pressurised absorption stage. The resulting gas is a nearly sulphur-free synthesis gas (syngas) consisting of mostly carbon monoxide, hydrogen and carbon dioxide.

Most of the development of large-scale systems for BLG has been aimed at using the syngas to fire a gas turbine in which power is generated. The hot flue gas from the gas turbine is then used to generate steam in a waste heat boiler, and the generated high-pressure steam is used in a steam turbine for additional power generation. The concept is known as Black Liquor Gasification Combined Cycle (BLGCC). The use of

BLGCC, as compared to a recovery boiler system, increases the potential to generate power and reduces the heat surplus of the mill. Because a large amount of the sulphur can be separated from the smelt the possibility to generate liquors with different sulphidity increases. This is of interest to be able to further optimise the kraft cook. For example, it is easier to divide the sulphur between different white liquor streams for modified cooking. It is also straightforward to produce elemental sulphur from the H₂S gas if the plant is integrated with a Claus Reactor. Sulphur can be mixed with cooking liquors to produce polysulphide and then returned for use in impregnation. At the heart of the process is an oxygen-blown, entrained-flow gasifier. The gasifier can either be ceramic-lined or have water-cooled walls. BLGCC is described here to provide background information.

The alternative route for the use of the syngas, i.e., synthesis of motor fuels, is what has been investigated more recently. This new concept, Black Liquor Gasification with Motor Fuels production (BLGMF) is described below.

Market Opportunity

There are 236 recovery boilers in the world that have not been rebuilt during the last 20 years and thus can be suitable for replacement with gasification technology. However, the majority of these boilers have quite low capacities, less than 500-600 tDS/day. A BLGMF system would not be a realistic replacement alternative for these small boilers.

One can assume that a mill which is replacing an outdated recovery boiler would desire somewhat more capacity (perhaps 25%) than the old boiler provided. A BLGMF

system is a competitive alternative for capacities of roughly 1000 tDS/day and higher. Hence, the actual market is for replacement of boilers with a capacity of 800 tDS/day or more, and which have not been built or extensively renovated in the last 20 years. There are 57 such boilers in the world today, about half of which are in the USA. The majority of the remainder are located either in Canada or Japan.

The market for the BLGMF system will expand in the future due to the obsolescence of more and larger recovery boilers. In short, each of the world's 327 recovery boilers with a capacity of more than 800 tDS/day can be considered a candidate for eventual replacement by a BLGMF system. It is becoming common for mills with multiple recovery boilers to replace several or all with one unit which has a capacity of 2000 tDS/day or more. A BLGMF system is clearly an alternative for these mills, so the market is actually larger than earlier suggested. This is shown in Figure 4 which presents the year of start up and rebuild of North American recovery boilers.

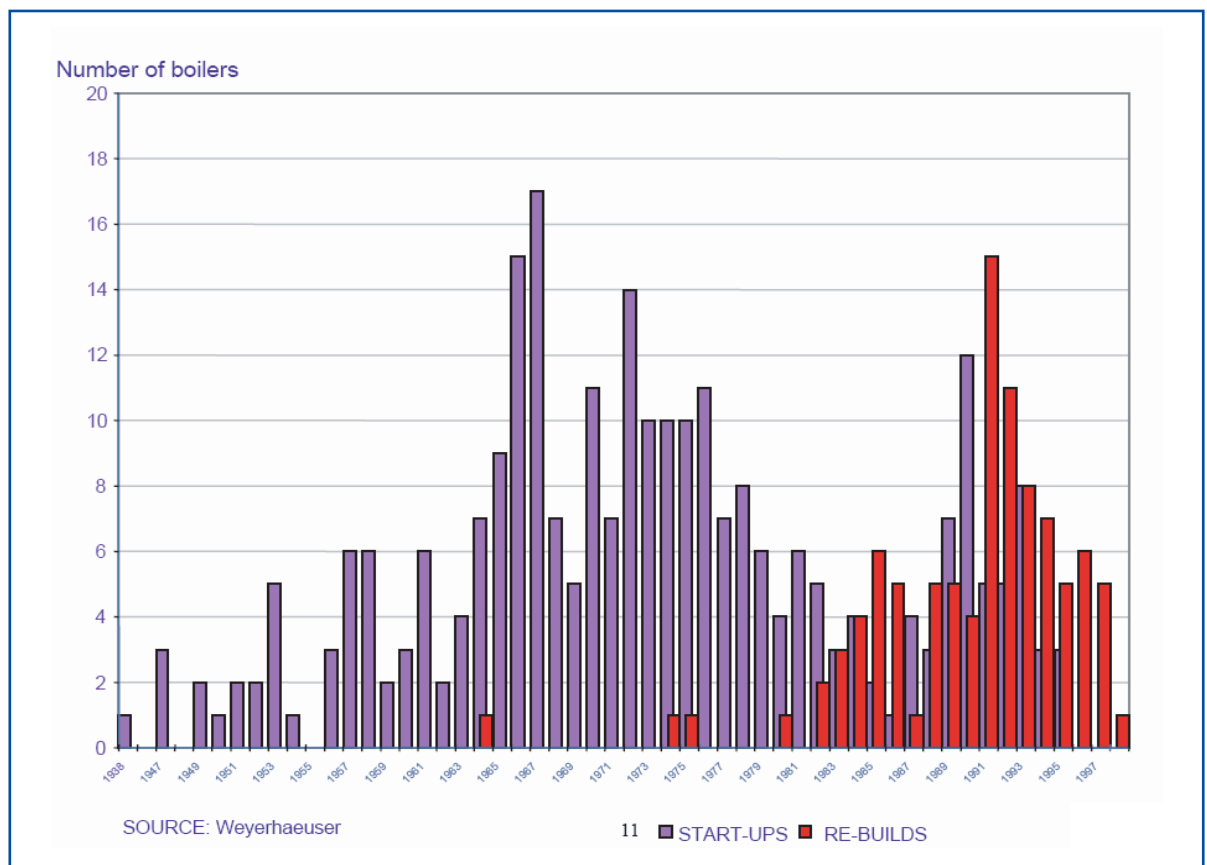


Figure 4: Year of start up and rebuild of North American recovery boilers.

PRESENTATIONS

The workshop consisted of six presentations from invited speakers, mostly from outside the IEA Bioenergy Implementing Agreement. The main points emphasised by the speakers are summarised below.

Presentation 1: 'The Case for a National Emphasis on Biomass Gasification Technology' by Dr D. Kaempf, DOE, USA.

Dr Kaempf presented the USA strategy for developing innovative technologies for biomass. The strategy was based on six 'technology platforms' being:

- Positively impacting the environment.
- Advancing the forest biorefinery.
- Technologically advanced workforce.
- Breakthrough of manufacturing technologies.
- Next generation fibre recycling and utilisation
- Advancing the wood products revolution.

He further explained that the DOE was assisting USA stakeholders to establish the 'Partnership for the Forest Biorefinery' consisting of several industrial actors, Associations, Universities and National Laboratories. Extensive analysis has showed that black liquor gasification increases significantly (by almost 100%) the power generated compared to the traditional Tomlinson black liquor boiler. This results in large benefits in electricity capacity or fuels and biochemical production. He concluded that the existing industry has the feedstock question resolved for the initial forest biorefinery while there is need for a strong partnership with the chemical industry.

Presentation 2: 'An Introduction to ThermoChem Recovery International', by Dr D. Burciaga, ThermoChem Recovery International, USA.

In his presentation Dr Burciaga explained that the objective of ThermoChem Recovery International (TRI) is to commercialise pulse enhanced, low temperature, steam reforming, black liquor gasification technology within the pulp and paper industry worldwide. The technology has been in development over 20 years with investments and grants from several USA sources. The result of these efforts is two commercial facilities operating today; Norampac at Trenton ON, Canada, and Georgia-Pacific at Big Island VA. TRI's proprietary technology for black liquor gasification can be used to steam-reform spent liquor solids to produce a hydrogen-rich synthesis gas and recover inorganic cooking chemicals. Today the syngas produced can be burned to create energy. In the future it will be used to feed fuel cells or processed into biofuels or biochemicals (Figure 5).

The process utilises proprietary pulse combustors to indirectly heat a steam-fluidised bed of sodium carbonate solids to recover energy and cooking chemicals. Black liquor is injected directly into the bed where the liquor uniformly coats the bed solids, resulting in high rates of heating, pyrolysis, and steam reforming. Bed temperatures are maintained at 605–610°C, thereby avoiding liquid smelt formation and the associated smelt-water explosion hazards. In the absence of oxygen, steam reacts endothermically with the black liquor char to produce a medium-Btu product gas that is rich in hydrogen. The sodium component of the spent liquor reports to the bed as sodium carbonate. Bed solids are continuously removed and mixed with water to form a

carbonate solution. If sulphur is present in the liquor it is removed with the product gas as H₂S.

In summary the steam reforming reactor vessel has three inputs; fluidising steam, black liquor, and heat, and has three outputs; bed solids, hydrogen-rich product gas, and flue gas. TRI is in the process of commercialising its black liquor gasification process with the last development being the Georgia-Pacific plant at Big Island where the construction was completed in the fourth quarter of 2003 and commissioning commenced in the first quarter of 2004.

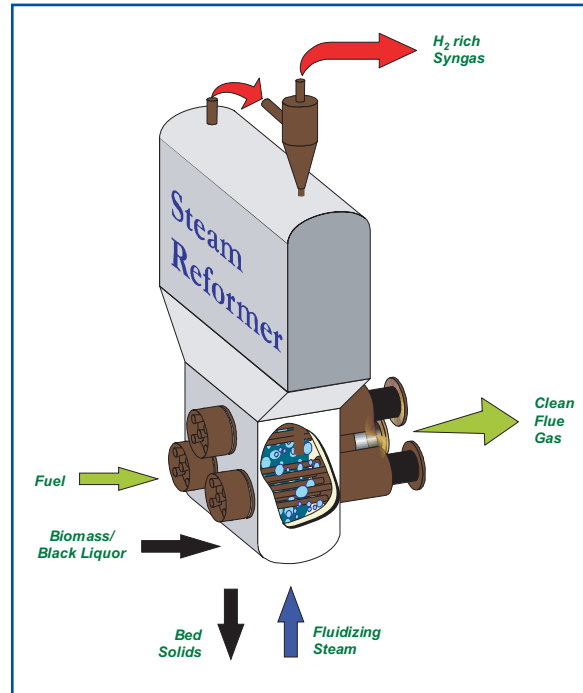


Figure 5: The steam reformer of TRI

Presentation 3: 'CHEMREC Black Liquor Gasification Technology', by Dr I. Landäl, Chemrec AB, Sweden

Dr Landäl presented the Chemrec technology for BLG. He started his presentation with the scope of Chemrec AB being the technical development and commercialisation of energy and chemical recovery systems based on BLG. After a presentation on the black liquor industry he presented the main drivers for the development work and put emphasis on the improved coking methods (more pulp per tonne of wood), improved energy recovery (for power and automotive fuels), and improved safety. In Chemrec's BLGMF process the recovery boiler in the mill is converted to a gasification-based fuel generating system. In a slagging black liquor gasifier, as in the Chemrec case, black liquor can efficiently be converted to a high-quality syngas which is highly suitable for production of automotive fuels. This is because the reactions in the gasifier are efficiently catalysed by the presence of sodium and potassium in the black liquor.

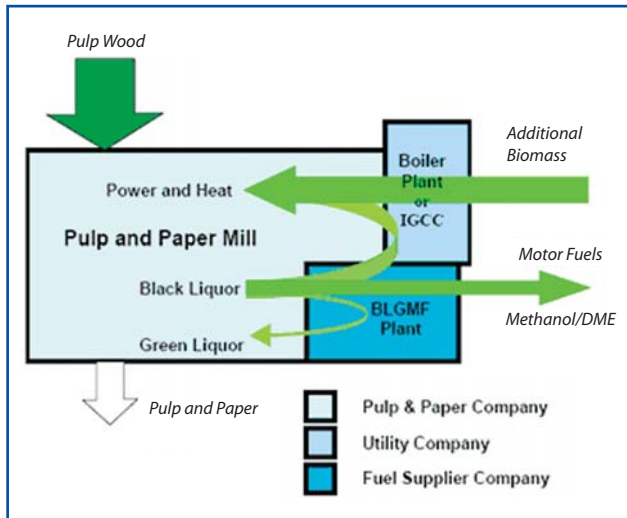


Figure 6: The BLGMF concept where biomass energy is added to the pulp mill and is, indirectly via gasification of black liquor, converted to automotive fuels such as DME or methanol.

When the black liquor is converted to automotive fuels the mill will require additional energy to make up for the energy withdrawn (see Figure 6). If the required extra energy is supplied to a boiler in the form of (low quality) energy from biomass, the fuel generated from the pulp mill/BLGMF complex will be of renewable origin. The overall energy efficiency of the conversion into fuels of the additional biomass added to the mill is in the range 65-70% depending on the efficiency of the bark boiler.

$$\eta_{\text{DME or methanol, biomass boiler}} = \frac{\text{DME or Methanol,}}{\text{Added biomass}} = 65-75\%$$

If the biomass boiler also is replaced by gasification in the form of a biomass-fed IGCC this will raise the efficiency to 85-90%. Note that these energy balances have been performed while keeping the net energy need (for power

and other energy streams) the same for the old mill with a recovery boiler as for the new mill with a BLGMF plant. The energy efficiency is thus calculated for the incremental increase in energy flows of biomass and motor fuels. The BLGMF plant is a chemical plant with no stack losses, only losses to cooling water in parts of the process. This contributes to the high efficiency of the conversion process compared to the recovery boiler, which is fairly inefficient because of flue gas losses.

Dr Landälv concluded with a description of the R&D activities of Chemrec at the Pitea pilot plant as well as other EU and USA projects.

Presentation 4: ‘Black Liquor Gasification and Biofuel Production in Canada’ by Dr M. Byron, CANMET, Canada

Dr Byron described the Canadian pulp and paper industry that is characterised by relatively small mills, often in remote locations, and has a generally conservative and risk averse attitude. The industry is a net energy user supplemented from fossil fuel and purchased power and uses 100% of all wood and wood residues resulting in a shortage of excess biomass. He described the basic process of a pulping cycle with gasification of the black liquor and reiterated the conclusion that black liquor gasification offers energy self-sufficiency for the industry as it more than doubles the ability to generate electricity or produce synthetic biofuels. Important considerations for the mill are the need to recover and convert the sulphur and sodium to pulping chemicals, and that a very high recovery rate of 99+% is needed to ensure a clean gas. Furthermore the product gas should have turbine inlet specifications as far as particulates, sulphur, and chlorine are concerned.

He concluded his presentation with the remark that BLG will be hard to sell to the Canadian pulp and paper industry and the combination of BLG and biorefinery even harder due to the characteristics of the industry. BLGCC was a more attractive option since it would meet the energy demands of the industry and would provide the flexibility of selling excess power to the grid.

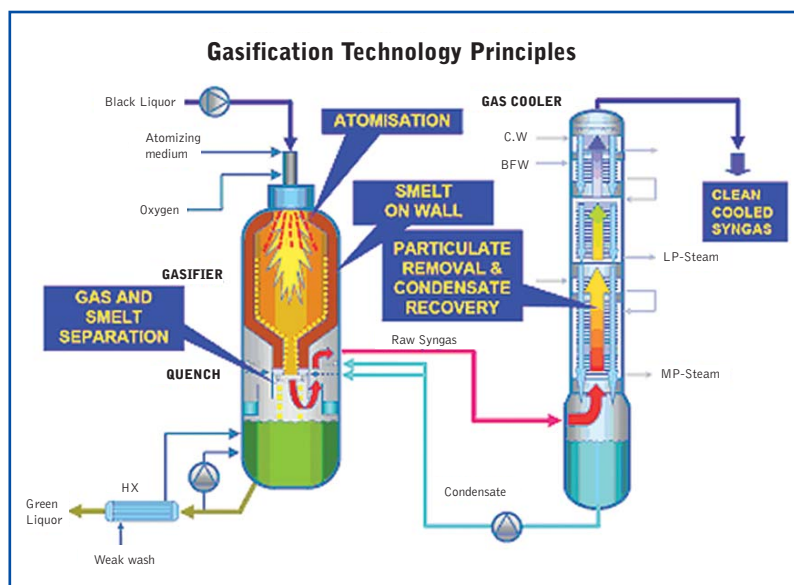


Figure 7: The pressurised black liquor quench gasifier (showing cooling of the green liquor), and the counter current gas cooler in a Chemrec type of pressurised black liquor gasification plant.

Presentation 5: ‘CHEMREC BLGMF Technology: System Impact on the Mill and the Biomass Usage at the Mill Site’, by Dr I. Landälv, Chemrec AB, Sweden

In his second presentation Dr Landälv analysed the system impact of BLG on the mill. His starting point was a systems analysis for the best fuel and the optimum process and after comparing the power and synthetic biofuel routes he concluded that black liquor gasification for vehicle fuels is the more attractive option for the industry. Several car manufacturers including Volvo have come to the same conclusion since this a sustainable process with high well-to-wheel energy efficiency and low CO₂ emissions. The economy, and existing infrastructures, as well as other pulp mill synergies, offer additional benefits.

However, he emphasised that when energy in the form of synthetic biofuels is withdrawn from the mill cycle it results in a heat sink that must be filled with an increased supply of primary energy in the form of surplus biomass. Modern mills are already efficient users of large quantities of forest biomass and have an optimum location for increased use of biomass with existing infrastructure. Since pulp mills operate all year round they offer an attractive option for efficient heat and power production via a boiler or integrated gasification combined cycle, in contrast to other applications that may be influenced by seasonal demand.

Presentation 6: 'BTL-fuels for the Transportation Sector: Volkswagen's View on Future Powertrains and Fuels', by Dr H. Heinrich, Volkswagen, Germany

The Volkswagen Group set itself the task of devising a strategy (Figure 8) for a step-by-step transition from present-day powertrains and conventional mineral oil-based fuels to future powertrains and the related fuels and primary energy sources needed for their operation, and Dr Heinrich explained that this strategy encompasses three challenging areas:

- A systematic further increase in the efficiency of powertrain units.
- The incorporation of alternative energy sources in the fuel production process.
- The development of CO₂-neutral paths for vehicle operation.

From today's point-of-view, the hydrogen fuel cell has the highest efficiency of all vehicle powertrain units. However, a precondition for its use is the availability of hydrogen. Hydrogen can only contribute to the reduction of CO₂ emissions if it is produced in a renewable form but there are three critical barriers that must still be overcome: the lack of mobile fuel storage acceptable to the customer, the lack of infrastructure and, finally, the lack of an economically viable technology for the renewable production of hydrogen. As no solution to any of the three barriers is available yet, hydrogen can only be regarded as a long-term solution.

At present, no single energy source, not even hydrogen, is able to meet the five key demands on a future fuel for the mobility industry:

- safe supply,
- easy handling and storage,
- high energy density,
- economical competitiveness, and
- fulfilment of environmental and climate protection requirements.

Given this background, a diversification of fuels would seem to be the next logical step. However, the simultaneous market availability of diesel, petrol, methanol, ethanol, natural gas, and other fuels is not an economically viable solution as a separate powertrain would have to be developed for each of these fuels, accompanied by a specific distribution infrastructure. It is therefore important to look for a way to diversify primary energy sources whilst concentrating the energy sources for mobile applications on as few variants as possible.

The advantage of synthetic fuels is their independence from a specific primary energy carrier by using a production process consisting of the main steps shown in Figure 9.

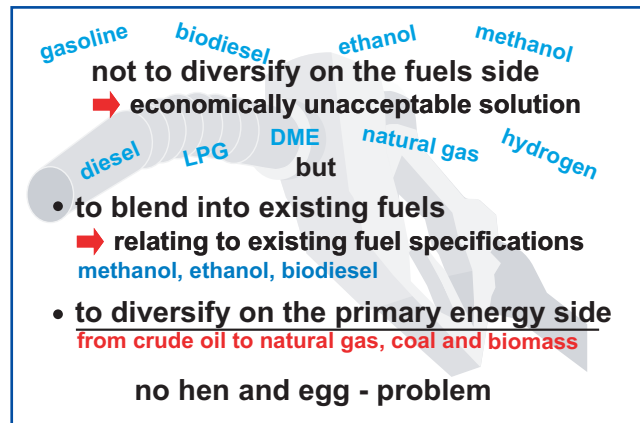


Figure 8: Basic elements of Volkswagen's fuel strategy

Coal-to-liquid/Gas-to-liquid/Biomass-to-liquid fuels have the same molecular structure and thus the same properties. They are liquid at ambient conditions and thus similar to conventional fuels. They can be used in the existing engine technology and be brought to market via the existing distribution chain. The only exception is their CO₂-reduction potential: coal-to-liquid and gas-to-liquid need sequestration, whereas biomass-to-liquid brings the needed breakthrough.

The gas-to-liquid technology using gas from regions of abundance (like e.g., Qatar) is already very economical given the current price of petroleum in many regions of the world where natural gas or petroleum gas can be produced cheaply. It will, no doubt, take another 5-8 years, which are needed for investments and the construction of synthesis plants, before we see a secure and relevant supply of these synthetic fuels. This, therefore, represents a short- to medium-term solution.

The intermediate stage of this technology – synthetic gas – now also allows the use of renewable energy sources such as waste wood, straw, energy plants or organic waste. The decisive factor is that the quality of the end product is not dependent on the primary energy used. This solution eliminates the finite availability and CO₂ emission of synthetic fuels. The energy content stored in the world's annual plant growth is equivalent to many times the energy consumption of the human race, i.e., there exists

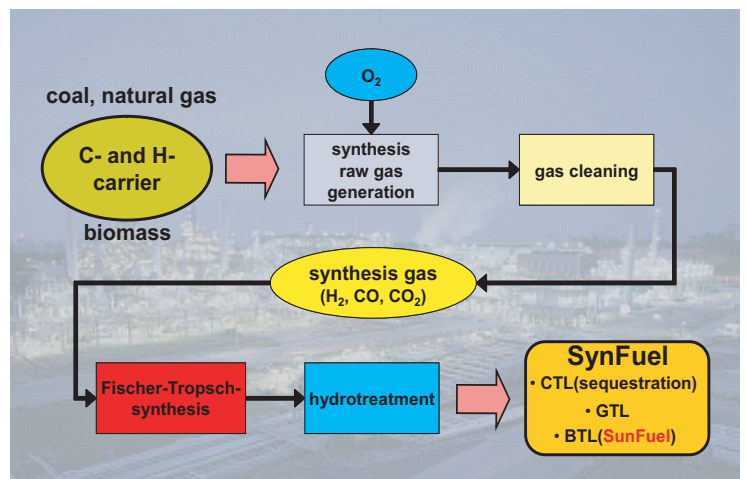


Figure 9: Simplified synthetic fuel production process

an enormous potential for substitution. From a political viewpoint, the supply situation can be improved by using biomass since it is distributed relatively evenly around the world, unlike the fossil energy sources. This will not lead to zero CO₂ exhaust emission but will see the creation of a CO₂-neutral cycle powered by solar energy. By doing so, we integrate the fuel cycle into the natural CO₂ cycle.

Figure 10 shows the CHOREN CarboV process. In the first process step, the biomass is broken down into a gaseous constituent and a solid constituent (organic coke) by means of low-temperature gasification. The second process step involves producing the synthetic gas. The synthetic gas is then converted to fuel in a Fischer Tropsch synthesis process with downstream fuel optimisation by hydrogen after treatment i.e., hydro cracking.

Biomass-based SunFuel can be seen as a medium-term solution, as it is not yet economically viable. The production costs of SunFuel, excluding taxes (based on a plant size of 200 MWth), are approximately €_€,30/litre higher than those of petroleum-based fuels. However, the production costs are well below today's pump prices in Europe, so the onus is on the politicians to adopt suitable fiscal legislation promoting the development and introduction of SunFuels until such time as these fuels become economically feasible. In the long term, subject to the availability of an inexpensive and renewable hydrogen source, this hydrogen could be added to the BTL process, nearly doubling the fuel output of the process. The implementation of a hydrogen economy, therefore, will not necessarily result in the use of hydrogen for mobile applications. Biomass-based synthetic fuels could, on the whole, prove to be the better option from a sustainability viewpoint. Fuels of this kind are CO₂-neutral as they do not produce additional CO₂ emissions.

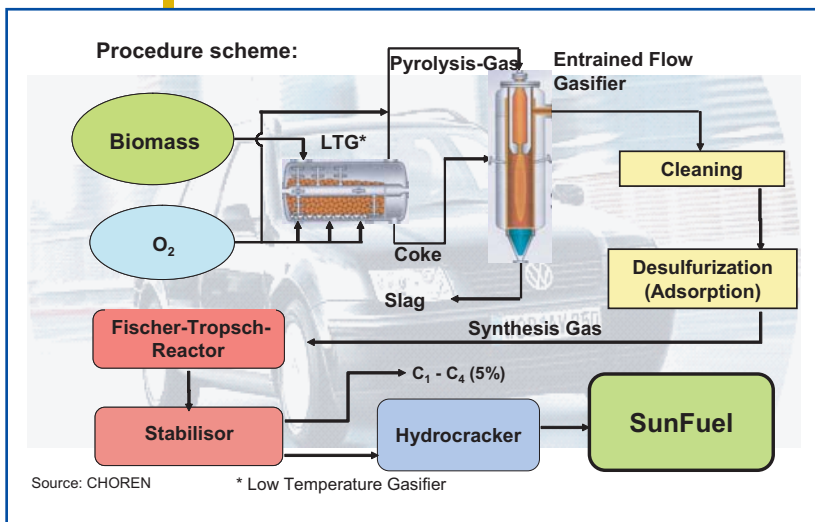


Figure 10: SunFuel production by Choren's CarboV process

DISCUSSION OF KEY POINTS

The key points from the above presentations and subsequent discussions can be summarised under the following headings.

Opportunities for Black Liquor Conversion to Biofuels for Transport

There is a global need to develop a reliable and economic process for the production of biofuels for transport applications due to the rising cost of oil and the continuously rising demand for automotive transport fuels. Black liquor is an attractive resource for such a development since it is found as a by-product of the paper making industry – where technical expertise is available – and in large quantities that can justify large investments. Technically, black liquor is easier to handle and process than wood or biomass being homogeneous and at relatively constant quality. However, the use of black liquor for biofuels production will create an energy void in the overall paper making process that needs to be filled with additional biomass. Such a combination of technologies and processes will make the paper mill a biorefinery where various consumer products – paper and biofuels – are produced as well as energy that under some conditions could be exported to the network.

Bioenergy is often promoted as a substitute for fossil fuels in order to meet climate change commitments, since biomass is considered to be CO₂-neutral, and to improve the security of energy supplies for both the OECD countries and the developing economies. Given the successful development of the technologies that were presented at this workshop and sufficient biomass supplies, black liquor conversion to biofuels can certainly lead to a reduction in both traditional pollutants (particulates) and net greenhouse gas (CO₂) emissions. In addition to improving the air quality in cities, such a development would improve the security of energy supplies of many nations.

Biomass Supply

Delivered biomass costs can be relatively high, particularly for feedstocks that are produced and dedicated for energy purposes, i.e., fuels that are not by-products or waste. Herbaceous biomass, particularly agricultural residues and annual energy crops, are more difficult to handle, and the high alkali and ash content tend to cause fouling on heat exchange surfaces. Biomass derived from MSW can be even more challenging, but supplies may be cheap and plentiful. The pulp and paper industry is experienced in procuring and handling relatively large volumes of wood and other biomass on an annual basis, and international trade is already well developed.¹ Recent studies² indicate that the European Forests continue to grow at a rate of about 4% per year while it has been shown that only about 40% of the forest wood harvested is used in industrial processes. This has led the European Commission to prepare and adopt the Communication 'European Union Forest Action Plan'³ which among other policies addresses the use of forests for energy purposes under sustainable development principles.

¹ Task 40 'Sustainable International Bioenergy Trade: Securing Supply and Demand' of IEA Bioenergy has the vision of a global commodity market in bioenergy. The expanding membership of this Task indicates strong interest in this topic.

² European Environmental Agency Report No 7/2006 'How much bioenergy can Europe produce without harming the environment?', Copenhagen 2006.

³ Communication from the Commission to the Council and the European Parliament on an EU Forest Action Plan, COM(2006) 302 final, http://ec.europa.eu/agriculture/fore/action_plan/index_en.htm

IMPLICATIONS FOR BIOENERGY DEPLOYMENT

General

Black liquor utilisation for biofuel production is of interest primarily among countries with strong pulp and paper industries and with national policies which promote substituting petrol and diesel by biofuels. There is significant potential for producing biofuels from black liquor and creating large biorefineries in the forest products sector. However, although such biorefineries could be very attractive for local and national economies, they can contribute only a few percentage points of biofuels in the global demand for transport fuels. Therefore, besides realising this dedicated potential in a relatively short time scale and with reasonable economics, being the 'low hanging fruits' for synthetic biofuels, the efforts to further develop other biomass to biofuels technologies and processes have to be continued.

Technology

- The most cost-efficient bioenergy applications are often those which can utilise the existing infrastructure and/or process by-products and residues, or where energy products such as biofuels are co-products in processes for higher value products.
- Black liquor gasification to synthetic biofuels makes use of the large-scale pulp and paper plants' infrastructure and technological expertise. As a result BLG could be substantially more competitive than dedicated biomass to biofuels plants.
- The forest products sector is qualified and experienced in handling and processing large quantities of wood and distributing the products; thus the logistics of BLG and the additional supply of biomass for energy use should not present any serious problem.
- The catalytic conversion of synthesis gas to biofuels is considered to be a reliable process, and the same seems to be the case for gasification technology. Thus the critical process step that still needs to be demonstrated is the cleaning and purification of the producer gas to synthesis gas quality.
- Biofuels in general and second-generation biofuels such as those to be produced by BLG are dependent on policy instruments and on sufficient RD&D support for the development of the technologies to a commercial scale process.

Policy

- In general most governments support the development of technologies to produce biofuels, with emphasis on second-generation technologies due to their improved energy and CO₂ balances. However, only in countries with well established and strong paper industries is there particular attention to BLG. USA and Sweden lead the development in this field.
- It is important that policy instruments aiming to support and increase use of resources such as forest biomass should achieve this under sustainability principles with appropriate certification systems such as those already employed by the forest-based industries. These are well established in the forest products industries, but need further strengthening.

- While the national or international research programmes continue to support the more efficient production of first-generation biofuels (biodiesel and sugar ethanol) or new biofuels from oils (such as the NESTE NExBTL Biofuels⁴) priority should be given to the second-generation biofuels in close cooperation with the industrial developers.

Market Development

- BLG and the need to deliver large quantities of biomass to replace the black liquor used for energy production in the pulping process have the potential to utilise large quantities of biomass, thereby driving the development of new feedstock supply infrastructure. Given that good quality wood should be used for the pulping process rather than for energy, the effect on feedstock infrastructure may be most notable on short rotation coppice, forest residues, or other types of currently less-utilised feedstocks.
- BLG is one of several technologies under development for the production of biofuels and it may be closer to full-scale demonstration than the other processes; however, attention needs to be paid to the biomass supply issue.
- The recent increase in the cost of oil and its effect on transport have focussed great attention on biofuel blends in diesel and petrol. The second-generation of biofuels are close to commercial demonstration and in the medium term it can be envisaged that the market development for biopower may be restricted due to competition for resources with the market development for second-generation biofuels.

ACKNOWLEDGEMENTS

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⁴ <http://www.nesteoil.com/default.asp?path=1;41;450;1259;1260;5396;5397>



Forest residues are a source of biomass to replace the Black Liquor used for energy production in the pulping process. The Timberjack Slash Bundler manufacturing Compacted Residue Logs after final harvest. Courtesy Dr Arto Timperi, Timberjack.

IEA Bioenergy

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