

DME from Biomass

A study within the
DME project, Annex XIV
of the
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Alternative Motor Fuels Agreement
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Summary

Di-Methyl-Ether, DME, can be produced from biomass, such as wood, via gasification of the cellulosic raw material to synthesis gas followed by purification and subsequent catalytic synthesis of such gas into the final product.

DME represents an alternative diesel fuel, which may offer considerable reduction of air pollutants from the diesel engine. The reason for producing DME from non-fossil feedstock is that with such raw materials also the amount of carbon dioxide addition to the atmosphere may be reduced.

In this study the different process steps and the integrated process for wood-to-DME have been analysed. It is concluded that except for the gasification of wood and related gas cleaning all the process steps are proven technologies. The time required for advancing the pressurised wood gasification process so that a full scale integrated wood-to-DME plant can be erected is estimated at approximately 5 years, provided that sufficient funds are allocated to such research and development efforts.

For a plant using wood as feedstock and with a DME production capacity of 600 metric tons per day (MTPD), equivalent to approx. 200.000 tons per year, the total investment cost for a green field installation in Sweden is estimated at 440 million USD. If the same plant was erected at an industrial site, where utilities could be purchased over the fence, the total investment is estimated at 330 million USD.

The production cost of bio-DME has been estimated at 483-506 USD per ton. As the energy content per ton of DME is lower than that of diesel, the diesel equivalent production cost for DME is about 50 per cent higher, i.e. some 700 - 750 USD per ton.

On this basis, the production cost of bio-DME can be estimated to be about 4 times greater than the cost of producing DME from low cost, "remote", natural gas.

However, production costs of other liquid biofuels, e.g. ethanol from both grain and cellulosic materials, are probably even higher than DME or methanol from wood in large-scale production.

1. Introduction

Within the Alternative Motor Fuels Agreement of the International Energy Agency several participating countries, in co-operation with national and international companies, have agreed to undertake a joint study regarding DME as a motor fuel.

The overall project is led by TNO of The Netherlands, and TNO is in charge of compiling the final overall report for the project.

Among the tasks that were agreed to be addressed, Sweden volunteered to undertake a study on Bio-DME, i.e. DME manufactured from renewable biomass. The Swedish Government Agency for technical development, NUTEK, agreed to a substantial financial contribution for the project and appointed Atrax Energi AB to lead the work in Sweden. Four Swedish companies, Aspen Petroleum AB, PREEM Petroleum AB, SCANIA AB and Växjö Energi AB, have also agreed to financially support the project.

Atrax Energi AB was the coordinator of the activities. The work was carried out in cooperation with TPS Termiska Processer AB, Kemiinformation AB and Haldor Tospoe A/S(HTAS). TPS provided data on the gasification system and its integration to the synthesis unit, at which point HTAS took over as the technology information source for the synthesis and product upgrading sections. TPS and Kemiinformation have provided the cost estimation on the basis of budget quotations and other sources.

2. Background

DME (DiMethylEther) was proposed as a novel transportation fuel for diesel engines only a few years ago. As a neat fuel DME has the potential to give very low emissions in the exhaust gases from vehicle diesel motors. Methanol has been used as a fuel for Otto engines for more than a decade. However, the lower alcohols are generally poor diesel fuels due to their low cetane numbers. DME, with its high cetane number, is in this respect a "natural diesel fuel" and hence may acquire a market in the diesel fuel sector.

The main obstacles for a large scale DME introduction as an automotive fuel for diesel engines are deemed to be its use in the engine, the distribution and infrastructural issues and the costs related thereto.

An introduction of DME as an alternative diesel fuel could result in reduced emissions of air pollutants and hence an improved air quality situation could be achieved. The most notable effect of this would be in urban areas.

DME also potentially provides the natural gas industry with a new market for gas based products. The production route for DME from natural gas is very similar to that for methanol; an initial step of synthesis gas production by means of steam reforming, i.e. converting CH_4 to $\text{CO} + \text{H}_2$, followed by a synthesis step to produce the final product. More or less, "only" the synthesis reactor has to be substituted and the catalyst replaced, and the product purification system changed. In fact, a co-production of methanol and DME is sometimes suggested.

As for methanol, the manufacturing costs for DME are very sensitive to the scale in which the production is performed. To be competitive with oil products such as gasoline and diesel fuel, very large units - 2.500 – 10.000 MTPD - are required (Haldor Topsoe, 1995).

The largest methanol units today are of approximate sizes of some 2.500 MTPD. Consequently, the process technology can be regarded as "proven and conventional" for methanol.

For the carbon dioxide issue, DME made from natural gas the substitution effect is marginal, if any. In itself, natural gas (methane, CH_4) holds an advantage over diesel oil (roughly equivalent to " CH_2 ") as only two thirds of carbon dioxide (CO_2) are produced for the same energy input. However, in the production of DME an energy efficiency of some two thirds is also estimated which over-all implies an equivalent carbon dioxide production as long as the raw material is of fossil origin.

In order to achieve a significant CO_2 reduction other raw materials than natural gas have to be considered. Biogas from fermentation could be one, but such gas is produced only in limited quantities in any particular site, and thus is ruled out on the basis of economy of scale for the production.

Biomass, i.e. wood or agricultural crops, is another possible renewable raw material. Although a large total abundance exists (some sources claim up to 30 EJ/year or about 8 % of the current global energy use) , the amounts that can realistically be collected for any specific plant, are limited. Cost of transportation of biomass makes long distance transport uneconomic. Due to this factor and the present costs for the raw materials, the manufacturing costs for DME from biomass can be expected to be very different for DME from natural gas.

In Sweden and elsewhere, the reduction of fossil CO₂ emissions by increasing the use of biomass, is focused at present. In the long run, a larger use of such renewable raw materials is envisaged and several options are being studied and developed. For the realisation of such options, more or less development work is usually required, before the true potential can be assessed.

In the case of DME, gasification of biomass into a raw gas for further treatment into synthesis gas of the required quality is feasible (The first Haber-Bosch ammonia plant installed in the Soviet Union was based on wood gasification as the source for hydrogen). Once such a synthesis gas has been produced, the source of the gas is no longer of importance, and conventional process technology is available for the manufacture of DME.

The task undertaken was to study the technology for the development status of and the potential cost to produce DME from biomass.

The evaluation of DME production from biomass is presented below in this report.

The resources allocated, and the status of the technology itself did not allow an in-depth detailed engineering study. Instead, the approach taken was to identify the process requirements and on this basis make a conceptual process design, utilising the experience accumulated within the project team in this area since the 70's. This conceptual design was used to arrive at mass and energy balances for the entire plant, also quantifying the utilities, waste products and other streams of economical consequences. From this basis, the cost estimate was done, mostly on the basis of vendor information for defined plant section. In this evaluation only some of the data presented are unconfirmed. Reliable experience or tests verify the majority of data used to the extent required for this study.

3. Overall process description

This section is meant to give the reader who is not so familiar with the technology in general, and biomass in particular, a brief introduction in this area and highlighting some of the key aspects resulting from fuel and process characteristics that must be resolved in a realistic assessment of a biomass to DME scheme. The following section 4 gives a description of the conceptual process used for mass and energy balances and cost estimation.

3.1 *Plant capacity*

As discussed above, methanol and potentially also DME can be produced from natural gas in plant capacities between 2 500 and 10 000 ton per day. However, for plants based on wood biomass as feedstock such capacities are not feasible. Pulp mills have wood intakes up to maybe 100 ton D.S./hr, i.e. about 500 MW in energy terms. The largest CHP (Combined Heat and Power) installations using wood in Sweden are about 150 MW, using the residue produced in the forest when the wood industry has taken the prime product. As a reasonable balance of, on one hand, wood availability, and on the other hand, economy of scale for the DME production, a plant capacity of 600 tons per day of product was selected. This corresponds to 67 tons D.S of wood input or about 300 MW thermals input, i.e. a size intermediate to CHP installations and pulp mills.

3.2 *Process Conditions and Requirements; Process Design Philosophy*

Although DME production from biomass (wood) is technically feasible and to a large extent similar to manufacture from natural gas, certain differences exist in relation to the latter. Wood is a very different raw material from natural gas, or even coal, and requires substantial processing before analogies to natural gas can be obtained.

As part of the fuel is used in combustion reactions, the fuel is preferably dried prior to gasification, as the energy for drying will otherwise be taken from the fuel itself. This can be done in a hot gas or in steam. From an overall energy balance perspective, steam drying was selected, as energy recovered in the process is recovered as steam, and otherwise fuel wood be used again for drying as no waste heat suitable for drying purposes was available in the form of a gas.

Solid wood is composed by mainly carbon, oxygen, and hydrogen and the transformation into gaseous products is carried out by means of thermal gasification, as opposed to biogasification by fermentation. In this process stage, the biomass raw material produces hydrogen and carbon monoxide is formed in conjunction with carbon dioxide from the parallel processes of pyrolysis (thermal decomposition), partial oxidation (combustion) and gasification with steam and carbon dioxide. This is shown in Figure 1.

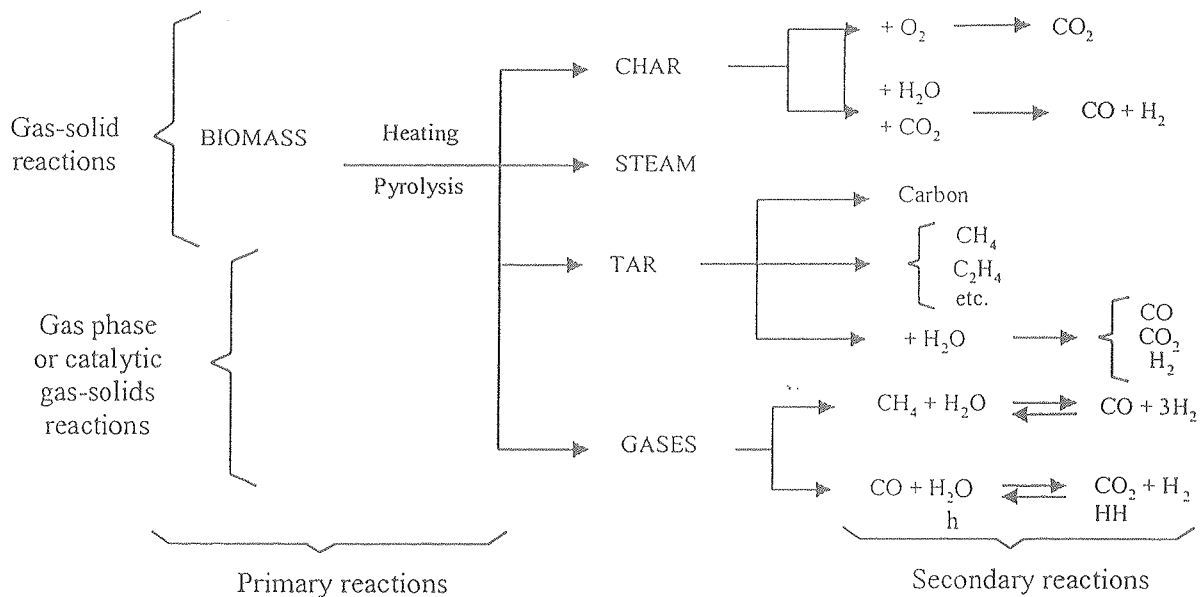


Figure 1 Generalised Biomass Gasification Reaction Scheme

Although the gasification of wood bears some similarities with established coal gasification technologies, the process has to be carried out differently in practice. Wood is highly reactive in comparison to coal, which enables a lower gasification temperature, typically 800-900 °C. Due to the nature of the biomass fuel, far more hydrocarbons are produced in the case of biomass compared to coal. These hydrocarbons range from methane, i.e. the main chemical constituent of natural gas, to heavy polyaromatic hydrocarbons usually referred to as "tar". In the bottom right hand corner of the scheme in Figure 1, the steam reforming of methane (CH_4) into additional synthesis gas is shown. This is the main processing step in the case of synthesis gas generation from natural gas. The amount of this component in the gasifier gas, in the case of biomass, constitutes a potential loss of synthesis gas, and hence a lower yield of DME. As is discussed below, methane and other inert gases, i.e. gases that do not participate in the synthesis reactions, also cause losses of synthesis gas in the synthesis section of the plant, such that the detrimental effect on the yield is twofold.

In Figure 2, (Source VTT, Finland) the tar yield from various fuels in a fluidised bed gasifier is shown. The tar yield when utilising biomass is very high compared to lignite.

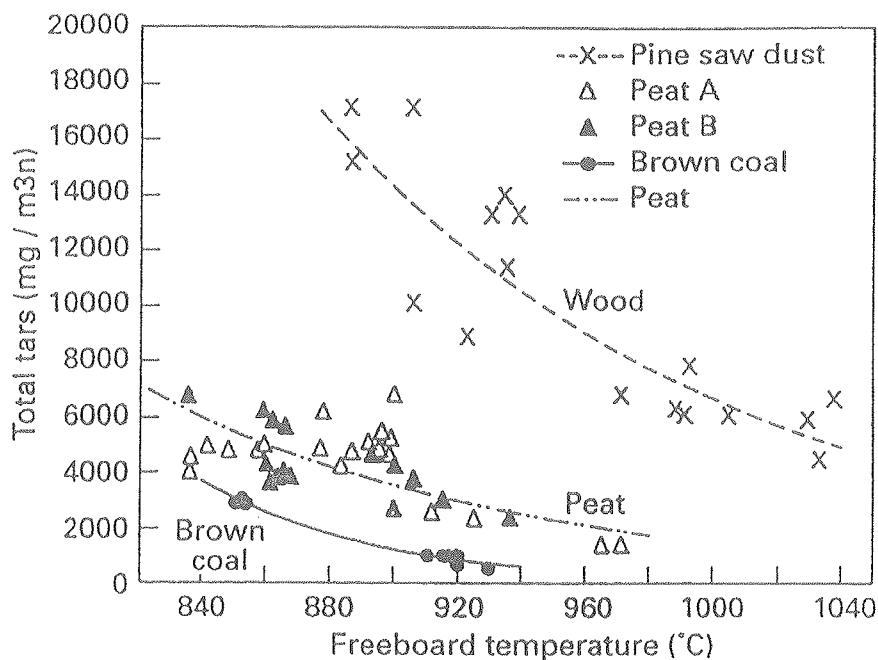


Figure 2 Tar yield from various fuels (Source VTT, Finland)

Tar is not only an additional loss of yield, but also causes operational problem during cool down of the gas, when it goes from vapour to liquid phase, and also causes severe pollution of the process condensate.

To overcome this negative effect of the hydrocarbons produced from biomass gasification, a steam reforming reaction step must be used. This step can either be thermal, i.e. increasing the temperature sufficiently which will cause homogenous gas phase reactions to proceed at sufficient rate, or catalytic, i.e. using a catalyst to have more favourable kinetics at lower temperatures than required for the thermal reaction.

The first alternative, thermal treatment is used by the High-Temperature Winkler (HTW) process developed for lignite, and the catalytic steam reforming was used in the MINO process developed for peat and biomass in Sweden. Experience from development work in Sweden in the 80's, and from a HTW plant in Finland using peat, indicate that catalytic reforming is more efficient in terms of yield of synthesis gas. This is because thermal treatment uses combustion of part of the synthesis gas to arrive at high temperatures, that high volatile fuels need much higher temperatures than lignite to reduce the hydrocarbons sufficiently, and that at these high temperatures, ash agglomeration and melting can potentially cause serious operating problems.

Catalytic reforming is similar to the secondary reformer in natural gas based ammonia plants, a refractory lined vessel containing a nickel based catalyst in a fixed bed. The gas, together with air or oxygen is introduced in a burner at the top, and the

temperature from the burner drops to typically 950-1000 °C from endothermic reactions. In the case of a gasification gas, the secondary reformer has to be preceded by a high temperature filter to avoid dust blocking. This is a technology that has been undergoing strong development over the last thirty years.

Gasification is carried out in a reactor at elevated pressure. For reasons of capacity, only fluidised, circulating fluidised bed or entrained flow reactors are suitable in order to feed a large-scale synthesis loop without requiring an abundance of parallel reactors. On the other hand, pressurised feeding of this low bulk density fuel, having not too good handling properties, requires a complicated and sensitive system consuming a lot of inert pressurisation gas.

For capacity reasons, feed system design and from the conditions of the subsequent steps in the process an elevated pressure in the gasifier is advantageous and the design preferably includes a pressure of 2-3 MPa in the gasification section. The DME synthesis is carried out at pressures exceeding 7 MPa, such that a saving in compression work results.

Further, inert gases such as methane and nitrogen in the DME synthesis have a major, negative impact on the efficiency of the process as accumulation of these components in the recirculating unconverted gas must be prevented by bleed-off, causing losses of synthesis gas. A value as low as possible but not higher than a few % is acceptable. Consequently oxygen is preferred to air as oxidant in the gasification section, and also carbon dioxide, which is removed in the gas processing, to nitrogen as inert gas.

In summary, the gasification of (predried) wood should be pressurised and oxygen blown, but all gas treatment at high temperature can not be achieved in one single stage. A secondary, preferably catalytic steam-reforming step, increasing the synthesis gas yield from the hydrocarbons present in the gas and also decomposing tars in the raw gas must be added.

The gas thus generated has a small amount of sulphur resulting from the sulphur in the fuel, and a large amount of carbon dioxide. The CO/H₂-ratio is also less than what is required for synthesis of DME. The sulphur has some deactivating effects on the catalyst for the steam reforming section and the water gas shift reaction catalyst used to correct the CO/H₂-ratio, but must be entirely removed from the gas down to < 1 ppm before the synthesis section. Also CO₂ has to be removed to meet the requirements of the synthesis section, i.e. <2-3 %.

The low ratio of sulphur to carbon dioxide makes the selection of acid gas removal processes difficult. However, because of the substantial heat requirement in a chemical wash system, e.g. amine or carbonate system, and the potential for removing also all sulphur compounds and enriching them into one stream makes a physical wash look more attractive.

For the process design in this case, the TPS gasification technology is chosen which consists of a primary CFB gasifier using steam (for gasification) and oxygen (for

energy supply to the reaction), a high temperature filter and a secondary, catalytic reformer to handle the tars. In the second step the tars as well as the primary gas is converted to mainly hydrogen and carbon monoxide. After cooling, partial shift is done to adjust the ratio, and the gas is cleaned from carbon dioxide and sulphur components.

The resulting raw gas is similar to the gas obtained from reforming of natural gas and is processed largely in accordance with this, compression and synthesis followed by product purification and storage.

As there is energy available in the hot product gas and from reaction heat in the synthesis section, while heat is consumed in fuel drying, as gasification steam and for gas cleaning and product purification, and also energy is used for compression of air, oxygen and other gases, a substantial effort has gone in to make a first rough optimisation of the energy/ steam/mechanical energy system to utilise the various possibilities for energy recovery for steam generation at such pressure conditions that back-pressure turbine drives could be used on some compressors and that the demand for low level energy was satisfied at an appropriate temperature level.

3.3 Block Flow Diagram

Figure 3 below illustrates the overall block flow diagram for production of DME from cellulosic biomass, such as wood.

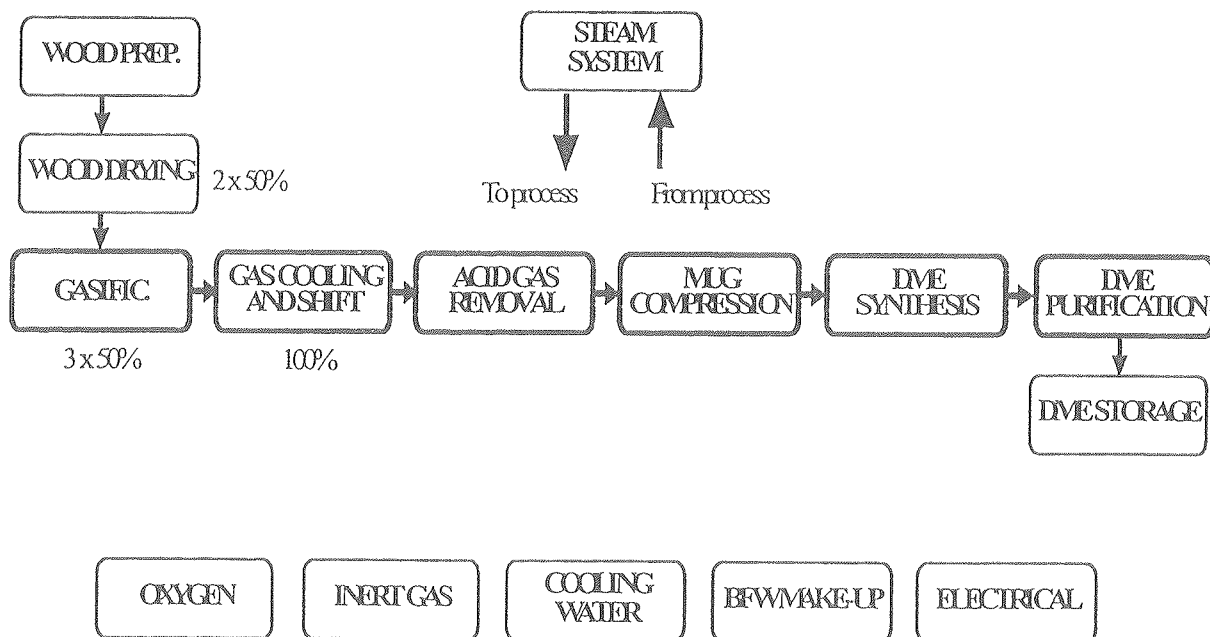


Figure 3: Simplified block flow diagram for DME from wood

In the feed preparation section the wood raw material is first given the required particle size and is then dried before it is injected into the gasifier. In the gasifier the wood feedstock is reacted with steam to hydrogen and carbon monoxide. The required energy is produced by a partial oxidation of the biomass by means of oxygen. The raw gas is desusted in a filter, and its composition is further adjusted by steam reforming. The gas is cooled, and the CO/H₂-ratio is adjusted. The gas is cooled to ambient temperatures, CO₂ and sulphur are removed by a physical wash process and, finally the gas is compressed to the required synthesis pressure. The gas is then fed to the DME synthesis section in which the synthesis gas components combine to DME, with the help of a catalyst. The DME raw product is finally purified before being sent to storage.

The flow scheme is further discussed below on the basis of the more detailed general process scheme presented in figure 4 on the following page.

3.4 Process description

GENERAL PROCESS SCHEME

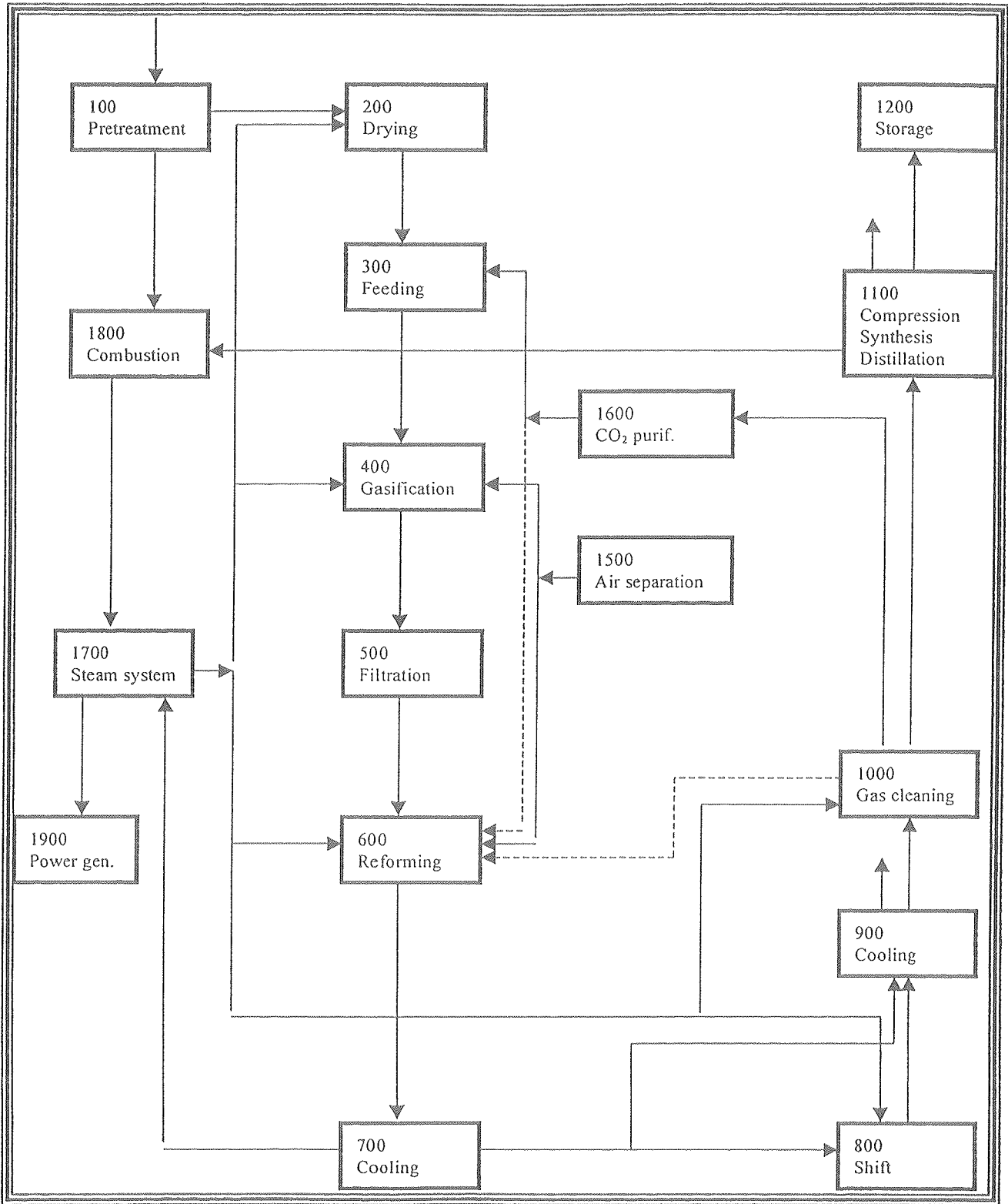


Figure 4. General process scheme

In plant section 100, the wood as received is chipped and screened to the required size of the dryer and gasifier.

For energy efficiency reasons the biomass raw material is preferably dried from typically 50 % to approx. 10 % moisture before use in the gasification section. This is carried out in the drying section located prior to the gasification process (200). The drying section consists of a two stage drying system. The first stage drying is a belt type of dryer, where the fuel is dried by means of preheated air. The energy used to preheat the air is taken from the LP steam produced from the evaporated water in the second stage drying. The condensate from the dryer is treated in the waste water section. Second stage drying is performed at 4 bar in a pressurised steam atmosphere in a pneumatic conveyor type of apparatus, also containing heat exchanger tubes. Externally, steam at 20 bar is used as a heat source, the heat being transferred to these heat exchanger sections. Two lines of second stage dryers are used in parallel.

The dried wood is pressurised by means of inert gas in the lock hopper system, 300, before being introduced into the gasifiers. To have high availability two lines of feed hoppers are used for each gasifier.

Biomass is gasified (400) by means of oxygen and steam into a raw gas consisting of mainly hydrogen, carbon monoxide and carbon dioxide. Other constituents of the raw gas are water (surplus steam), methane, ethane, nitrogen and traces of gases such as COS and NH₃. Ash is produced as a solid residual and removed via a ash hopper system. The ash is sent to a disposal site. The gasifiers are designed as a CFB system with return cyclones to achieve good and uniform temperature control, in view of the use of oxygen, while at the same time the specific throughput is high. The operating conditions are about 850 °C and 30 bar.

The raw gas from the gasifier is cleaned from solids in the filtration unit (500) and thereafter further reformed by oxygen and steam in the reformer (600) at 950 °C exit temperature. In this process step methane and ethane are converted, in the presence of surplus steam, and the resulting gas consists of mainly H₂, CO and CO₂ in the approximate relation 4:3:2.

Sections 300, 400, 500 and 600 are schematically shown in the following Fig 5. To achieve a high availability in the plant, also considering the start-up time, and to limit the vessel diameters, the gasification section is designed in three parallel lines. Each of these lines have 50 % capacity, i.e. two lines are operated in parallel and one line is on stand-by.

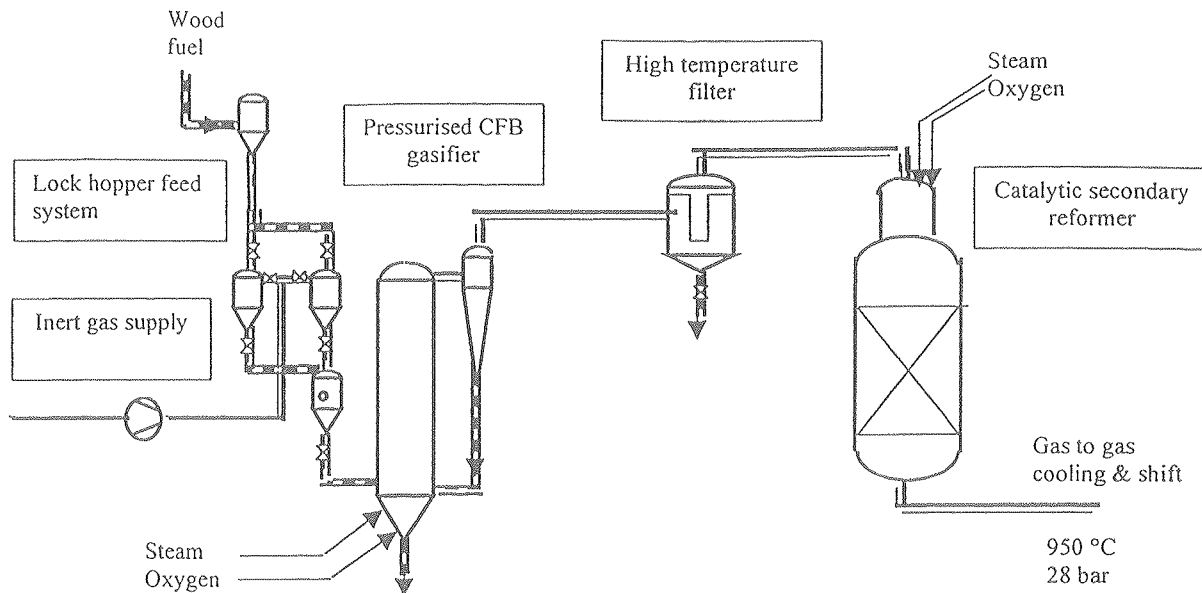


Figure 5 Schematic flowsheet of gasification block

Oxygen to the gasification block is supplied from a conventional air separation unit (1500), where also part of the inert gas is produced.

For the synthesis into DME $H_2:CO$ a ratio of $\geq 2:1$ in the synthesis gas is required. Thus a partial shift reaction (800) is carried out after cooling of the gas in a steam generator (700).

In the shift reactor CO is "converted to" H_2 by means of the reaction $CO + H_2O \rightarrow CO_2 + H_2$. The CO_2 content is further increased by the water gas shift reaction.

Excess water is condensed and sent to water treatment. The water will contain some dissolved organic compounds and also sulphide and ammonia, such that physical treatment is required prior to biological treatment.

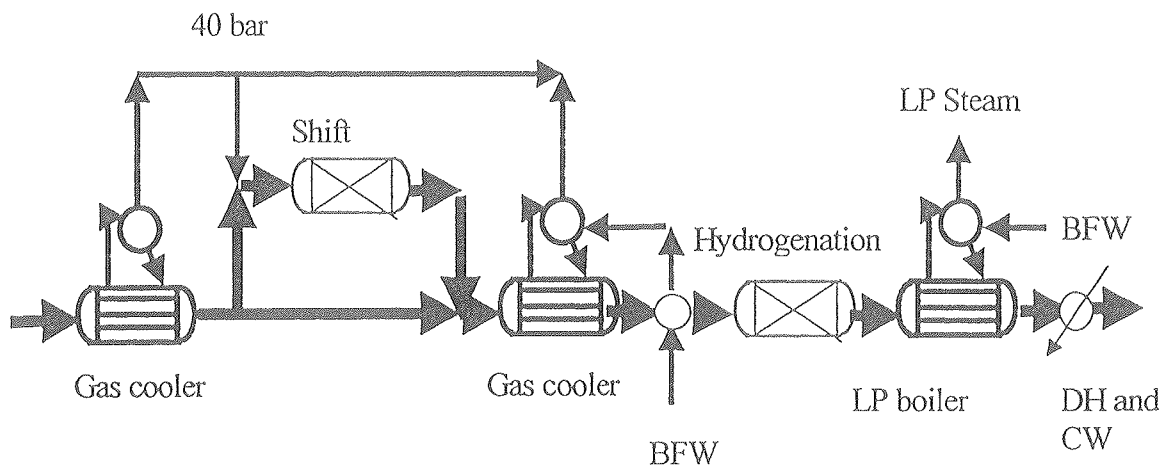


Figure 6 Schematic flowsheet of the gas cooling and shift blocks

The CO₂ is removed in a conventional sour gas wash (1000). In this case a physical washing by means of methanol (Rectisol) is suggested also providing a removal of H₂S and COS.

The choice of this process is based on the partial pressure of the gas components to be removed, the energy consumption of the process and the availability of make-up methanol in the plant as a by-product of the DME synthesis. Figure 7 shows a typical Rectisol flowsheet.

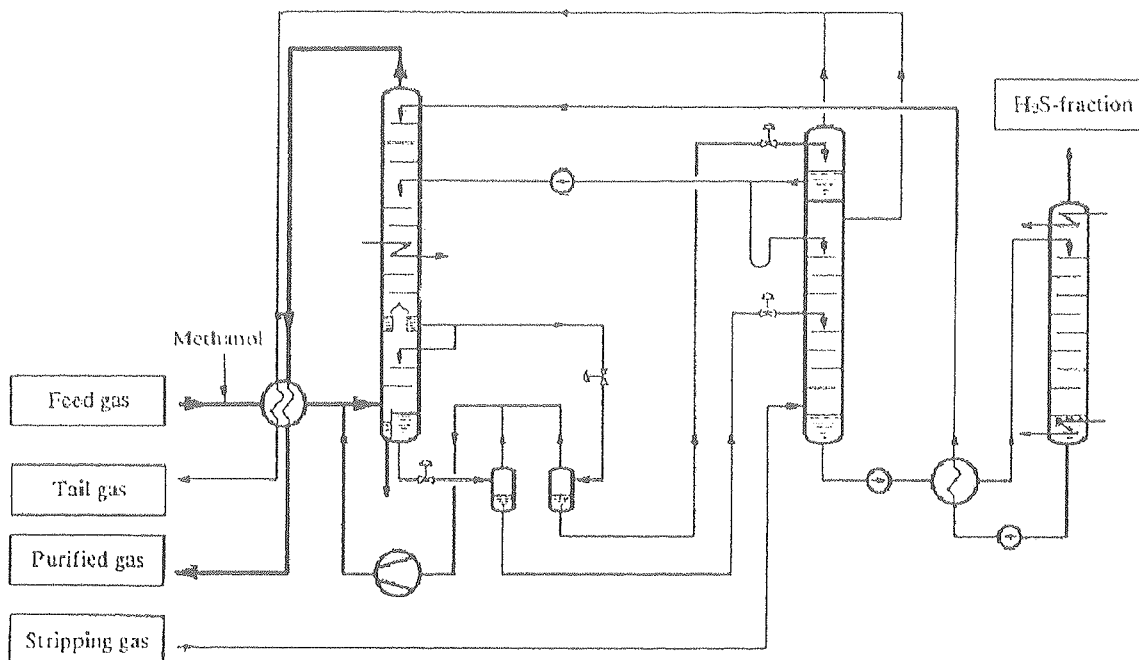


Figure 7 A typical Rectisol flowsheete (Linde, Germany)

The sulphur compounds, in a final concentration too low for Claus processing or flaring but still higher than allowed for direct release to the atmosphere, are finally oxidised to elemental sulphur in a liquid oxidation type process e.g. LO-CAT

The recovered CO₂ is partially used as an inert gas in lockhoppers in the raw material handling system and the rest can be recovered for external use (1600).

Table 1 below illustrates the transformation from raw gas to make-up gas.

The raw gas, containing about 8 % methane is transformed to less than 1 % in after the secondary reformer, and increases to 1.4 % as a result of water and carbon dioxide removal in the make-up gas. To this inert gas, another 3.6 % is added from nitrogen and argon up to a total 5 %. The CO/H₂ ratio is transformed from about 1 after the secondary reformer to slightly above 2 in the make-up gas, and CO₂ is reduced from about 22 % to about 1 %.

MOL%	GASIFIER EXIT	REFORMER EXIT	AFTER SHIFT	MAKE-UP GAS
C2H6	0,1%	0,0%	0,0%	0,0%
C2H4	1,6%	0,0%	0,0%	0,0%
CH4	7,9%	0,8%	0,7%	1,4%
CO	10,3%	21,3%	14,2%	29,8%
CO2	21,6%	16,9%	20,9%	1,0%
H2	16,0%	27,2%	30,3%	64,1%
H2O	38,8%	31,5%	31,8%	0,0%
N2	2,5%	1,9%	1,7%	3,6%
AR	0,05%	0,06%	0,06%	0,12%
NH3	0,4%	0,3%	0,3%	0,0%
H2S	0,015%	0,011%	0,010%	0,000%
COS	0,0014%	0,0004%	0,0003%	0,0000%
C6H6/Tar	0,7600%	0,0057%	0,0046%	0,0000%
Temp C	850	950	393	35
Pressure bar	30	28	26	24

Table 1 Gas composition in various process steps

The make-up gas leaving the gas cleaning, 1000, is first compressed from 24 bar pressure to the synthesis pressure, see fig 8. This is done in a one casing multi-stage compressor driven by a steam turbine.

The DME synthesis reaction is carried out in a recycle - or "loop" - reactor (1100) which implies that the make-up gas should be low in inert compound that have to be withdrawn as bleed gas since otherwise impurities will build up to too high levels. The bleed gas, containing a large fraction of synthesis gas and also products apart from the inert constituents, is fed to the combustion (1800) for steam superheating and generation.

The synthesis reactor is of a tubular design and the energy released from the reactions is used for steam production at 40 bar. The reactor exit gas is cooled and the raw product mixture of DME and methanol is condensed. DME is upgraded to product quality by rectification and condensed and chilled to a liquid product.

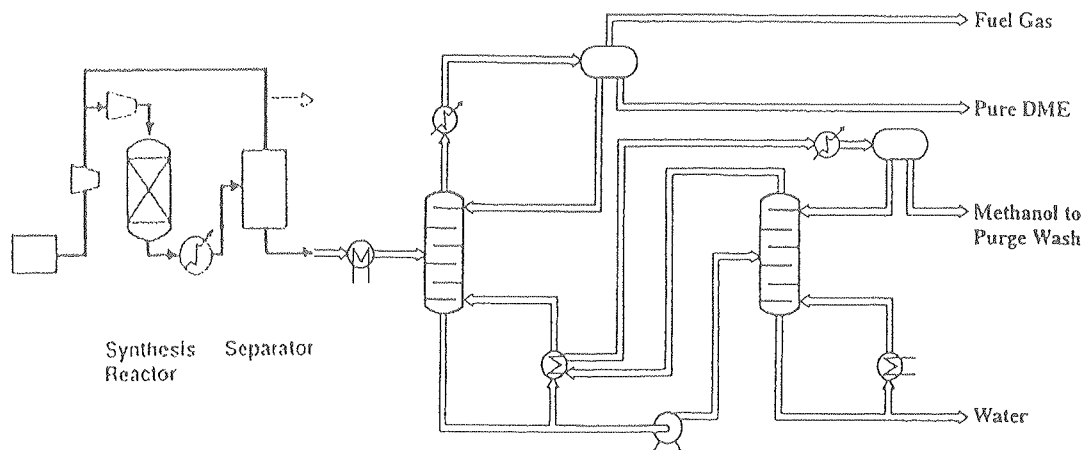


Figure 8: The DME synthesis

The total steam produced in the plant from heat recovery and waste streams (1800) covers the consumption for process steam and also for drying and other heat consumers in the plant. Additionally, a large part of the mechanical energy requirement of the plant, i.e. the synthesis gas compressor drive energy, can be extracted from the steam generated. However, the balance of mechanical energy must be imported. The alternative is to use additional biomass raw material as fuel to the steam generator. This possibility is indicated as a power production block (1900) This, however, depends on the size of the plant and the market price of imported power.

4. Technical development status for the individual processing steps for DME production from biomass

4.1 General description

As mentioned above, the biomass-to-DME process is to some extent based on established and proven technology. In fact some of the process steps may be purchased as "package units" with analogous use in - for instance - methanol production from natural gas.

Below the overall process is discussed step by step according to the general process scheme in Figure 2.

4.1.1 Pretreatment (100)

The raw material is milled in conventional hammer mills. This technology is well-known and proven, both from paper and pulp mills and from nergy systems. Several systems by different suppliers are available on the market.

4.1.2 Drying (200)

As pointed out earlier, the raw material should be dried to 10 % moisture or less. This can be effected in the conventional type of flue gas dryers or in a more novel steam dryer that acts in multiple steps where the evaporated steam in one step provides energy to the next. The latter dryer requires steam at elevated pressure at the front end and delivers low-pressure steam at the end.

An overall energy balance shows advantages for the steam dryer.

Both flue gas and steam dryers are available in full scale at a number of biomass fuel factories in Sweden. After some initial problems in this application they can now be regarded as more or less established technology, even if size considerations justify that parallel lines of drying are installed for the capacity discussed here. Also improvements on the waste condensate treatment may be required.

4.1.3 Gasification (300, 400)

Considering the pressure requirements of the synthesis step, it is preferable to perform the gasification under pressure. The final synthesis to DME is performed at 5-10 MPa and a separate compression of the synthesis gas, containing two thirds of hydrogen, is not recommended. In addition, the process steps downstream of the gasification are more economically performed under elevated pressure.

However, gasification under pressure is an expensive operation as it necessitates charging of the solid raw material into the gasification reactor under pressure. Consequently, efforts are made to keep this pressure as low as possible and to accept a final compression of the synthesis gas. A minor optimization study shows that the pressure in the gasifier is to a large extent determined by the capability of the compressors for the final compression; i.e. the number of casings or subsequent compressors required.

Gasification of biomass with steam and oxygen at 3 MPa is not yet a proven technology. During the 70's and 80's large efforts were made in gasification of coal as well as peat and biomass under these conditions. Various coal gasification processes were demonstrated in large-scale applications in USA, Germany and elsewhere. Gasification of peat was also demonstrated in Finland in connection with ammonia production. Some problems were encountered but mainly overcome.

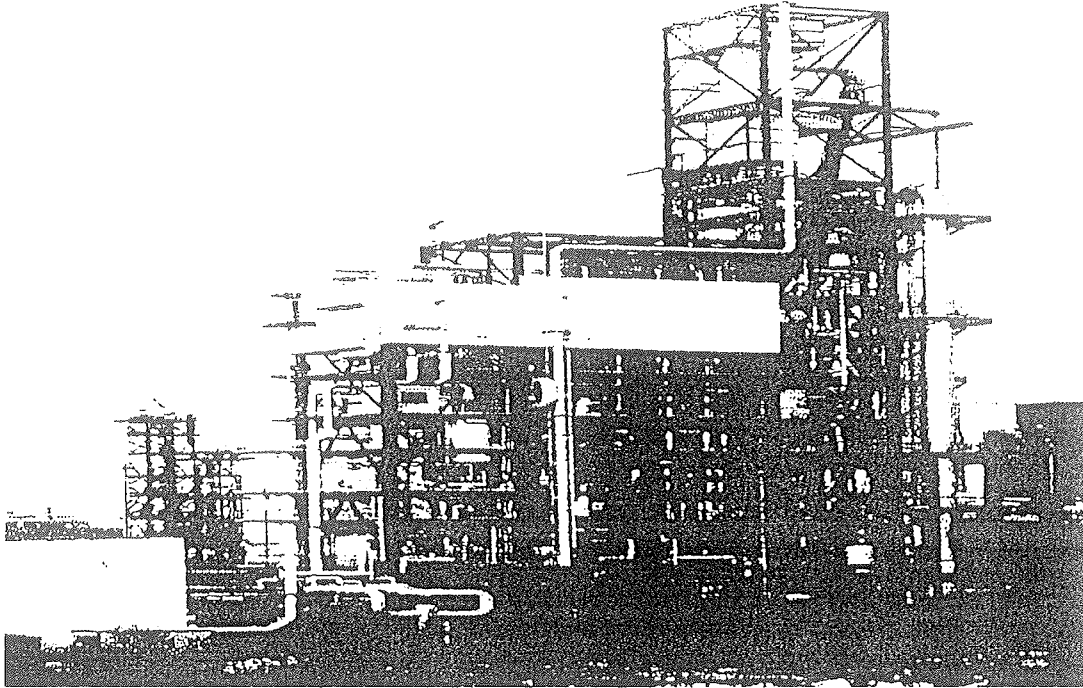


Figure 9. The HTW gasification plant at Kemira OY, Oulu, Finland

Pressurised gasification of biomass has been developed in a smaller scale than discussed here. In Sweden a 20 MW thermal, pressurised pilot plant for power production in an Integrated Gasification Combined Cycle (IGCC) has been running since a couple of years. In this application, however, air is used instead of oxygen as oxidising medium.

An overall conclusion is that gasification of biomass differs substantially from gasification of coal. The reaction chemistry for the gasification is regarded as well known and firmly established. Lacking in the development are mainly the feeding systems and demonstration in larger scale. Thus the biomass gasification technology cannot be regarded as proven, but experience exists from similar applications in terms of feed system, reactor design, both from process and mechanical aspects and of the chemistry.. The current development status is illustrated by Figure 10.:

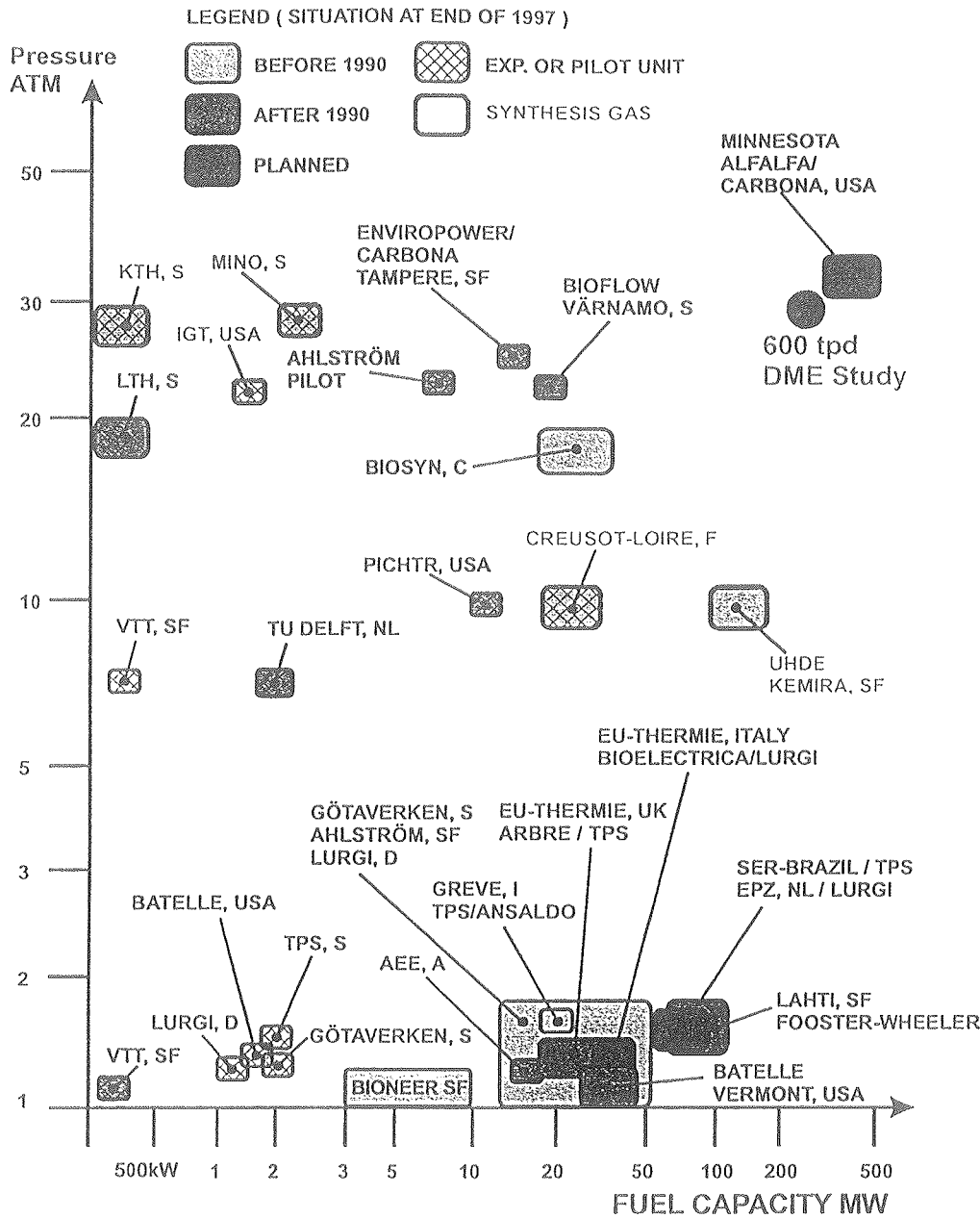


Figure 10. Development and demonstration units for gasification of biomass in terms of pressure and capacity

4.1.4 Filtration of the raw gas (500)

The raw gas from the gasifier must be cleaned from particles before further processing. The traditional wet gas cleaning gives disadvantages regarding the energy balance from first cooling and then reheating, causing increased oxygen consumption.

High temperature filters, both rigid porous metals and ceramics, were tested during the earlier development of gasification in Sweden at around 800 °C and were proven to be efficient. In other applications such filters are today more or less proven technology at a temperature of 300-600 °C. A typical design based on ceramic filters is shown in Figure 11.

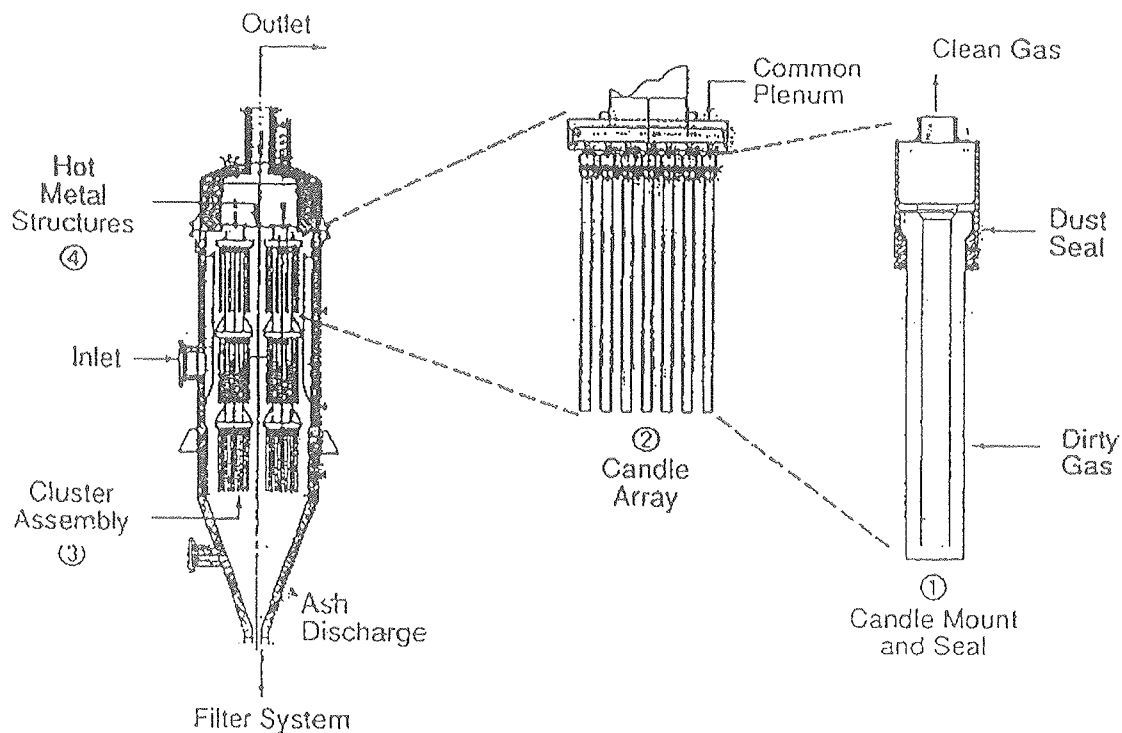


Figure 11 Example of high temperature filter design

For the biomass-to-DME process further testing is probably required, and specific design of filters for this capacity and conditions must be developed. Generally, however, the high temperature filtration technology can be regarded as proven, e.g. one has been supplied to the Krupp-Kopper 335 MW electrical coal gasification plant at Puertollano, Spain, by LLB, a German consortium formed by Lurgi, Lentjes and Deutsche Babcock.

4.1.5 Reforming (600)

The particle free gas to the reformer still carries some differences relative to a conventional synthesis gas feed from natural gas. Methane and tar vapours and a catalyst in the reformer. The mechanical design, and the catalyst, are both similar to what is used in secondary reformers in ammonia plants for decades. The effect of sulphur in the gas on the catalyst is predictable, but other minor constituents may still cause concern, and require additional testing. Development of the gas burner to fit the feed gas is also necessary.

However, the technology has been demonstrated for several years in small scale and can be regarded as near proven technology.

4.1.6 Cooling (700, 900), shift (800) and gas cleaning (1000)

After the reformer a conventional feed gas is obtained from the biomass and the cooling operations as well as the shift and the gas cleaning are established and well-known technologies.

The low sulphur content of the biomass/gas implies that "dirty" shift catalysts may not be used while on the other hand no specific sulphur removal is required upstream of the shift reactor, as "clean" catalysts can tolerate in a predictable way the sulphur content. Again long term effects of trace components remain to be seen.

The acid gas removal systems available can with certain modifications be used for this specific gas. A battery of processes is available. Sulphur handling should however be developed further. The liquid oxidation processes available are sensitive and consume chemicals. In general, for biomass combustion plants, no sulphur cleaning is required because of the low content and the release of the sulphur as dioxide. In the case of a gasifier, the sulphur product is mainly hydrogen sulphide, which is both more poisonous and odorous. Hence, catalytic gas phase oxidation may be one option in this case as the total amount of sulphur is small.

4.1.7 Gas compression (1100)

Synthesis gas compressors of the barrel type have been used for several years both with e-motor and turbine drives.

Recently GHH-Borsig announced that a gear-type compressor is available for this service which can provide an extended compression in one unit. Based on initial contacts with GHH-Borsig a gasification pressure of ≤ 3 MPa can result from such development.

4.1.8 DME synthesis (1100)

The direct DME synthesis from synthesis gas (H_2/CO) has been developed by Haldor Topsoe A/S. Largely, the process is very similar to the methanol synthesis process from the same feed. The catalyst is, of course, different and some alterations are introduced in the upgrading since DME is gaseous at ambient temperatures/pressures.

The process has been developed in a pilot unit of about 50 kg of DME per day and the pilot has been operating since several years. With reservation for the usual scale-up work the DME synthesis process can be considered as demonstrated although not established large-scale technology.

4.1.9 Other units (1500-1900)

The other units, comprising air separation, CO_2 purification, steam system, combustion and power generation are all established and proven technologies.

4.2 Summary of the technical situation

As is discussed above, further development work is required primarily in the feeding/gasification and filtration steps. All of these are, however, interconnected with each other and with the reformer and may be regarded as an integrated process:

Apart from a required demonstration of the DME synthesis in a larger scale, the remainder of the process sections will need adaptations only and no specific development.

In the following Figure 12 the critical process elements are marked with assessed development and demonstration needs:

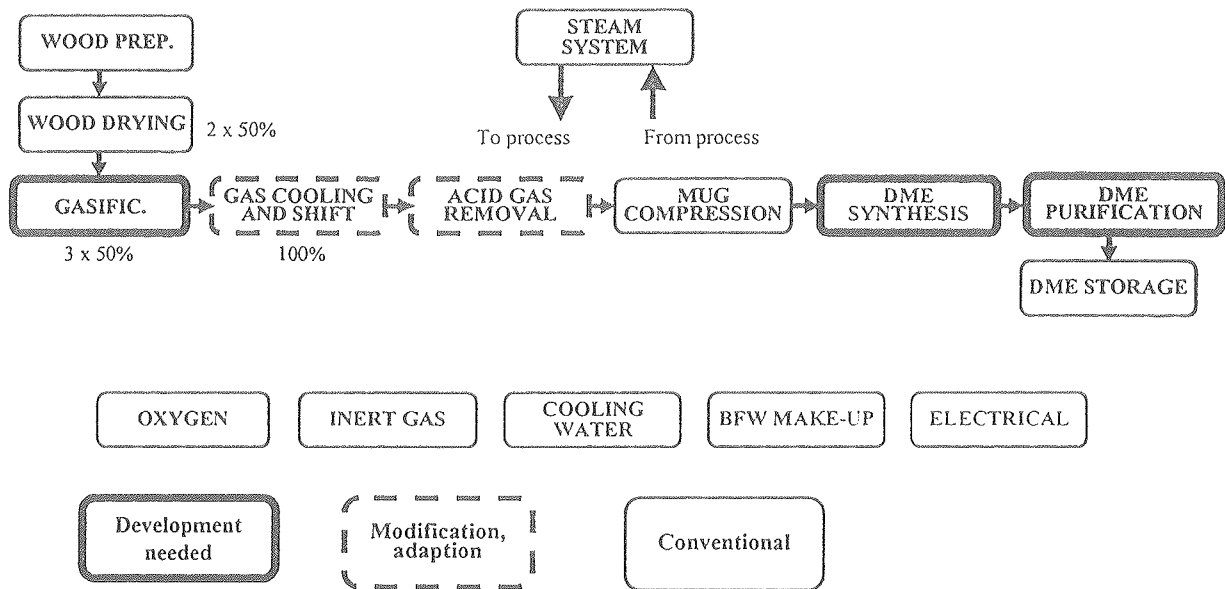


Figure 12. Block diagram illustrating the technology status for biomass-to-DME

The development of the gasification section most likely represents the critical time and it is estimated that 3-5 years may be required before a complete demonstration plant for Biomass-to-DME can be erected, however, not necessarily at the capacity investigated in this study. During that time period the demonstration of DME synthesis and the rest of the modifications may well be carried out.

5. Assessment of the Biomass-to-DME process

The Biomass-to-DME process, as outlined in Figure 4, has been evaluated in terms of material and energy balances and in terms of investment and production costs.

For performance data and budget figures on investments, engineering and manufacturing companies for the process units have been contacted. Additionally, previously obtained, in house data, have been used. For most units at least two potential suppliers of equipment have been contacted. The design bases provided to them have been based on the following overall data.

5.1 Basis of design

For the evaluation a plant capacity of 600 MTPD was decided. This would be a reasonable size for Swedish conditions regarding raw material – at least as a first unit.

Feedstock

The raw material is wood.

Composition:	moisture	50 %
	carbon	51.7 % on maf basis
	hydrogen	6.2 % on maf basis
	oxygen	41.5 % on maf basis
	nitrogen	0.6 % on maf basis
	sulphur	0.04 % on maf basis
	ash	2.1 %
Lower heating value		19.68 MJ/kg on maf basis

Products

DME of motor fuel grade

Composition:	DME	min 99.8 wt%
	Methanol, water, higher alcohols and ethers	max 0.2 wt%

Steam of 0.4 MPa pressure and bleed gas are internally consumed

Utilities

Steam and power are internally produced.
Cooling water at 15 °C

Cooling air at 25 °C.

Instrument and plant air at 0.7 MPa.

Nitrogen is internally produced or purchased at 99.9 % purity, 0.6 MPa (1 MPa, 100 °C design (mechanical)).

5.2 Product yield and raw material consumption

Key material flows are summarised in Figure 13.

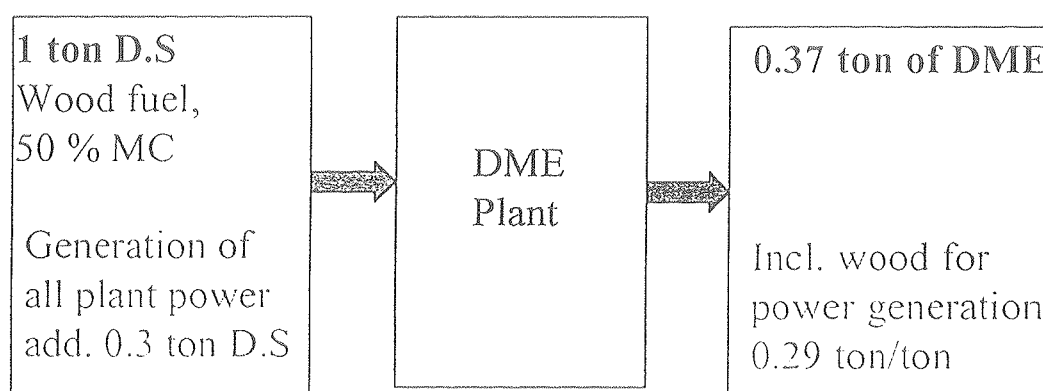


Figure 13. Yield of DME per ton of biomass feed.

Depending on the strategy for power supply an extra amount of raw material may be fed to a dedicated wood fuelled steam generator. In the base case no additional such fuel is included, the balance of the required electrical energy is assumed to be supplied from the grid by purchase from external suppliers.

For the production of 25 tons of DME/hr a supply of 67.3 tons/hr of wood D.S. is required. Thus, the raw material consumption is 2.7 tons D.S. per ton of DME. In the optional case with internal power production some 0.8 tons/hr of biomass fuel has to be added per ton DME. Some 20.000 m³ (normal) per hour of oxygen and 38 tons of steam per hour are needed for the gasification section 400 and 600.

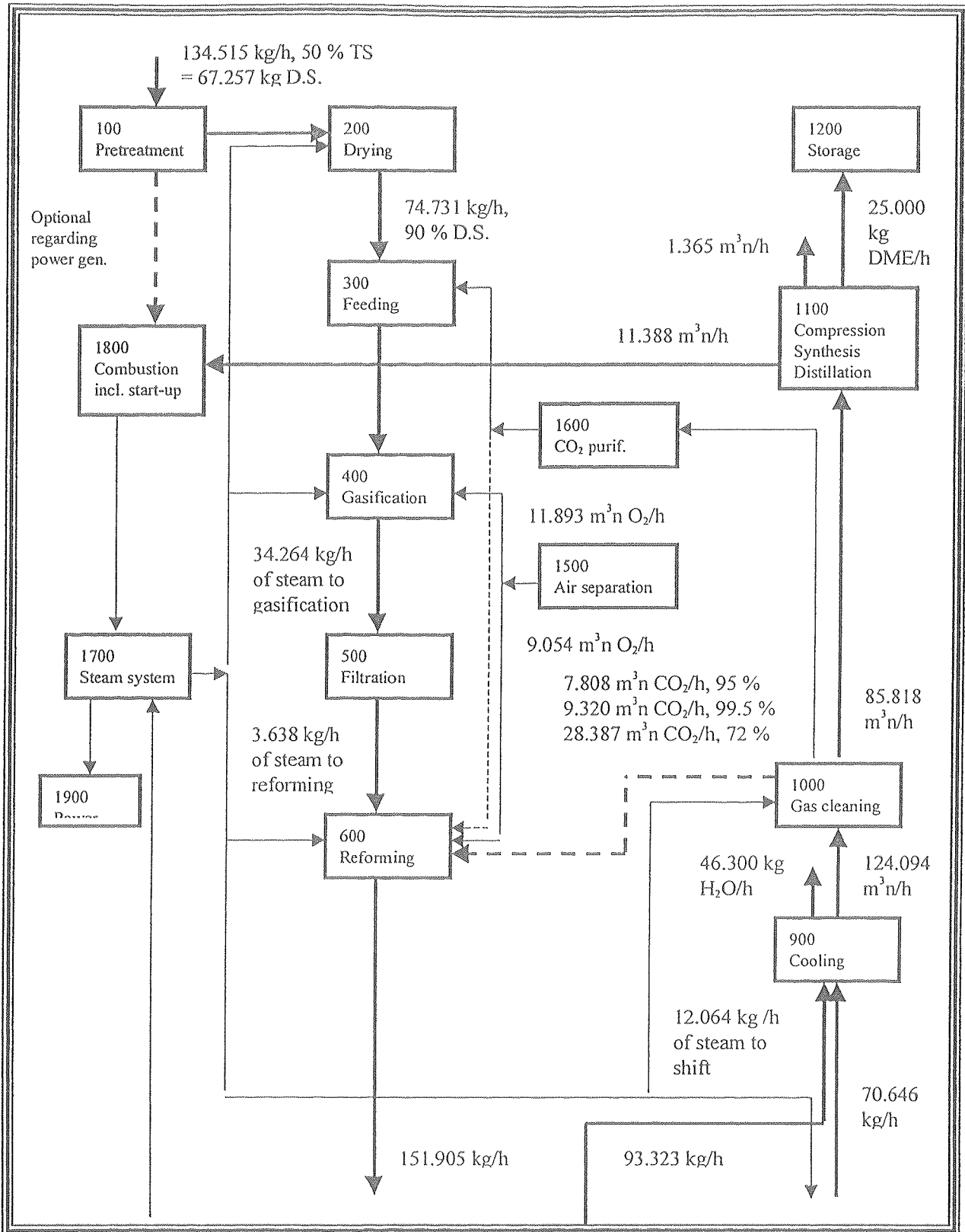


Figure 14. Major material flows in the process.

5.3 Utilities consumption

The consumption of chemicals and water and the ash production are shown qualitatively in Figure 15. Apart from the feed water supply to the steam generation and the ash, all the material flows are less than 100 kg/h.

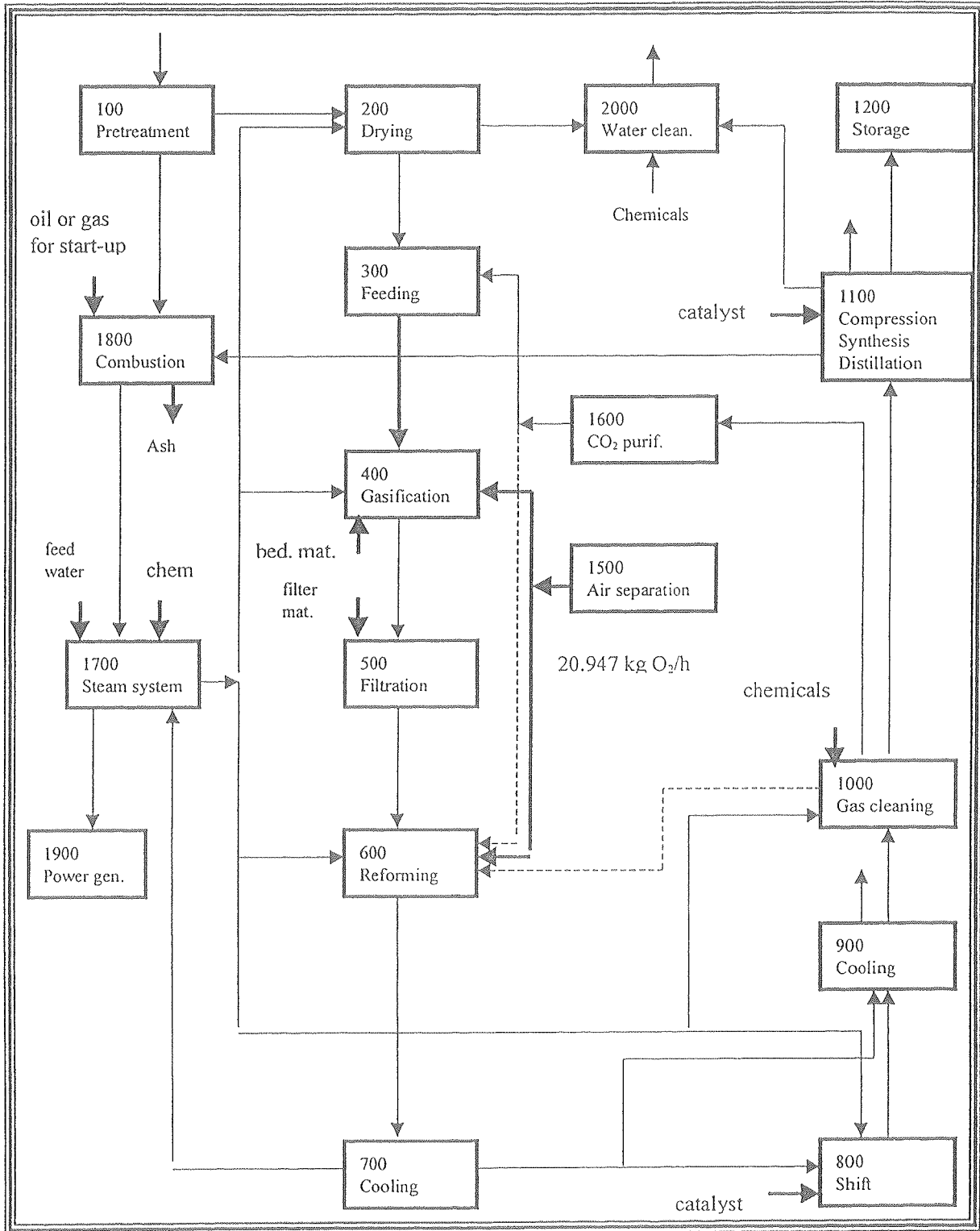


Figure 15. Consumption positions for chemicals and water.

5.4 Energy balances

The steam balance, as illustrated by figure 17, produces a marginal surplus of steam; the use of which for power production may be argued. The potential benefit of internal power production is so small that it cannot be decided within the accuracy of this study.

The major power consumption of the units is shown in figure 10 and the total power requirement is about 25 MW. Potentially, some 5-10 MW may be produced from the surplus steam (mostly low pressure) by a condensation process but the main part has to be purchased.

Depending on location, low-pressure steam and hot water may be sold for district heating. This implies that the overall energy efficiency may be calculated in several ways:

- ◆ energy in the DME divided by the energy in the biomass raw material,
- ◆ the same energy in the DME divided by total ingoing energy in the biomass and purchased power and, finally
- ◆ sum of energy in the DME and in the potential supply to district heating divided by the total ingoing energy.

Figure 16 shows the efficiencies to be 0.49 – 0.63 for the various cases:

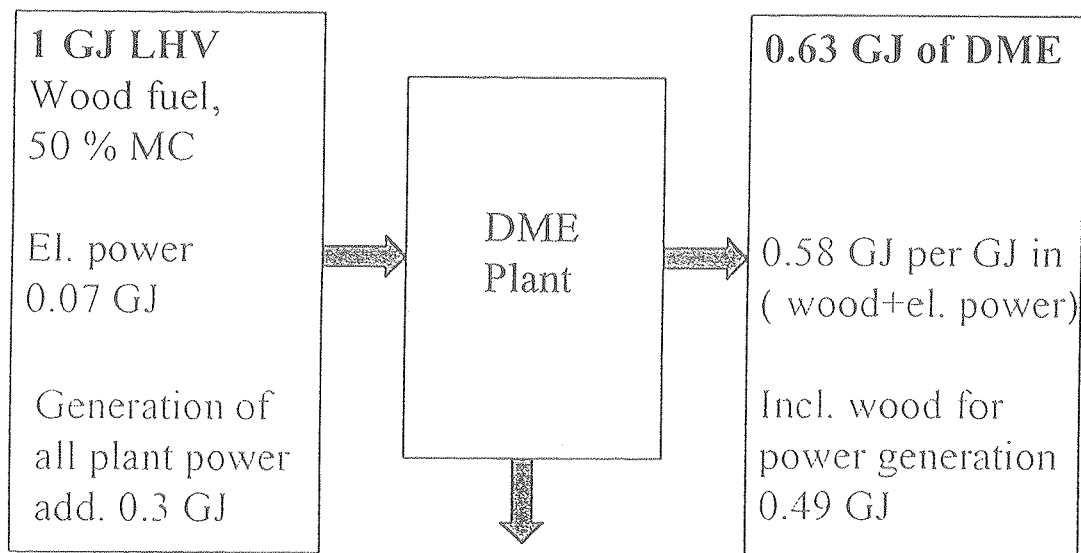


Figure 16. Energy efficiency for the process

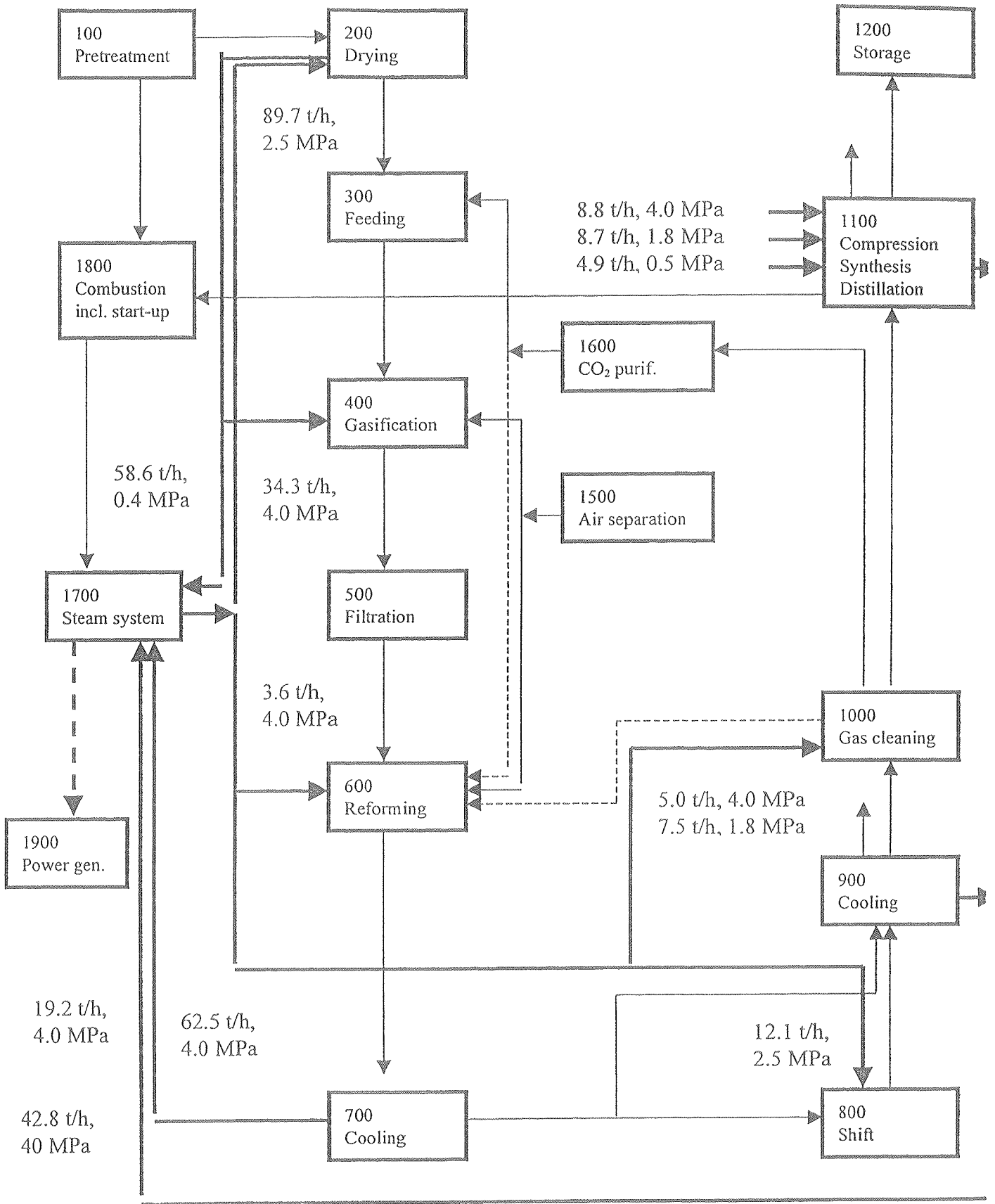


Figure 17: Steam consumption and production.

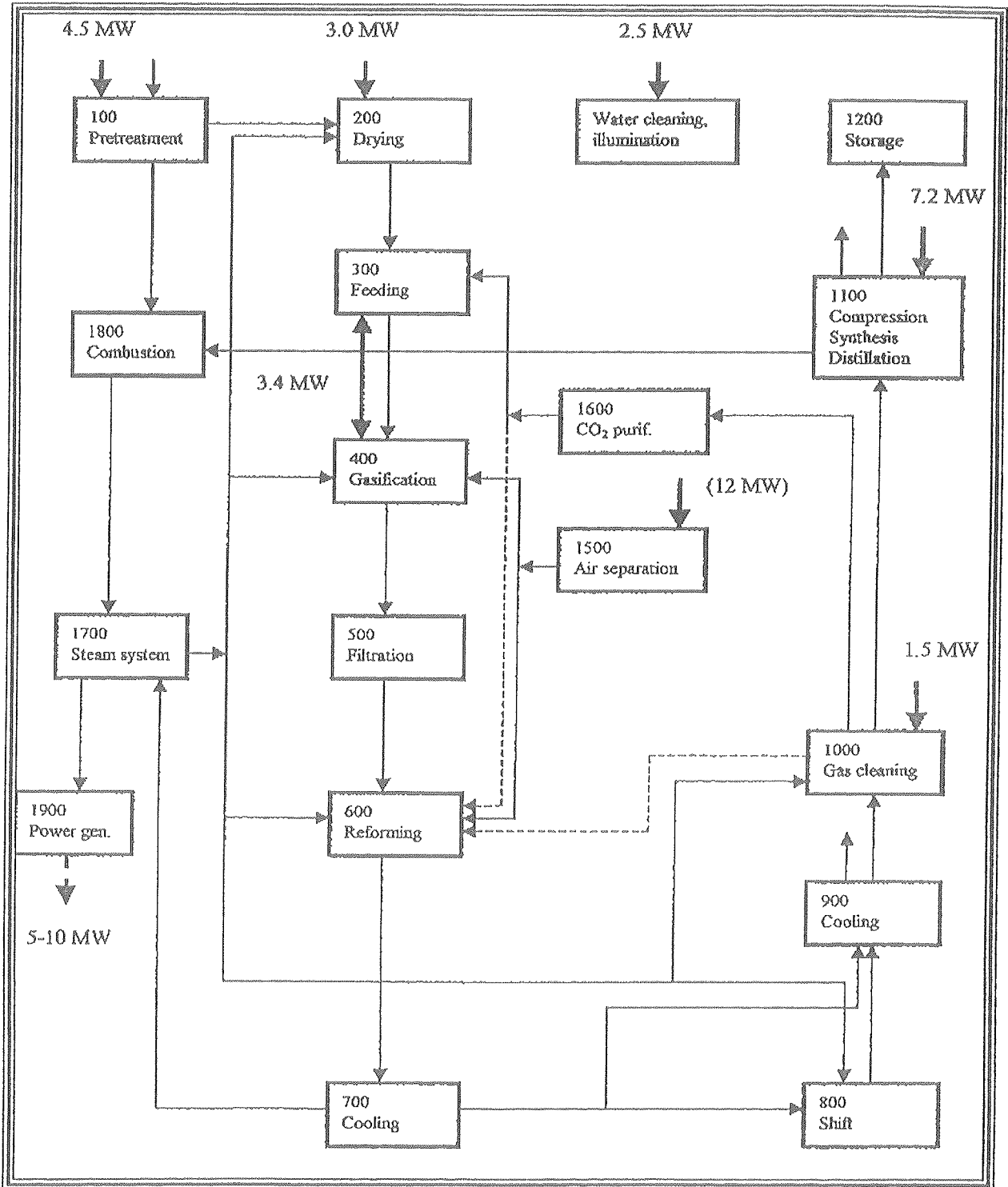


Figure 18. Power consumption.

5.5 Investment cost estimates

The investments have been estimated for two situations:

- One where the plant is located adjacent to another relevant production facility in Sweden; e.g. a district heating plant of significant size, a biomass fuel factory, or a pulp industry,
- One in a green-field location.

In the former case an infrastructure is existing at the site, water treatment facilities are assumed to be available as well as unloading and storage resources for the raw material. The site is also assumed to be attractive for an air separation plant owned by a third party such as a gas company, enabling oxygen to be purchased over the fence.

For the green-field location, all units have to be provided within the total investment. Contingencies are also expected to be larger.

The investments were originally estimated in Swedish currency. Converted to USD at a rate of 8 SEK/USD they are summarised as plant unit investments in Tables 2 and 3.

Considering the technical development status for the proposed process, multiple gasification units are assumed for the first plant to ensure continuous operation. As mentioned in the discussion of the technical development status, the gasification is the only process unit which is considered to require this “security” measure.

	Industrial site, Sweden	Greenfield somewhere
Fuel prep .	32	32
Drying	11	11
Oxygen plant	- see notes	22
Gasification	37	37
Shift & gas cooling	5	5
Acid gas removal	16	16
Compr. Synthesis , distillat .	56	56
Storage	- see notes	18
Subtotal, Process units	157 MUSD	197 MUSD
Boiler, steam & water plants	16	54
Electrical & controls	10	10
Site prep ., building & civils	6 (see notes)	10
Safety & fires	3	3
Subtotal, Plant units	192 MUSD	274 MUSD

Table 2. Plant units costs. (For notes, see Table 3)

	Industrial site, Sweden	Greenfield, somewhere
Subtotal, Plant units	192 MUSD	265 MUSD
Engineering, project control & fee	38	44
Temp. Fac., permits & inspections	13	13
Owners costs	4	5
Total installed cost	247 MUSD	327 MUSD
Comissioning & start-up	18	18
Interest during construction	14	35
Contingencies	51	63
Total investment cost	330 MUSD	443 MUSD

notes. Oxygen plant over the fence operation
 Storage in distribution cost
 Developed industrial site

Table 3. Total investment costs.

The difference in investment costs is considerable between the two cases. At an industrial site the total investment amounts to 330 MUSD equivalent to some 1.650 USD per ton of DME and year. At a green-field location the corresponding sums are some 440 MUSD and 2.200 USD per ton, year.

5.6 Production costs

As mentioned, Swedish conditions are assumed throughout this study. This implies the following provisions for the production cost estimates:

Cost item	Unit costs, etc
Financial	<p>A plant at an industrial site may be erected during two years from the definitive investment decision with a depreciation time of 15 years from that point and the long-term interest rate is assumed at 6 %. Short-term interest is assumed at 8 %.</p> <p>For the green-field location the same data are assumed with a prolonged construction time of three years.</p> <p>The interest on working capital is calculated on the total costs, less capital costs during</p>
Raw material	<p>Raw material cost as "wood fuel" in Sweden has varied between 40 and 70 USD per ton D.S. during the 1990's. In 1998 prices are approaching a top level. For long term contracts – required in this case – an average cost of 50 USD/ton D.S. (1 cent per kWh or 3.6 USD/GJ) is assumed.</p> <p>The price is of course largely governed by the oil price but it is also affected by Swedish taxation. In addition, new methods for acquiring "cheap" waste material from the forests are also on the way; e.g. thinning, etc.</p>
Utilities Consumption	<p>Oxygen is assumed to be bought over-the-fence from a gas company at a price of about 50 USD/ton. In the green-field location an ASU is included, the cost is included in fixed costs for the air separation unit and the cost for electricity.</p> <p>Electrical power is priced at 38 USD/MWh ; a common industrial price in Sweden.</p> <p>The water cost is set at 6 USD/m³. This cost also includes allowances for discharge etc., and may be considered high for Swedish conditions</p> <p>Gas or light fuel oil for start up is bought at 190 USD/ton.</p> <p>Chemicals, catalysts and filter materials are consumed in gas cleaning, water treatment and reactors. The costs have been estimated according to consumption figures and general chemical prices and – for catalysts and filters – according to budget quotations.</p>
Salaries	<p>The salaries have been averaged at 44.000 USD per man, year, covering the entire staff of some 50 people.</p>
Other costs	<p>For maintenance 3 % of the plant investment is assumed.</p> <p>Wastes, such as ash and sludge, are disposed of at a cost of 38 USD/ton.</p>
By-product credit	<p>Steam and hot water may be sold for district heating at a price of 13 USD/MWh averaged over the year.</p>

Table 4. Basis for production cost items.

For the production cost estimates, a consistent difference appears between the two cases due to the higher investment in the green-field location. However, the differences are, to some extent compensated by lower costs for oxygen and - possibly - power.

Table 5 shows the results of the production cost estimates in USD per metric ton of DME:

	Industrial site, Sweden	Greenfield site, somewhere
Wood fuel	136	136
Other fuel	6	46
Electricpower	20	-
Oxygen	53	-
Chemicals& catalysts	26	26
Water management	6	7
Wastemanagement	4	4
Personel	11	12
Maintenance	29	39
Capital cost	165	221
Interest on workingcapital	13	15
Byproduct credits	- 14	-
Production cost	483 USD/ton	506 USD/ton

Table 5 Production cost estimates in USD/ton DME for production in an industrial site and in a green-field location.

5.7 Sensitivities and uncertainties

The investment related costs (capital costs and maintenance) of the production costs are between 40 and 52 % of the total costs in the two cases. This emphasises the mentioned importance of scale as well as the effects of accuracy in the investment estimates.

Unfortunately, it is not possible to estimate the investments to an accuracy better than approximately +25 % to -15 % at this stage. Consequently, the production cost may increase by some 10 % due to uncertainties in the investment estimates.

The second largest factor in the production cost estimate is the raw material cost, which accounts for some 27-28 %. As was commented in figure 14, the price fluctuations during the 90's have been +40 to -20 %. However, considering the large volumes and long term contracts it is not likely that actual fluctuations of this magnitude should be anticipated. A price variation of ± 15 % implies a DME cost variation of ± 5 %.

Regarding oxygen and power prices, cost calculations for the two alternatives (industrial site and green-field/stand alone location) indicate that the oxygen may be only slightly more expensive before an internal production is justified. In-plant generation of power is justified at power prices at a level about 40 % higher.

The overall conclusion from these numbers is that in the proposed process DME may be manufactured from biomass (wood) at costs of about 0.5 USD/kg with a maximum of some 0.6 USD/kg and a likely minimum of 0.45 USD/kg.

These numbers are valid for the design capacity of 600 TPD (200.000 tons/year) of DME. If the capacity is halved to 300 TPD the cost increases by some 10 % whereas a doubling of the capacity to 1200 TPD results in a somewhat smaller decrease in costs - about 8 %.

6. Results and discussion

6.1 Cost comparisons

The manufacturing cost for DME from Biomass (e.g. wood) is estimated 0.5 USD per kg under present Swedish conditions and in a unit of 600 MTPD.

1 kg of DME contains 28 MJ of energy as LHV (Lower Heating Value, literature data vary between 27.6 and 28.8) which means that 1 kg of DME corresponds to 0.8 (0.795) litres of conventional diesel fuel. Consequently, the manufacturing cost for DME from Biomass is equivalent to a diesel price of 0.63 USD per litre if the same energy efficiency of the engine is assumed.

At present (autumn 1998) the European price of diesel in Rotterdam is about 0.13 USD/litre. This price level has roughly prevailed during the 90's.

Consequently, it must be concluded that DME produced from biomass is substantially more expensive than the current market price of diesel. Any other result would have been highly surprising since the driving forces for substitute fuels are not primarily the cost.

Methanol produced from biomass in a unit of corresponding size would probably cost about 0.4 USD/kg which corresponds to a diesel equivalent price of 0.7 USD/litre "diesel"; i.e. some 10 percent more than the DME.

At present the world market methanol price - with methanol made from natural gas - is some 0.12 USD/kg but the fluctuations in the methanol prices makes it very difficult to draw any conclusions. Methanol production is carried out under special circumstances and the real costs are almost impossible to evaluate with reference to local natural gas values and the capital costs.

However, if 0.12 USD/kg for methanol price is used as a manufacturing cost, the corresponding DME cost (from natural gas) would probably be in the region of 0.15 USD/kg which corresponds to a diesel equivalent price of slightly less than 0.2 USD/litre "diesel".

This figure is about 50 % higher than the current diesel price and is roughly in line with earlier statements that in larger units (10.000 MTPD of DME) a cost competitive with diesel could be achieved.

Consequently, the data in the table below may represent a reasonable accuracy:

Raw material	Diesel price (USD/litre)	DME cost (equivalent diesel price in USD/litre "diesel")	Methanol cost (equivalent diesel price in USD/litre "diesel")
Oil	0.13		
Natural gas		0.19 (0.09 in large units)	0.21
Biomass (wood)		0.63	0.70

Table 6. Estimated manufacturing costs in diesel equivalents for DME and methanol.

6.2 Costs and environmental value of DME from biomass

If the emissions of air pollutants from the diesel engine are lower with DME as a fuel, the cost of this benefit is the difference between diesel (from oil) and DME from gas. This question is handled elsewhere within the IEA/AMF DME project and is not further dealt with here.

The difference between the use of biomass and natural gas as raw materials for DME is reflected in the net contribution of CO₂ to the atmosphere. A comparison can be made between the two raw materials as follows.

The cost difference, based on the estimates presented in this study, is some 0.44-0.49 USD/liter of diesel equivalent. From 1 liter of diesel (0.81 kg) approximately 2.5 kg of CO₂ is produced at complete combustion. Thus, the cost to decrease the CO₂ production is about 0.18 USD per kg of CO₂ when natural gas is substituted for biomass.

Since biomass utilisation is one of the few realistic ways of reducing the CO₂ contribution, a comparison may also be made to other routes for fuel production from biomass. The most established way for this is ethanol production from biomass such as sugars, starch and cellulose. Since only the latter raw material is considered for DME manufacture the comparison is made regarding cellulose/wood despite the fact that no established process so far exists.

Under the same Swedish conditions as previously, current cost estimates for Ethanol from Biomass range roughly from 0.65 to 0.75 USD per liter of 96 % ethanol. This corresponds to an equivalent diesel price of 1.1-1.3 USD/litre of "diesel" (with an LHV energy content in 96 % ethanol of 20.3 MJ/litre); i.e. a considerably more expensive way for CO₂ reduction than the DME route. The cost for CO₂ reduction in this case is about 0.5 USD/kg CO₂.

(For ethanol from starch (grains) the ethanol costs are in the range of 0.5-0.6 USD/litre under present Swedish conditions, giving equivalent diesel prices of 0.85-1.0 USD/litre of "diesel" and costs for CO₂ reduction in the range of 0.34-0.41 USD/kg CO₂).

The Swedish CO₂ tax at present is some 0.05 USD/kg CO₂ (\approx 0.1 USD/litre of diesel fuel). Consequently, the cost to reduce the net CO₂ production by going from natural gas to biomass as raw material for DME is almost four times the Swedish CO₂ tax.

The overall conclusion is that DME from Biomass can by no means compete with diesel fuel on a cost/price basis on the market today. The international CO₂ reduction plans may constitute arguments for introduction of this substitute fuel but the economic incentive then has to be at least threefold today's CO₂ tax in Sweden. At the same time, however, it has to be emphasised that ethanol needs still higher economic incentives and that such are in fact provided in several countries. In comparison to other biomass-based fuels, such as ethanol and methanol, DME appears to be an attractive alternative.

6.3 Investments

The total investment for a 600 MTPD DME plant in Sweden is estimated at 330-430 MUSD, depending on location and availability of infrastructure. This corresponds to a specific investment of 1.65-2.15 USD/kg DME, year.

This figure puts the DME plant in an upper region for “base chemicals” manufacturing in Sweden. A comparison can be made to ethanol production from grains which carries an investment of some 1-1.5 USD/kg ethanol, year. Plants for sulphuric acid probably have investments down to 0.5 USD/kg, year whereas a plant for, for instance, plasticizers might cost some 2 USD/kg, year.

These orders of magnitude of investments are much higher than what is practice in the oil and fuel industry. For large refineries the investments are rather in the order of tenths of a dollar per kg of product and year.

Comparisons may also be made to the energy industry. The DME plant has an investment of some 1.000 – 1.300 USD per kW thermal energy in the raw material. A “simple” boiler plant in Sweden - which is smaller in thermal effect - bears an investment of some 250 USD/kW thermal energy in the solid wood fuel. With simultaneous power production the investment increases up to some 750 USD/kW.

In short, these figures underline the differences between a chemical manufacture such as DME (and ethanol) and production of fuels and energy commodities. The magnitude of the markets for the latter has induced a scale that creates a ground for much lower investments. The “first, large unit” that is studied in this report of course further pronounces this.

7. Development requirements for DME production from biomass.

Time perspective

The development situation can be summarised as outlined in the following table:

Process element	Comment
Pretreatment (100)	Well established technology in, for instance, the pulp industry
Drying (200)	Established technology in biomass fuel industry (Sweden). May require further testing despite several suppliers.
Feeding (300)	Improved technology is required regarding feeding at elevated pressures of 2-3 MPa. Generally lock hopper technology is available.
Gasification (400)	Technology has been developed to pilot plant stage. Long time demonstrations are required in larger scale.
Filtration (500)	Technology has been demonstrated in full scale. Improvements are required regarding life-times of filter materials.
Reforming (600)	Technology has been demonstrated in pilot plant scale. Long time demonstrations are required in larger scale.
Cooling (700)	Established technology.
Shift (800)	Established technology. Adaptation need only.
Cooling (900)	Established technology.
Gas cleaning (1000)	Established technology. Adaptation need only.
DME synthesis (1100)	Technology proven in small scale. Requires further testing, optimisation and demonstration in larger scale.
Storage for product (1200)	Technology to be adapted in large scale for LPG. Analogous technologists are established.
Air separation (1500)	Established technology.
CO ₂ purification (1600)	Established technology.
Steam system (1700)	Established technology.
Combustion (1800)	Established technology.
Power gen. (1900)	Established technology.
Waste water clean. (2000)	Established technology, which requires conventional adaptation for the particular case.

Table 7. Summary of the development situation.

As mentioned earlier, the critical path in the required development work centres around the gasification unit. Although proven qualitatively in pilot scale, the technology cannot be regarded as mature enough for even a demonstration plant. Biomass gasification has to be further developed and tested in smaller scale for at least two years before a demonstration can take place. In the pilot/demonstration IGCC in Värnamo, Sweden, the plant had to be in operation for several years before all "practical" problems were solved.

Before testing in long runs in a demonstration unit some further development is required regarding the feeders, secondary reformer catalyst and the filters. This is estimated to demand another two years of work, which implies that the erection of a first large scale plant for DME from Biomass, not being at the capacity studied here lies at least five years ahead even if required decisions were taken right now.

During this time the other process elements may well be developed to an extent that they can be fitted into the complete and integrated process. For the DME synthesis the scale up is comparatively easy made by using synthesis gas from elsewhere – and from other raw materials. The original raw material bears little effect on this process unit.

8. Conclusions

As discussed in this report a DME production from biomass is technically feasible, subject to a few years additional development work. The development time for the entire process is in the order of five years with the main part of the work being on scale up and demonstration of the gasification process.

The gasification will remain to be the most critical part of the integrated process and for the economic evaluation in this study multiple gasifier units have been assumed. This induces a certain extra investment for the first, large-scale plant. But also for subsequent plants the investments will be of the order of magnitude of large-scale chemical manufacturing plants; i.e. some 1.5-2 USD/kg DME, year for a 600 MTPD plant in Sweden and the current cost level.

Consequently, the capital costs are about 0.3-0.4 USD/kg of DME.

With Swedish raw material costs today, the total manufacturing costs are about 0.5 USD/kg, which corresponds to an equivalent diesel price of 0.63 USD/litre. With today's prices on diesel of 0.13 USD/litre, this exceeds the price with a factor of about four.

Future units for DME from Biomass may be lower in investments and larger (which induces the same effect). With a specific investment 25 % lower, the DME cost is reduced by some 10 % but still more than three times as expensive as today's diesel.

Lower raw material prices - which may be encountered in some areas - could result in another 15 % decrease in costs (at halved prices; 0.5 cent/kWh) but they will still be several times the present diesel price.

Under today's circumstances, lower costs than this (≈ 0.4 USD/kg DME or ≈ 0.5 USD/litre of diesel equivalent) can hardly be anticipated for DME from biomass.

In very large units, i.e. in the same scale as in the oil and fuels industries, and with natural gas at a comparatively low price, DME could probably be produced at costs in the at the same order of magnitude as current diesel prices. This reflects the differences between a "chemical manufacture", like the DME case studied in this report, and a very large "fuel production" as established in this industry today.

In spite of the high cost/price, DME may still be viable as a diesel fuel for environmental reasons. In urban areas the exhaust gas emissions may justify a higher price relative to conventional diesel.

Regarding the CO₂ issue, comparisons are not made between oil or natural gas products and DME but rather between DME and other feasible products from biomass.

Under Swedish conditions - with ethanol costs > 0.85 USD/litre of diesel equivalent and estimated methanol costs of 0.70 USD/litre of diesel equivalent - the DME alternative seems favourable in these comparisons.

In the USA, ethanol prices are lower than in Europe. Recent quotations are in the order of 0.45-0.5 USD/litre of diesel equivalent. Such ethanol is, however, not made