BioMeeT II

Planning of Biomass based Methanol energy combine – Trollhättan region, II

An INTERMEDIATE report

Contract No. 4.1030/C/00-014/2000

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Preamble

This studie is preceeded by two earlier studies;

- The Altener-project "BAL-Fuels" (Biomass derived alcohols for automotive and industrial use; contract no. XVII/4 1030/Z/95-124) the technology status for production of biomass based alcohols (methanol and ethanol) was reviewed and updated.
- The Altener II-project "BioMeeT" (Planning of Biomass based Methanol Energy Combine –Trollhättan region; contract no. XVII/4.1030/Z/98-368). A second step was taken towards realisation of a concrete plant for production of motor fuels (methanol), fuel gas, electric power and heat from mainly lignocellulosic feedstocks via primary conversion by gasification. This conversion route shall be seen as step to produce "clean" secondary energy carriers for a transition to long term sustainable energy system.

The project is headed by the Trollhättan Municipality (Sweden) with local interested parties including Trollhättan Energy, Saab Automobile, Volvo Aero, Volvo Truck Corporation, Volvo Bus Corporation, Vattenfall Trollhättan. European participants are Air Products PLC (UK) and Methanex Europe S.A. (Belgium). The Swedish National Energy Administration lends financial support. Ecotraffic ERD^3 AB is contracted as project leader and administrator and works together with the engineering company Nykomb Synergetics AB (Stockholm).

The study focuses on areas that have not been investigated at all or not investigated enough in the earlier studies. The results shall contribute to form a decision basis for further action.

All studies provide background to coming engineering of plants. The configuration and product slate of such plants will be decided depending on market needs and economical environment at the time of realisation.

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SUMMARY

The study

The part of the BioMeeT II-project covered by this intermediate report comprise results of phase 1 and describes the ongoing work of phase 2 and 3. Some sections are only represented by a headline but will be completed in the final report.

The work in phase 1 comprised formation of potential stakeholder group with local community representatives and entrepreneurs, national and regional energy authorities/companies, auto and oil companies and international interested companies including auto and oil industry.

Phase 2 comprises discussions and hearings with the stakeholder group formed in phase 1. Some deeper studies are also made in smaller groups consisting members of the stake-holder group.

In phase 3 the work is focused on identification of technical, environmental, organisational, legal and economical barriers, market obstacles and necessary conditions for implementation of a system to use motor alcohols.

The knowledge basis will be used to study how a bio-based conversion plant (energy combine) based on primary gasification can be configured to suit the replacement of fossil-based energy carriers on the markets. The conversion yields a gas that can be used as fuel gas, for synthesis to motor fuels (methanol, DME or other) or for electric power production. A certain amount of waste heat will appear and can be used for district heating or for drying of the biomass raw material and produce dry, solid biofuel.

The work follows the estimated time schedule and resources employed are as budget.

Sufficient biomass availability for large replacement of fuels

The great but largely not yet utilised biomass resource is wood and residues from the forestry, particularly tree residues (branches and stem tops) at clear cuttings. The by-products from the forest industry are considerable but to a large extent already utilised. Purpose-grown energy crops (Salix) on agricultural land can give a substantial and profitable contribution if systematically developed. The greater part of the wastes in the society comes from households and has mainly bio-origin and is treated as such. A great part is already being utilised as fuel in combustion plants to produce district heat (and some power).

The potential of new biomass from the forestry and the forest industry, including recovered wood waste in the society is estimated to about 10 million ODt/yr (55 TWh/yr) out of a total amount of nearly 20 million ODt/yr. Thus, there is basis for a substantial replacement of fossil-based fuels, and there would not be any difficulty to find feedstocks to the energy combine studied in this project.

It is important to consider the replacement of fossil motor fuels to be able to reach the national goals for CO_2-reduction. The integration of the production of all energy carriers

will then become still more important. This is also important in order not to create distorted mixes at the refineries.

The regions studied include large and concentrated consumption areas (Gothenburg) and cannot be expected to become self-sustained with bio-feedstocks from the region but has to rely on imports from neighbour regions with surplus and from more remote areas. The three-city region (Trollhättan-Uddevalla-Vänersborg) has better prospects for supply from the nearby area.

Although biomass resources have been thoroughly mapped in Sweden, corresponding studies in a wider European context including coming, new EU-members in central and Eastern Europe are lacking. The wider issue of land utilisation for biomass energy purposes should urgently be studied to establish potential.

The configuration of the energy combine

The production and the configuration of the energy combine used in the project are based on the results from the previous BioMeeT-project. Some complementary studies will be made during phase 3. The chosen plant will preliminary consume 380 000 ODt/yr of biomass (2 TWh/yr).

The flexibility in deliveries of fuel gas, methanol/DME, power and heat to meet varying demands during summer and winter seasons and transition periods is desirable. This is technically possible but need further investigations for economical purposes. No physical market restrictions can be seen for a plant of the size mentioned or somewhat bigger.

1 PROGRESS REPORT

The work progress follows the work schedule (Table 1) as planned. There are still work to be done in phase 2 and 3. The employed resources follow the cost estimations as well (Table 3).

The steering committee have had 3 meetings since start of the project in april 2001 and one project planning meeting before that. See protocols in Appendix 1.

Table 1. *Work schedule.*

Phases/ Months*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
	2001-04	2001-05	2001-06	2001-07	2001-08	2001-09	2001-10	2001-11	2001-12	2002-01	2001-02	2002-03	2002-04	2002-05	2002-06	2002-07	2002-08	2002-09	2002-10	2002-11	2002-12
Phase 1	■	■	■																		
Phase 2				■	■	■	■	■	■	■	■										
Phase 3						■	■	■	■	■	■	■									
Phase 4													■	■	■	■					
Phase 5																	■	■	■	■	■

Table 3. *Task description, duration and costs per phase.*

TASK DESCRIPTION	Indicators or "Milestones" for the completion of the task	DURATION OF PHASE (Months)	Costs €
Phase 1	A stakeholder group is formed	3	44 500
Phase 2	Discussions completed with all the chosen interested parties and actors	8	101 000
Phase 3	Barriers, engineering work and necessary conditions for implementation of a system using motor alcohols/ethers are identified	7	151 500
Phase 4	Recommendations from the stakeholder group of how to proceed is delivered	4	40 500
Phase 5	The seminars proposed to be held is completed	5	27 500
Total	A stakeholder group with the ability to prepare for erection of a methanol/DME energy combine and with the knowledge of the conditions for it, is formed.	**21**	365 000

Four working groups have been initiated in order to get a broad view on certain issues. The group tasks are:

1. Strategic arguments on automotive fuels from biomass versus stationary biofuel applications
2. The potential of waste-fuels instead of forest-fuels as feedstock for the gasification and fuel production
3. The potential benefits of flexibility in time of the product-mix.
4. Reassessment of demand structure in the region

2 INTRODUCTION

2.1 Introduction and background

The interest in biofuels has increased the recent years and the reason for that is the international ambitions to reduce emissions of greenhouse gases. It is also a question of security of energy supply not only as Sweden and EU are highly dependent on imported fossil oil but also the fact that the amounts of fossil oils are limited. The fossil fuels will not be completely exhausted but the costs will increase to a level comparable to production of biofuels.

The regulated emissions from vehicles are considerably lower today than a couple of years ago and this development will continue but with a continuously increasing transport demand these emissions are still a problem. But as the emissions of NOx, HC and particulate matter are decreasing the focus on CO_2-emissions will grow.

In spite of increased interest in biofuels and a lot of successful technical projects, there is still no Swedish or European strategy for an introduction of biofuels.

In Sweden both ethanol and methanol has been used from time to time and perhaps Sweden is the country in Europe today with the greatest experience and knowledge regarding to use of alcohol as fuel. A lot of studies and projects on other alternative fuels have taken part but still no fuels have had a breakthrough. The costs have either been to high or the environmental advantages lower than expected.

Looking at feedstock supply wood has the highest bioenergy potential and an energy efficient way to utilise this potential is making methanol and/or DME through gasification and gas synthesis. Making ethanol is also a possible path but is not studied in this project.

2.2 Scope and work organisation

In the process towards implementation of biomass-derived fuels for transportation, such as methanol and Di-Methyl-Ether (DME), stakeholders in the entire chain from biomass resource development to end use of motor fuels in vehicles and providing fuel gas, power and district heat must be involved. Thus, this project aims at bringing together these stakeholders and to analyse the technical, economical, organisational and environmental framework conditions and barriers.

The main aims are:

- To create and negotiate a group of stakeholders willing to support preparations for investments for developing resources, for plant construction and for marketing of renewable energy products
- To define the economic framework conditions and identify barriers of various kinds and market obstacles to implementation of said project under conditions for private enterprises

The work is organised with a steering committee, a stakeholder group and several working groups on special tasks. The steering committee consists of the participants in the Trollhättan region and is headed by Trollhättan Municipality with Ecotraffic as secretary and its role is to approve and overlook the project plan as outlined in the Altener application. Ecotraffic is entrusted with the project co-ordination/administration and of being canal to EU. The steering committee will have two to three meetings per year.

The stakeholder group consists of different kinds of organisations that would have an interest in a contemplated future with biobased motorfuels. The participants in the stakeholder group could vary depending on actual issues and The gathering in stakeholder groups will be made during the whole project in purpose to establish a close contact with industry actors and to get feedback on project results.

The members in the working groups consist of those participants in the project that have special competence for the actual task. A working group will be formed when there is a need for certain deep-loading investigations.

A special co-operate with Air Products and Methanex and subcontractors will be set out to work with the configuration and preliminary engineering of the combine and handling of products.

The time schedule is start of the project in March 2001 and finalisation in December 2002. An intermediate report (this document) is given 10 months after project start and covers phase 1 and main parts of phase 2 and 3.

2.3 Purpose – Background

The participants are committed to co-operate with the purpose to investigate the barriers and the presumptions for a biomass based energy combine in the Trollhättan region for production of energy carriers such as methanol and DME for use as motor fuels, fuel gas, electric power, heat (hot water for district nets), and dried solid fuel (pellets).

Both within Sweden and within the EU there are adopted policies on development towards a long-term supply of sustainable energy carriers based on renewable energy sources (100 % RES) and to improve air quality. The renewable resources can be hydropower, wind power, photovoltaic cells, and use of biomass in various forms. Origin for all is the sun radiation. Total sun energy flux to the earth is of the magnitude 10,000 times the energy usage in the world and if only one of thousand of this is bound yearly in biomass (actually more) this biomass represents 10 times the total energy usage. The potential for photovoltaic cell and for biomass based fuels is immense. This gives a challenge for increased and improved utilisation of land use.

The energy demand side requires energy carriers such as electricity, motor fuels, firing fuels, steam and hot water. The composition of this product mix varies from country to country and region to region.

Sweden, among others, represents a case in which oil dominates the fossil fuel use. Motor fuels take more than half of the oil consumption but little is used for power (dominated by hydro and nuclear). LFO (light fuel oil) is used for small house heating (for which electricity has gained an important share), and HFO (heavy fuel oil) for district heating centrals and industrial boiler fuel. Solid waste biomass (bark and other wood wastes, tall oil pitch) has gained a substantial fuel of the heat market.

Any substantial transition from fossil resources must obviously start to include motor fuels and a balanced substitution is desirable in order not to create costly problems elsewhere in the supply system (refineries).

In absence of breakthroughs in battery development to be able to drive on electricity only for multi-purpose vehicles, liquid motor fuels will be the preferred choice for engine power, in piston engines, turbines or fuel cells in conventional vehicles or hybrid drive vehicles. Methanol should have a good chance to be an all-purpose, easily handled fuel, also as hydrogen carrier for future fuel cells. Fossil methanol is today an internationally traded commodity and bio-methanol can be handled in that logistic system.

DME is at normal atmospheric conditions a gas, with handling characteristics similar to LPG, and therefore requires a more complex, non-existing infrastructure. DME is under practical conditions a harmless gas from health and environmental point of view and is among others used as propelling gas in spray cans. DME is a low octane but very high cetane motor fuel. DME can probably also act as hydrogen carrier, although not yet tried. DME is readily ignitable and has been suggested as clean burning fuel for diesel engines with low-emission characteristics.

The same technology, by gasification of biomass to an intermediate gas, can be used for subsequent synthesis to methanol or DME or use for more efficient electric power production in the conventional combined cycle scheme (gas and steam turbines) or the advanced humid air turbine (HAT) system. The same gas can also be distributed as firing fuel replacing fossil fuels. In all cases recovery of low-grade heat is made for heating and/or drying to improve the total efficiency. Integrated production seems suitable to satisfy the market of various energy carriers and meet seasonal variations.

3 PHASE 1 - FORMATION OF THE STAKEHOLDER GROUP

The project builds on the wish of the participants in, firstly, the Trollhättan region to create as a first example of a biomass-based plant to replace fossil-based energy carriers in all sectors, transport, industrial and space heat, electrical power. Trollhättan municipality, which aims at 100% RES, has already included this in their energy plan. Since Trollhättan is situated in an industrial area with satisfactory biomass stock, the conditions are favourable.

Local and regional authorities wish to support the transition to an ecologically sustainable energy system based on renewable energy sources (RES). Knowing that sufficient resources are at hand or possible to develop, the formation of a local consortium has been made.

This consortium includes the regional energy/utility companies, the power industry and the motor industries in the area.

The local consortium in Trollhättan comprises:

- Trollhättan municipality
- Trollhättan Energi AB
- Vattenfall AB
- Saab Automobile AB
- Volvo Aero AB
- University of Trollhättan/Uddevalla
- Trollhätteåkarna Last AB (hauliers)

Ecotraffic ERD^3 AB acts as administrator on behalf of the consortium at Trollhättan, as in the previous related projects. Ecotraffic acts on basis of its know-how on all aspects of the area of motor alcohol/ether use in the transportation sector and on production technologies. In the latter area Ecotraffic work together with the engineering consulting company Nykomb Synergetics AB, who has expertise on plant construction and are responsible for the technical parts of the plant configuration.

Participants:

- Ecotraffic ERD^3 AB
- Nykomb Synergetics AB
- Volvo Truck Corporation
- Volvo Bus Corporation
- Air Products PLC, UK
- Methanex Europe, Belgium

The stakeholder group consists of different kinds of organisations that would have an interest in a contemplated future with biobased motorfuels. The participants in the stakeholder group could vary depending on actual issues and the gathering in stakeholder groups will be made during the whole project in purpose to establish a close contact with industry actors and to get feedback on project results.

The stake-holder group includes the regional energy/utility companies, the power industry (Vattenfall) and the motor industries in the area (Saab Automobile, Volvo Aero, Volvo Truck). An engineering and a methanol producing and trading company are natural members of the group.

The stakeholder group established in September 2001 gathered besides the actors mentioned above members representing, motor fuel distribution, environmental authorities and organisations and communities (see chapter 4).

4 PHASE 2 - DISCUSSIONS WITH INTERESTED PARTIES AND ACTORS

4.1 Stakeholder seminars

A stakeholder seminar was held 2001-09-19. The purpose was to gain knowledge on alcohols as motorfuel. Both ethanol and methanol where considered due to the fact that there is a lot of experience using and producing ethanol in Sweden. The stakeholder group consisted of 23 persons representing oil-, car- and ethanol industry, authorities, municipalities, engineering and environmental organisations.

The aim of the seminar was to make a survey of the conditions for a large-scale introduction of biobased motoralcohols in Sweden for use as fuel in both light and heavy-duty vehicles, pure or mixed with gasoline or diesel oil. The whole production chain from feedstock to end-use where considered.

The one-day seminar comprised 13 talks delivered by persons representing oil companies, car manufacturers, ethanol and methanol production, authorities and technical consultants.

4.1.1 Results

The seminar comprised several interesting talks and discussions. The talks, discussions and following completing interviews with the participants resulted in a good overview for the conditions of producing, distributing and using alcohols as motorfuel.

4.1.1.1 Feedstock

Alcohols can be produced from several biological resources. This flexibility in feedstock is one major advantage if alcohols shall reach an international breakthrough as motor fuel produced from local feedstock.

Both ethanol and methanol can be produced from cellulose. In the Nordic countries there are large wood resources available for this purpose. For example, the new not yet utilised biomass in Sweden from forestry and the forest industry, including recovered wood waste in the society, could be used to produce ethanol or methanol corresponding to 53% respectively 60% of the use today of petrol based on energy content.

Regarding ethanol produced from agricultural crops there are two limiting factors. First there are not enough available acreage of arable land in Sweden and second, the demand for feeding-stuff based on the waste from ethanol production are limited.

Transport of feedstock to production plants constitutes a new logistic and transport link that may result in increased local transports and emissions.

4.1.1.2 Production

There are technologies available for wood based production of both ethanol and methanol but there is a lack of experience of large-scale production.

4.1.1.3 Distribution

Transport of alcohols is not a problem. Ethanol and methanol are commonly used chemicals all over the world. Methanol is more corrosive than ethanol but both requires correct choice of materials in tanks and piping. Some older equipment on fuel stations needs to be replaced if alcohols are to be used.

Storage in existing rock shelters for petrol is not possible due to alcohols solubility in water. Storage must therefore be done in tanks or rebuild rock shelters.

The lower energy content in alcohols, especially for methanol, compared to petrol will lead to more transports.

4.1.1.4 Application in vehicles

Both ethanol and methanol are suitable as motor fuels for road vehicles. As pure alcohol fuel or blended with petrol or diesel oil. Methanol is also an excellent fuel for fuel cell vehicles. Alcohols are corrosive compared to petrol and methanol is more corrosive than ethanol. Both require correct choice of materials in fuel systems and engine but it implies no technical barrier. There are thousands of methanol vehicles in use today.

The lower energy content by volume will increase fuel consumption compared to petrol and diesel oil. This is particular to methanol, which energy content is only 50% of petrol. Ethanol has 30% lower energy content than petrol. The efficiency is slightly higher for alcohols.

4.1.1.5 Environmental impact

The environmental impact from emissions are lower for alcohols compared to petrol and diesel oil.

There could be local environmental impacts if the forestry or agriculture is to intensive.

4.1.1.6 Health effects

Alcohols have a lower cancer risk ranking than petrol and diesel oil. Methanol is toxic when consumed or by skin contact. Methanol has the same chemical classification as petrol and should be handled in the same way.

4.1.1.7 Risks

By fire there are both advantages and disadvantages with alcohols. The heat radiation is lower compared to petrol and diesel oil and water can be used to extinguish the fire. In sunlight the flame is hard to see unless no other combustible material are burning at the same time which is normally the case.

Pure ethanol is especially liable to be stolen for drinking purposes and therefore require high security arrangements.

4.1.1.8 Economy

All biofuels of current interest need economical support, for example tax exemptions, to become competitive with fuels based on fossil oil. EU:s mineral oil directive do not allow long term tax exemptions.

The feedstock costs are high for wood and even higher for agricultural crops.

4.1.2 Conclusions

Alcohols are good alternatives for a changeover from fossil-based fuels to biobased alternatives. The potential in wood based feedstock is high. Methanol is an excellent fuel for future fuel cell vehicles. In a first phase ethanol and methanol should be introduced as low blend in petrol. The standard specification for petrol allows up to 5% ethanol or 3% methanol today. Both levels can not be utilised at the same time but 3% ethanol and 2% methanol would be permitted.

Technologies for large-scale production need to be further developed and requires governmental financial support.

5 PHASE 3 - IDENTIFIED BARRIERS, ENGINEERING WORK AND NECESSARY CONDITIONS

5.1 Planning of stepwise integration of energy combine

Work in progress...

5.1.1 Localisation and integration in the region

5.1.2 Today's regional energy structure

5.1.3 Alternative regional energy structures

5.1.4 Discussion of measures

5.2 Handling of raw fuel material

The presumption is that renewable raw materials shall form the basis of the production of energy carriers for end use. As the technology chosen for the primary conversion is suitable for reactive feedstocks, these comprise mainly biomass of lignocellulose type. Peat and municipal and industrial waste could be included to some extent. Peat should be considered as renewable as long as the quantities used not exceed the renewal rate in the area. Municipal waste can also be seen as biofuel since the fossil mass fraction (plastics etc) is low.

Biomasses from productive forestry land (defined as land with yearly growth rate of stem wood per hectare greater than 1 m^3sk ("forest" cubic meter ≈ 0.4 ODt) and other land reviewed are described in **Table 5** below:

Table 5. Biomasses from productive forestry land and other land

Forestry residues:	- Logging residues, stem tops and branches (incl. needles) from clear cuttings for pulp wood and timber - Small trees - Cut but left trees incl. wind or snow broken - Lumps left (stumps and roots, dead trees are not used)
Fuel cuttings:	- Small trees from thinnings - Small trees from clearings - Direct wood fuel cuttings
Non-forest land:	- Clearings from agricultural land - Clearings under power transfer lines, road- sides, etc - Cuttings from non-forest land

Reference: SLU/SIMS 1998

Table 7. Other biomass sources

Forest industry by-products	- Discarded stems (rot affected) - Bark from saw mills and pulp plants (spent sulphate pulp liquors are not included)
	- Leftovers, saw dust and shavings from saw mills and other wood industry
Recovered wood	- Building industry residues, - Used packings/wrappings
Wastes	- Agricultural wastes (straw and similar) - Sorted industrial, office and household wastes, mainly paper, cardboard, etc (may contain some other combustible organics of fossil origin)
Energy crops	- Purpose grown energy crops (SRF, short rotation forestry, e.g. Salix) on surplus agricultural land

Reference: SLU/SIMS 1998

5.2.1 The National availability

The results from the national survey (which can be broken down into sub-surveys for four geographic, stem wood balance areas) are given in **Table 8** and are illustrated in Figure 1.

Table 8. Total yearly raw materials (incl. needles), thousand ODt

Raw material category	Brutto	Ecologically Available	Ecologically and technically available
Cutting residues			
- Tops and branches at clear cutting	10,336	9,313	7,170
- Tops and branches at thinning	4,880	4,447	2,260
- Standing small trees	400	400	200
- Left trees and lumps	1,000	500	250
Part sum	16,616	14,660	9,880
Direct fuel wood cuttings			
- Small trees at thinning	2,145	2,056	1,656
- Trees from clearing	600	600	480
- Fuel wood cutting	1,600	1,600	1,600
- Cutting on non-forest land	600	600	480
Part sum	4,945	4,856	4,216
Wood without industrial use			
- Discarded	1,000	1,000	1,000
Forest industry by-products	3,400	3,400	3,400
Recovered wood	800	800	800
TOTAL	**26,761**	**24,716**	**19,296**

At planned levels of cuttings up to 2008 a gross potential nearly 27 Mt/yr dry fuel biomass (OD, Oven Dried) can be available. This figure is reduced to somewhat above19 Mt/yr after ecological and technical restrictions and will be further reduced to about 16.5 Mt/yr at today's accepted market price levels. Slightly less than 9 Mt/yr is already being used (mainly forest industry by-products and direct fuel wood cuttings) leaving about 10 Mt/year as today's potential expansion reserve for tree energy raw materials.

The future availability will probably be somewhat higher as the planned level of cuttings does not fully use the yearly growth in Swedish forests, whose store of biomass is increasing. Continued improved silviculture leading to enhanced growth rate must also be taken in consideration in estimating the long term potential.

5.2.2 Availability in the Trollhättan region

A special study using the Biosims model for the area in closer vicinity to the studied site at Trollhättan (max. about 100 km) has been accomplished as a special task by the Swedish University of Agricultural Sciences. Calculations were made for three areas with indicated productive forest land, these are given in **Table 10**.

Table 10. Area definition and productive forest land

AREA	FOREST LAND
A – circle with 50 km radius around Trollhättan;	280.000 hectares
B – circle with100 km radius around Trollhättan	1.010.000 hectares
C – the entire county Västra Götaland (53 communities incl. two in south-west Värmland)	1.320.000 hectares

Based on the cutting plan for the next 10 years (which as said above is below the annual growth) the following quantities and categories of tree fuel biomass (including needles) has been found potentially available **Table 12**

Table 12. Calculated forestry and forest industry tree fuel/feedstock potential, ODt/yr

AREA	A	B	C
Annual acreage clear cut, hectares	10,000	39, 000	51,000
"Grot"[a] from clear cutting and thinning	355,000	1,260,000	1,570,000
Direct fuel cuttings	98,700	345,000	442,000
Wood without industrial use	32,000	118,000	140,000
Forest industry by-products	9,700	97,000	150,000
T O T A L, ODt/year	**495,400**	**1,820,500**	**2,302,700**

Comment

[a] "Grot" = branches and stem tops

The quantities already used today are about 120 000 ODt/yr in district heating centrals within area A and about 250 000 ton ODt/yr within area C. The potential for expanded thus is high. The total sum of potential woody resources of forest origin amounts to 2.6, 9,9 and 12,3 TWh/yr (LHV) in energy terms for area A, B and C respectively.

5.2.3 Purpose grown Salix energy crops

The economical conditions for cultivation of Salix energy crops in the entire county of Västra Götaland have been studied by the Swedish University of Agricultural Sciences (SLU 1999). The county is in the statistics divided in 30 sub-areas for normal harvests of various crops dependent on ground, geographical and meteorological conditions. Data on costs of production, incl. capital cost for new machinery and labour, have been established. Available for crop production is acreage not used for animal breeding and is calculated as total acreage minus arable grazing land and 1,5 times pasture land needed. Out of a total arable acreage of 495 000 hectares in Västra Götaland about 245 000 hectares is estimated to be *available* for grain crop and/or Salix growing, i.e. in average nearly 50 %, although widely varying in different parts of the county.

For this available land calculations have been made on the profitability of growing various grain crops and Salix under the conditions prevailing within the agricultural policies (EU and Sweden).

The Salix yield was assumed to be 21 ODt per hectare at year 5 after planting and 34 ODt per hectare year 9, 13, 17 and 21. The primarily calculated harvest has been reduced by 10 % with the presumption that Salix will be planted on the less fertile part of the land. In average thus 157 ODt per hectare is harvested during a 21-year turnover period or 7,5 ODt per year and hectare. If only 1 % of available land in Västra Götaland will be used for Salix cultivation, this corresponds to 17 000 ODt per year in average. How high percentage that actually will be utilised for Salix is a matter of speculation, as Salix still is a very marginal crop. Experiences from other areas where Salix cultivation has been in use during longer period, although still embryonal, may indicate a percentage of 2-3 % corresponding to a yearly production of 34 000 – 51 000 ODt per year. This percentage should be compared with the land now as forced lay land, which is about 10 % according to existing farming policy. Under favourable conditions a future production well above 100 000 ODt per year seems possible.

The results of the calculations show that Salix cultivation was found to be more profitable, before subsidies, than any other crop in all sub-areas when the income from Salix was based on a price of 509 SEK/ODt (SEK 95/MWh LHV or SEK 26,5/GJ). The profitability will be further enhanced under the new farming policy within the EU involving a 15 % reduction of the intervention price for grains. Important factors for the willingness to grow Salix, besides the profitability, are good preparatory guidance and the reassurance of safe deliveries to large and growing fuel/feedstock markets over long time. Decisive factors are, of course, also the development of subsidies so common within the agriculture.

5.2.4 Work methods – supply systems

"Grot" (branches and stem tops) from clear cutting is today mostly collected as such in the forest by special forwarders and transported to a roadside for further transport on special bulk lorries to terminal for storage and disintegration to chips. Due to the bulkiness of this material transport costs are rather high. Alternatively the chipping is made in the forest or at the roadside and the chips are transported, still rather bulky, directly to the user. This system is less flexible and demands more expensive energy for chipping, and storage is more susceptible for losses by biological degradation and for development of mould, creating a health problem. In both systems the bulkiness can be somewhat reduced by using vehicles with capability to some hydraulic compacting. An example is increase of the load weight of not disintegrated "grot" on lorries from 20 to 30 tons.

The great disadvantage connected with bulkiness of the "grot" can be greatly reduced by compression and packaging already in the forest or at the roadside. A baling or bundling system allows further transport by standard lorries and reduces costs for transport. Particularly promising is a bundling system, which can be used in the forest and delivers bundles that can be handled with the ordinary machinery and vehicles used for round wood. There is then a potential to develop machinery for simultaneous harvesting of round wood and tree fuels as bundles. Bundles of a diameter of 0,6-0,7 m and 3 m length (about

1 m^3) will have a weight of about 550 kg (275 kg dry wood), which means more than a doubling of the "grot" bulk density. Load weights for road transport can then be further increased towards 40 tons, which makes the cost less sensitive for transport distance.

"Grot" from thinnings and *small trees* will probably be handled in the same way as grot from clear cuttings and develop into systems with bundles. Alternatively whole tree methods (the whole tree except stump and root handled in one operation) with final processing into round wood and tree fuels at terminal or pulp plant have been considered. Such methods are not (or at least not yet) used at today's clear cuttings and are unlikely to be developed only for thinnings. The same is valid for *left trees and left lumps* at cuttings.

Direct fuel cuttings on forest and other land is not yet widely practised for industrial fuel or raw material but have potential to be an important source in the future. Today they are used in small scale by private persons for house heating but taken together the volume is estimated to 2,5 MODt per year. For trees in thinnings whole tree work methods seem to suitable for not too coarse trees (<10 cm diameter). The method can be further developed through bundling and compression techniques for very efficient handling. It is hoped that load weights at road transport can increase to well over 40 tons.

In clearing operations the same methods should be suitable, although costs will be higher due the smaller size of the trees. Clearings on other land, road sides, around agricultural land, under power transmission lines, etc will probably be best handled by a direct cutting and chipping machinery and road transport in bulk lorries.

5.2.5 Pre-treatment of storable raw material

Work in progress...

5.2.6 Wastes and their possibility

Combustible wastes in the society are defined partly as such handled by the community, partly as such emerging from industries. In the first category the main part is household waste after recovery of paper, wrappings, glass, and metals and is considered as biofuel. The fossil part has in investigations been estimated to 15-20% depending on level of recovery. Other wastes emerge from erection and demolition of buildings, from parks and gardens and from industries.

The county board of Västra Götaland has made a survey of the waste quantities amounting to, in energy terms, 2,7 TWh/year, of which 1,7 TWh had household origin. The estimate is based on statistical data within the municipalities. The total amount of wastes handled today by the municipalities in the county is about 1 Mt/yr, of which 0,5 Mt is household waste (in the "three-city"-region Trollhättan, Uddevalla, and Vänersborg about 34 000 t/yr). The wood part of other waste is estimated to 80 000 t/yr and other combustible matter in the society to 130 000 t/yr. There are two waste combustion units in the county (Gothenburg and Lidköping), which together burn 450 000 t/yr and then generates 1,2 TWh heat (hot water for district heating) and 0,13 TWh electricity.

According to the survey almost 3 Mt/yr wood waste is handled by the industries but this occurs almost entirely within the forest industry as chips to the pulp plants (material recycle) or is used as internal boiler fuel (bark, shavings, saw dust).

There are at present large quantities of household and industrial waste available in relation to the requirements of a plant of 20 MW discussed in this project. Due to the legislation and taxes on waste dumps, the fuel is available at a negative price.

From year 2002 it is prohibited in Sweden to put sorted combustible waste on landfills but during 2002 there are possibilities to get exemption from this legislation. The present waste incinerating capacity is not enough to meet the demand and taken into consideration the plans for building new incineration plants, this will be the situation for many years. Because of the time lag in building a plant the immediate waste problems will find other solutions in the mean time, possibly in the form of other investments or long term contracts.

The only known plant using waste for methanol production is at Schwarze Pumpe, Germany (Appendix 2). This plant was build under the economic conditions in the former GDR. There are no economic conditions for building a similar plant today of the size discussed in this project.

A critical technological component is the filter system used to clean the synthesis gas. The design and operation of that system is dependent on the composition of the fuel gasified. The designs are easier for homogenous forest fuels then for a plant that shall be prepared to cope with waste fuels showing variations in composition.

To take on waste fuels, demands would have to be placed on the composition of the fuel that would imply costs increasing the price of the fuel. A quantitative analysis of such a cost increase is difficult.

However, the robust conclusion is that the increased availability of waste fuels will increase the supply side of the solid fuel marked and therefor tend to decrease the solid fuel prices. Even if waste-fuels are not used for the production of automotive biofuels it will indirectly improve the conditions of such a plant by decreasing the price of forest fuels.

A more detailed analysis of the potential of using waste as a feed-stock for automotive fuel production will be made in the Altener-project RENEWA-Renewable Energy from Waste, in the near future. In anticipation of what that study will reveal, no more efforts will focus on waste feedstock in BioMeet II.

5.3 Product placing

Work in progress…

5.3.1 District heating

5.3.2 Possibility of biofuel gas

5.4 Process optimisation

Work in progress…

5.4.1 Improvements from earlier studies

5.4.2 Tri-production flexibility

5.4.3 Biomass gasification

5.4.3.1 How to maximise $H_2 / (CO + CO_2)$ ratio

5.4.3.2 4.3.2 Effect of gasifier operating parameters

5.4.3.3 Optimisation of gasifier performance

5.4.4 Fate of tar compounds

5.4.4.1 Definitions of tar

5.4.4.2 Tar measurements

5.4.4.3 Conclusions

5.4.5 Fate of alkali and trace elements

5.4.5.1 Introduction

The fate of alkali metals (Na, K) and eleven toxic trace elements (Hg, Cd, Be, Se, Sb, As, Pb, Zn, Cr, Co, Ni) in biomass gasification have been extensively investigated in the past ten years. The former due to the gas turbine requirements, and the latter to comply with environmental regulations. In this report the results of experimental studies to measure Na and K in the vapor phase after the gas cooler of the gas cleanup train are reported. Also, trace element emissions from the gasification plant using biomass as the feedstock are discussed and the concentrations of toxic trace metals in the vapour phase in the gasifier product gas are reported.

There, however, is not sufficient experimental data on the trace elements in general and especially for the BioMeeT case. This is why a computing model was developed to determine the concentrations of these elements after each step of the gas train.

Almost all solid fuels such as coal, peat, lignite, and biomass-based fuels (wood chips, straw, willow, forest residue, alfalfa) contain alkali metals (Na and K) in the range of 1 to several thousand ppm. The alkali content of the fuel and the gasification conditions determine the proportion of these metals which vaporize in the fluidized bed gasifier and exit in the vapour-phase in the product gas. In the case of biomass gasification, the total amount of the vapour-phase alkalis (Na + K) measured after the cyclone of the gasifier, before the gas cooler, have been in the 1-10 ppm range but after proper cooling and filtering only a fraction of this.

All the above-mentioned fuels also contain toxic trace elements; biomass much less than coal or lignite. The same criteria apply to these other trace elements partitioning in the gasifier and eventual emissions to the methanol process or the atmosphere. A few of the trace elements may also contribute to the problems of fouling and corrosion of the process parts. The removal of those trace metals, emissions of which exceed the allowable limits will be required. As a first step a reliable sampling/measurement system is required to determine accurately the emission rates of these trace elements. Such a system was assembled and used to measure the trace metals in vapour-phase in the gasifier product gas at the 15 MW_{th} pilot plant in Tampere, Finland.

5.4.5.2 Alkali metal measurements

The sodium (Na) and potassium (K) concentrations in the vapor-phase were measured at the Tampere pilot plant by an extractive sampling system which has been developed especially for vapour-phase alkali metal measurements from the gasifier product gas. The sampling point is located after the hot gas filter unit.

The sampling system

The alkali vapours easily condense on the walls of the sampling systems and on the solid particles when the product gas cools. To avoid this, the sampling line was kept to a minimum length possible and temperature of the sample stream was always maintained by electrical heating close to that of the product gas at the sampling point. The solid particles were removed by heated quartz-fibre filter (Munktell ET/MK-360) which is capable of removing 99.998% of solid particles larger than 0.3μm (DOP-standard). The quartz-fibre filter was placed in a stainless steel casing. The adsorption of alkali vapours onto the filter cake was not significant because the particle concentration of the product gas was very low.

After passing through the shut-off and pressure letdown valves and the quartz fibre filter the sample gas was quenched by injecting water through a nozzle, placed after the quartz-fibre filter. Water vapor and gas-phase alkali metals were condensed and captured by a cold-trap containing purified water. Water from the cold trap was recirculated by feeding it back to the quenching nozzle. Consequently, the volume of water was minimized and the absolute concentrations of alkali metals were increased. After the cold trap the gas stream was led through a series of six impinger bottles placed in an ice-bath the first of which contained purified water to ensure the capture of water soluble alkalis. The next three bottles contained toluene and PE granules to capture tar-phase and the last two PE granules to protect the gas meter (Kimmon N2).

The injected water as well as all the sampling labware were cleaned by 5% HCl solution and distilled water and analyzed before use to be totally free from alkali metals. To avoid alkali contamination (especially sodium) no glassware was used in any phase of the sampling procedure.

Before test runs the filter chamber of the sampling line was opened and the quartz fibre filter was changed. The chamber and the sampling line downstream were cleaned by flushing with 5% HCl solution and distilled water. The sampling system was heated up to the process temperature, pressurized to the process pressure and purged with high-pressure reverse nitrogen flow. The water injection/circulation of 25 ml/min was started and the control valves were opened. The sampling flow rate was 5-6 l/min and the sampling time was in the 60-120 min range. After sampling the whole system downstream of the water injection point was washed and all solutions were combined to one sample. The solutions were analyzed for their alkali metal content by an atomic absorption spectrometer (Varian Tectron AA-5).

Alkali metal measuring results

The vapour phase alkali metals were sampled in several test runs at the pilot plant. Table below shows the results of typical analyses in a measuring campaign for biomass and the temperature of product gas during the sampling period.

Table: Vapour phase alkali metals in product gas

gas temperature °C	Na, ppmw (dry gas)	K, ppmw (dry gas)	total, ppmw (dry gas)
432	0.02	0.02	0.04
434	0.01	0.01	0.02
430	0.02	0.01	0.03
404	0.02	0.01	0.03
406	0.01	0.01	0.02
401	0.03	0.02	0.05

The Table shows that the total vapour phase alkaline (Na + K) was in the range of 0.02-0.05 ppmw in dry gas which is for instance far below the requirement of any gas turbine manufacturer and negligible considering any process for gas utilization. The gas temperature at this test period was around 400°C compared to 250° which has been used in the BioMeeT process design. It is safe to say that in BioMeeT process the figures are in any case lower than these.

5.4.5.3 Trace elements measurements

The measurements were conducted by the laboratory of the Finnish utility Fortum at the Tampere pilot plant. This kind of measuring program has been unique considering biomass fuel, which in this case was alfalfa-straw. There, however, is a good comparison with other biomass fuels, most of which are much easier materials to gasify - like wood. Table below shows the concentration of the trace elements in the fuel. The trace element comparison of different fuels is at the end of chapter 2.

Table: Trace element content of alfalfa feedstock (mg/kg fuel i.e. ppmw)

Compound	Level
Mercury (Hg)	<0.07
Cadmium (Cd)	<0.2
Lead (Pb)	<5
Selenium (Se)	<5
Antimony (Sb)	<5
Cobalt (Co)	<2
Manganese (Mn)	26
Beryllium (Be)	<2
Arsenic (As)	<5
Cromium (Cr)	<2
Nickel (Ni)	<10

The concentrations shown above are averages of three determinations. The trace element content for all the metals were determined by AAS-graphite oven technique except for mercury for which AAS-cold vapour procedure was used.

Sampling methods

The trace element concentrations in the gas-phase after the HTHP ceramic filter unit measured by two different techniques: wet chemistry and using active carbon filter beds. Fortum delivered the filters. The wet chemistry technique is a modified version of EPA 29 method using an impinger train; three bottles containing 50%-50% HNO_3/H_2O solution followed by a fourth larger bottle containing silica gel. The product gas is led through a heated tube, a quartz filter positioned just above the condenser tube (made of titanium dioxide) and then to the impinger bottles placed in an ice-bath. The sampling line is kept to a minimum length and heated electrically to the same temperature as the sampling point to avoid condensation.

The pressure of the gas is reduced with three needle valves before the filter. After sampling the condenser tube is washed and collected and analyzed with all the other solutions. About 1.23 m^3n of product gas was collected.

The active carbon system used was recommended by Radian Corporation and built by Fortum. Basically the same system was used like with wet chemistry, except for the impinger train which is replaced by two tubes containing active carbon which acts as a filter. The comparison of the results of the two sampling lines is shown below.

Mercury content of the samples was determined using cold vapour atomic absorption spectroscopy (CVASS). For the rest of the trace elements either ISP or ASS coupled with a graphite oven were used.

Test results

Of all the trace elements analyzed cadmium and lead concentrations were above the detection limit as shown in Table below. Concentrations of cadmium and lead were 2.0 $\mu g/m^3n$ and 2.4 $\mu g/m^3n$, respectively with the impinger train. Corresponding figures with the active carbon filter system were 0.7 and 2.3 $\mu g/m^3n$, respectively. Concentrations of Ni, Mn and Cr were not determined.

Table: Trace element content of the product gas after the ceramic filter unit ($\mu g/m^3n$)

Compound	Level
Hg	BDL
Cd	0.7-2.0
Pb	2.3-2.4
Se	BDL
Sb	BDL
Co	BDL
Mn	NA
Be	BDL
As	BDL
Cr	NA
Ni	NA

BDL= Below Detection Limit

NA= Not Analyzed

The feedstock samples were analyzed in the USA at the University of Minnesota, Department of Soil, Water and Climate. The results agree very well those obtained in Finland at the Technical Research Center of Finland, VTT.

5.4.5.4 Fate of chlorine - HCl in the gasification process

The fate of fuel-bound chlorine in the gasification process is directly related to those of alkali metals (Na, K) and the calcium compounds. There is experimental evidence that both K and Na will react either with the chlorine released from the fuel or HCl, when formed in the gasifier, to form alkali chlorides (NaCl and KCl). As a result of these reactions, the measured concentration of HCl in the gasifier gas has been found to be a fraction of what it would be if all of the chlorine exit in the form of hydrogen chloride. These reactions help to remove gaseous halogens from the gasifier gas which are then bound with filter ash and gasifier ash in solid phase. The reactions of calcium compounds with both chlorine and hydrogen chloride are also investigated, primarily in conjunction with the addition of dolomite or limestone to the fluidized-bed gasifier. Experimental data show that when calcined, a significant portion of the HCl is removed from the gasifier gas in the filtration stage in the form of calcium chloride with the filter ash. In conclusion, most of the fuel-bound chlorine is removed either with the gasifier ash or bound in the filter ash in the solid-phase as alkali chlorides and in certain cases calcium chloride.

In clean wood based fuel the chlorine content is very low and the measured HCl – concentrations in gasifier gas after the filter have been under the detection limits, meaning less than 1 ppm concentration.

5.4.5.5 Trace element emission calculation

Theoretical calculations were carried out to determine toxic trace element concentrations in the BioMeeT gas stream. The trace element content of the wood feedstock (analysis results) and the product gas composition was used as input. The fractions of the trace elements volatilized in the gasifier can be varied from 0 to 100%. The product gas is cooled, filtered and scrubbed in 40°C.

The fractions of the volatilized amounts which are removed due to these combined mechanisms can, again, be varied from 0-100%. Finally the product gas is burned in the gas turbine like part of the BioMeeT plant gas.

In the absence of measured data, it was assumed that 50% and 100% of the toxic trace elements are volatilized in the gasifier and exit with the product gas. Past experience with coal and some other fuels show that up to 90% of volatilized fraction of most of these elements are removed with the filter cake alone, accumulated on the ceramic candle filters and practically the rest is removed by scrubbing. Mercury and cadmium may be exceptions.

In the absence of exact measured data 70% and 99% (min/max) removal was assumed due to combined mechanisms of cooling the gas, filtering and scrubbing for the most volatile trace elements. Hg and Cd were exceptions as mentioned above and reduced removal of 50% and 80% (min/max) was used for them. Finally the gas is combusted in a gas turbine. In the combustion stage the flue gas is diluted with 220% air.

The Table "Trace Element Emission Calculation" in the end of chapter 2 shows the trace elements concentration in the product gas after the gasifier, after gas cleanup train and in flue gas after the gas turbine at the stack. As can be seen that even with these very conservative assumptions none of the trace metals emissions exceed or are even close to the emission standards imposed in Europe or to be regulated in the USA under Title III of the Clean Air Act.

The Cd and Hg concentrations and the "total of other metals" are regulated in mg-units for instance in EU-waste combustion directive. In BioMeeT gas the concentrations are in μg, thus 1000 fold smaller than any regulation. The conclusion is that the emissions are harmless for the gas cleanup systems, methanol production and environment at the BioMeeT plant.

Table 14. Trace Element Summary For Different Fuels

Fuel	Coal	Peat	Wood waste	Fresh wood	Demol. wood	Waste paper	Sewage sludge	RDF	Alfalfa
Ash content, %w	12.77	5	2.1	1	1.8	5	45	7	7
Trace elements, mg/kg									
As	3.4	3.2	0.2	0.11	11	0.9	7	2.6	0.058
Cd	0.7	45.4	0.007	0.295	0.7	1.9	5	0.2	0.197
Co	5.3	2.1	5	0	0	14.8	8	0	0.36
Cu	17	0	0	6.8	1050	38.3	750	20	9.67
Cr	16.3	51.9	53	7.3	35	11.4	130	45	0.512
Hg	0.1	0.004	0.007	0.01	1.5	0.33	6	10	0.00399
Mn	200	56.8	126	0	0	86.9	270	84	36
Mo	1.1	9	0.7	0.855	0	13.9	4	0	0.978
Ni	24	37.2	11.3	2	0	14	90	15	1.36
Pb	32	460	0.445	2.1	590	49.5	390	243	2.1
Sb	1.6	0.174	0.127	0	23	0	2	0	5
Se	1.3	0.147	0.111	0.1	0	0	0	0	0.31
Sn	203	193	185	0	1	14	0	0	0
Zn	27	134	166	47.5	1410	850	1600	55	20.3
V	38	8.3	0.75	0	0	0	0	0	0.534
Tot. other met.	537	811	377	18	1710	215	1639	410	56

Table 15. Trace Element Emission Calculation. Oxygen blown gasification of fresh wood

Fuel:	fresh wood		vaporized trace elements		trace elements in product gas vapor phase						emitted trace elements in flue gas after GT	
	0											
moist (AF), %	30		(wet base)		aft. gasifier /bef. gas c-up		at 40 C removed in scrubber		after scrubber			
ash, %db	2											
Trace elements	mg/kg ash db.	mg/kg fuel db.	mg/kg fuel	mg/kg fuel	ppmw	Ppmw	%	%	ppmw	ppmw	µg/m3n; ppbw	µg/m3n; ppbw
			min	max	min	Max	min	max	max *	min **	max *	min **
As	0.11	0.002	0.001	0.002	0.001	0.001	70	99	0.000	0.000	0.066; 0.1	0.001; 0.0
Cd	0.30	0.006	0.002	0.004	0.002	0.004	50	80	0.002	0.000	0.297; 0.2	0.059; 0.0
Co	0.00	0.000	0.000	0.000	0.000	0.000	70	99	0.000	0.000	0.000; 0.0	0.000; 0.0
Cu	6.80	0.136	0.048	0.095	0.046	0.092	70	99	0.027	0.000	4.102; 3.1	0.068; 0.1
Cr	7.30	0.146	0.051	0.102	0.049	0.098	70	99	0.029	0.000	4.403; 3.4	0.073; 0.1
Hg	0.01	0.000	0.000	0.000	0.000	0.000	50	80	0.000	0.000	0.010; 0.0	0.002; 0.0
Mn	0.00	0.000	0.000	0.000	0.000	0.000	70	99	0.000	0.000	0.000; 0.0	0.000; 0.0
Mo	0.86	0.017	0.006	0.012	0.006	0.012	70	99	0.003	0.000	0.516; 0.4	0.009; 0.0
Ni	2.00	0.040	0.014	0.028	0.013	0.027	70	99	0.008	0.000	1.206; 0.9	0.020; 0.0
Pb	2.10	0.042	0.015	0.029	0.014	0.028	70	99	0.008	0.000	1.267; 1.0	0.021; 0.0
Sb	0.00	0.000	0.000	0.000	0.000	0.000	70	99	0.000	0.000	0.000; 0.0	0.000; 0.0
Se	0.10	0.002	0.001	0.001	0.001	0.001	70	99	0.000	0.000	0.060; 0.0	0.001; 0.0
Sn	0.00	0.000	0.000	0.000	0.000	0.000	70	99	0.000	0.000	0.000; 0.0	0.000; 0.0
Zn	47.50	0.950	0.333	0.665	0.320	0.639	70	99	0.192	0.003	28.652; 21.8	0.478; 0.4
V	0.00	0.000	0.000	0.000	0.000	0.000	70	99	0.000	0.000	0.000; 0.0	0.000; 0.0
tot.other met.	18.41	0.368	0.129	0.258	0.124	0.248			0.074	0.001	16.895; 13.1	0.282; 0.2

Note: total other metals: Sb+Pb+Cr+Cu+Mn+V+Sn+As+Ni+Se,

* maximum (100%) vaporized trace element in gasifier combined with minimum removal in scrubber

** minimum (50%) vaporized trace element in gasifier combined with maximum removal in scrubber

5.4.6 Status of oxygen blown gasification

5.4.6.1 Historical development of gasification development in Europe

In the beginning of the 80s the EC initiated four methanol-dedicated pilot test projects. Reactors with a gasifying capacity of 10 tonnes/day were constructed at: Lurgi (Germany), Foster Wheeler (England), Italenergi/AGIP-Spa (Italy) and Creosot-Loire (France). However only poor operational experiences were shown and the most ambitious project, Creosot-Loire operated at highest at 8 bar during just a few hours.

Rheinbraun of Germany developed during the 80s the HTW-technology (hochtemperatur Winkler), which aimed at gasification of mainly brown coal, but also peat and biomass. In 1986 a 730 tonnes/day brown coal gasification demonstration plant was built in Berrenrath. The plant was designed for methanol synthesis integration, but was shut down in 1999 because of economic reasons. The technology was later acquired by Krupp Koppers, who together with Uhde formed in 1997 Krupp Uhde, who in turn is part of the ThyssenKrupp Group.

Before this, Rheinbraun commercialised in 1988 together with Lurgi (and Uhde) the HTW-technology at Kemira in Uleåborg, Finland with a gasification plant (10 bar) of 1,000 tonnes/day of peat with oxygen for ammonia production. Problems arose at the feeding system, due to poor preparation of the fuel and varying quality of the peat. These problems were solved by better quality control of the fuel, although most of the time, the plant was operated on part-load together with an oil gasifier. Successful runs were however made on mixes of 60% peat and 40% sawdust. After several thousand hours of operation the entire ammonia plant was shut down in 1990 because of economical reasons (lower ammonia prices).

Lurgi has since 1983 developed their own CFB-gasifier reactor, which has a feeding capacity of 11 tonnes/day with variant pressure and w/wo air or oxygen as oxidising medium. A number of gasifiers have been commercialised since then, but none have been based on pressurised oxygen-blown gasification of biomass.

5.4.6.2 Gasification development in USA

The Institute of Gas Technology (IGT) in Chicago started in 1981 with support from the Department of Energy a development program of pressurised biomass gasification with air (oxygen) and developed the RENUGAS®-technology, which was tested in an 11 tonnes/day pilot reactor (6 - 24 bar). Continuous operation was established during 260 hours. These successful tests led to the start of a demonstration program of bagasse (sugar cane residue) gasification in Hawaii.

Apart from the other mentioned gasification technologies, which are based on circulating fluidised beds (CFB), the IGT's technology and the HTW-technology are based on a bubbling fluidised bed (BFB). In comparison, the BFB has as significant differences less complicated design, and as a result a lower investment cost but is lower in flexibility on fuel type and its moisture content.

In phase 1 of the program a plant of 100 tonnes biomass per day (22 bar) was built in 1995 on Maui, which was extended in phase 2 with hot-gas cleaning. In phase 3 electricity production in a combined cycle would have been demonstrated and plans were made also for future testing of fuel cells and methanol production. Changes during feeding in the fuel's physical properties made the feeding too difficult and the program was abandoned after only 170 hours of gasification operation.

BrightStar Synfuels Co has since 1996 demonstrated biomass steam gasification with indirect heating by natural gas firing inside tube in a 12 tonnes/day reactor in Louisiana. A medium-value heating gas can be obtained without the need for oxygen. The company has in parallel with development towards pressurising of the gasifier reactor tried to commercialise the technology in USA. Though, after Energy Developments Limited bought the majority of the shares, the pilot reactor has been moved to Australia.

Another interesting oxygen-free technology development is the LIVG-technology from Battelle Columbus, which is demonstrated, in a 200 tonnes/day (atmospheric) plant built in 1998 in Vermont. This is a scale-up from successful testing with a 12 tonnes/day pilot reactor which has also been tested with a 200 kW Solar gas turbine. The technology is based on indirect heating of the biomass fuel in a primary reactor with sand, which is transported from a secondary reactor, where unreacted biomass, which has been separated from the primary reactor is burnt. The sand acts thus as transfer medium of the released thermal energy back to the primary reactor.

After initial tests they experienced problems in mainly the feeding system because of changed physical properties of the fuel. Drying restrictions forced them to change the design fuel, wood chips to pre-dried wood residues from a local industry. Regaining the design fuel, which is instead dried externally, has solved this problem.

Other problems have occurred in the complicated cyclone system with the transport of large volumes of hot sand. Small particles is also carried with the cleaned gas and forms a thick layer of fine powder in the scrubber, where the pump discharge system had to be replaced. Besides, tar compounds in the gas have resulted in foaming in the scrubber. In consequence, the integration with a gas turbine originally planned for year 2000 has been postponed and so far no successful long uninterrupted runs have been reported or published.

5.4.6.3 Gasification development in Finland

In parallell to IGT's own development, IGT licensed in 1989 the RENUGAS®-technology to, amongst others, Tampella in Finland, (later transferred to Enviropower co-owned with Vattenfall, though the license is currently held by Carbona Inc.). However, Tampella chose in 1993 to further develop the similar UGAS®-technology (also from IGT) mainly for biomass with air as oxidizing medium (although oxygen is an alternative). As a result, a pilot reactor was built in Tampere with a 100 tonnes/day biomass capacity (up to 30 bar), see **Figure 1**.

Until 1997, 5900 tonnes of different biomass fuels have been gasified in 25 different campaigns during, in total 3700 hours. These fuels include wood chips, paper residues, wood residues, willow, straw, alfalfa and coal-biomass mixes. The pilot reactor is owned by Kvaerner Pulping, however the plant is not in current continuous operation due to high production costs, and that the location in central Tampere City prohibits use of a large number of trucks needed for fuel transport.

Carbona Inc. has the right to operate the plant for testing of fuels and equipment, but it is only at validation for a real project a campaign can be undertaken. The cost to operate the plant for a 1 - 2 week campaign totals about €1 million and demands 3 months of work.

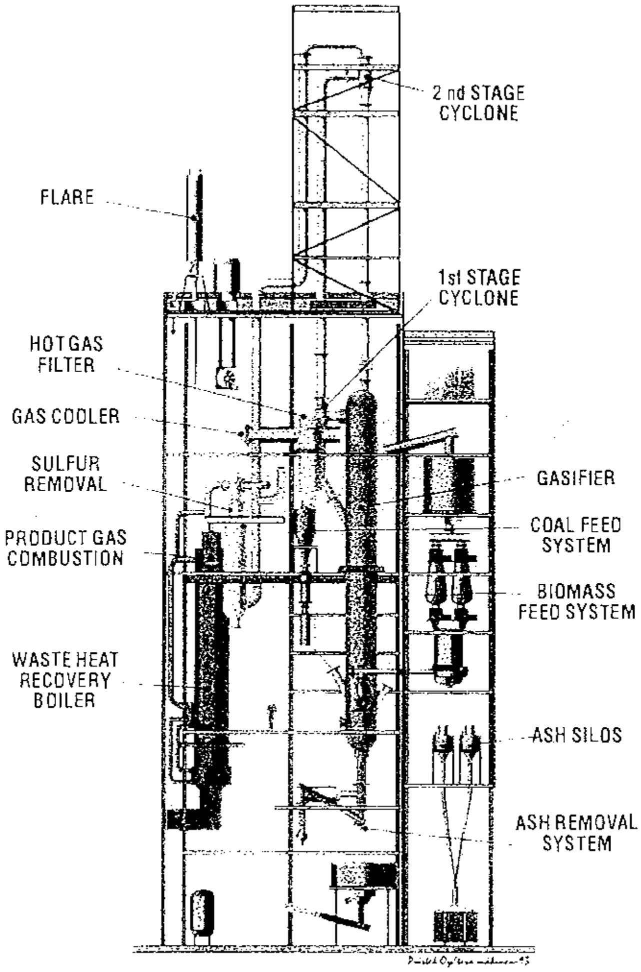

Figure 1 The UGAS-gasifier plant in Tammerfors, owned by Kvaerner Pulping.

5.4.6.4 Gasification development in Sweden

Pressurised gasification with focus on methanol production has only been tested in Sweden by TPS in Studsvik, with their own developed MINO-technology (minimum oxygen). The tests were carried out during 1983 - 1986 in a 12 tonnes/day pilot reactor (10 - 30 bar). After initial experimental difficulties, wood chips, peat and brown coal were tested, according to their statement, during an estimated 70 hours of continuous operation (10 - 25 bar). Falling oil prices, high production costs and technical problems however made them to abandon the technology in favour for atmospheric gasification towards electricity production.

Sydkraft/Ahlström (currently Foster Wheeler) started in 1991 jointly to develop an air-based gasification technology, BIOFLOW, which was demonstrated in 1993 in a 100 tonnes/day plant (22 bar) in Värnamo. The technology was integrated with a combined cycle for about 6 MW electricity and 9 MW district heat production. Problems with the feeding system, gas sealing, pressure valves and gas filters made the start-up time extensively prolonged.

After elimination of these problems, successful operation has been maintained, but due to low electricity prices and high production costs the demonstration program was stopped in October 1999. In total, after 6 years of operation and 400 million SEK (about €40 million), about 8000 hours of operation with the gasifier unit have been recorded and about 3500 hours of operation with the combined cycle in integration mode.

Växjö Municipality has however initiated a project, starting with an assignment given in 2000 to Sycon and TPS, to investigate the possibility to convert the existing plant to DME-production. An interest group has been formed and is currently trying to gather sufficient project funding (in total €45 million) for a 4 year operational demonstration with field trials.

5.4.6.5 Present situation

At present there are several projects on gasification of biomass in Sweden. The Swedish Energy Agency finances gasification project using waste and and black liqueur as feedstock.

The black liquor project is in progress in Piteå. This feed stock has high quality for synthesis of methanol or DME. The total quantity of black liquor available in Sweden would be sufficient to supply about 20% of the Swedish use of automotive fuels.

In Värnamo there is a feasibility study of DME-production from biomass initiated by Växjö municipality (see section 5.4.6.4). The project is stalled at the moment, waiting for a possible opportunity to continue with the support of the 6th framework programme. The project-budget is in the order of 450 MSEK. Volvo is one of the actors heading the project as they would like to achieve a complete supply chain from biomass to DME fuelled Volvo vehicles. Their vehicle development is proceeding in a project called AFFORHD, Alternative Fuel FOR Heavy Duty vehicles.

There is also a non-governmental supported project driven in Hagfors by the company Värmlandsmetanol AB. The project is headed by well-known environmentalist Björn Gillberg. The purpose is to demonstrate the technology in a small plant of about the same size as the Värnamo plant.The block diagram is shown in **Figure 3**.

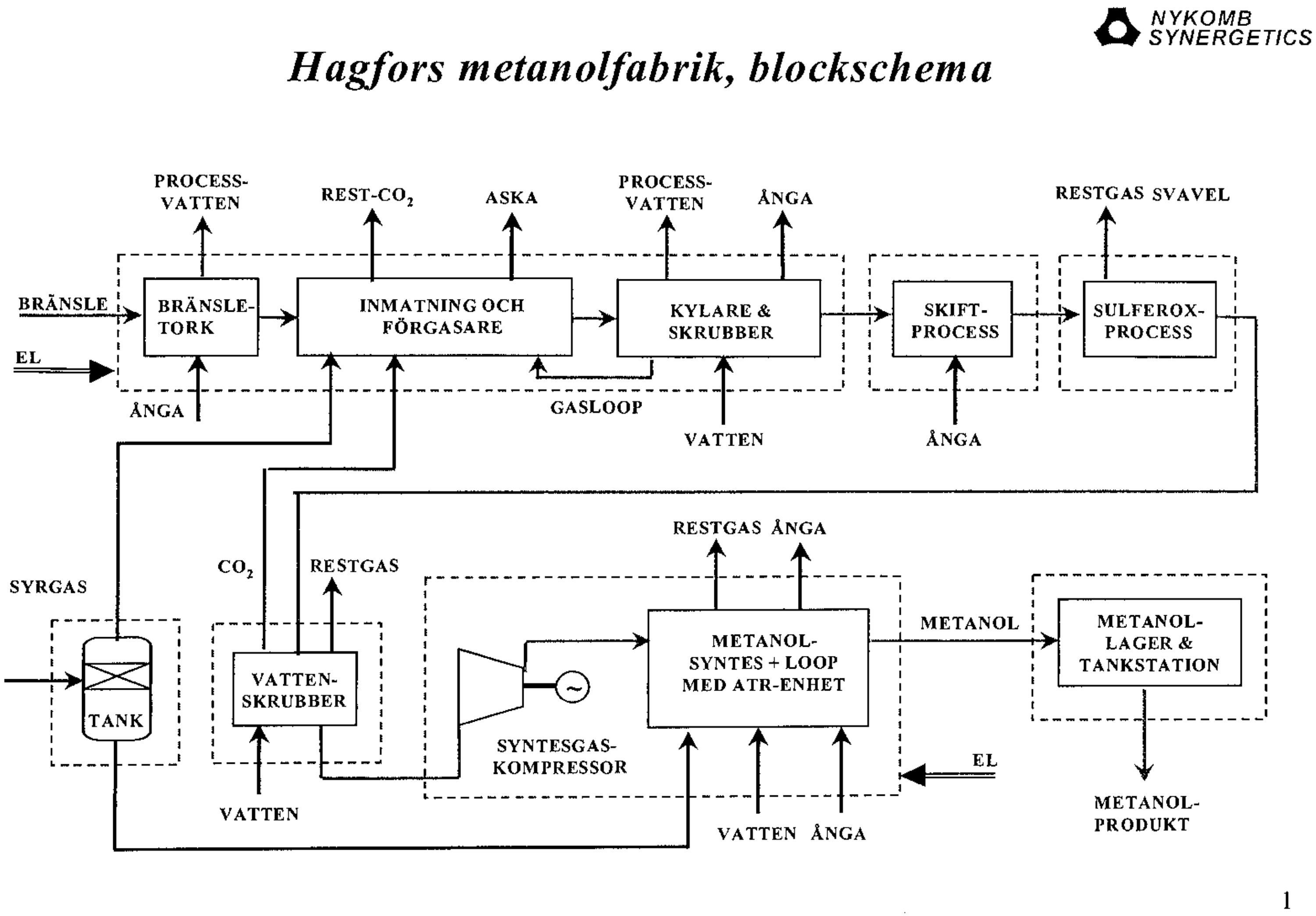

***Figure 3**. Methanol plant, blockdiagram. Hagfors*

5.4.6.6 Commercialisation of the technology

5.4.7 Alternative CO_2-separation technology

5.4.8 Methanol synthesis

5.4.9 Upgrading purge gas to biofuel gas

5.4.10 Commercial status of process units

The chosen design of the process plant comprises several process units integrated in a complex. Generally, all process technologies have been commercialised in their respective business areas, apart from pressurised oxygen-blown biomass gasification. Handling and preparation of biomass can be said to be commercial in the biomass based co-generation industry, which has developed considerably the last decade in Sweden. The amount of biomass used in Sweden for heat and power production has roughly doubled in the last 10 years, mainly because of increased carbon tax on fossil fuels. Other process units with gas cleaning and methanol synthesis have been commercialised in large-scale plants within mainly the petrochemical industry all over the world and can be supplied by various known companies.

The most unproven process in this context is gasification, and therefore the most important one. In previous studies a number of comparisons have been made of the different technologies. The first assumption is that the process should be pressurised, due to that the downstream methanol synthesis is carried out at 55 bar, and that the energy efficiency would severely suffer from such big gas compression ratio. In our earlier BAL-study, three pressure levels were studied, and where 20 bar pressure in the gasification unit was found to be most energy economical. As an example, the syngas compressor may not then need to raise the pressure with a factor of 3.

The second assumption is that the gasification process must be oxygen-blown, with as high purity as possible to be able to achieve a high product yield, or carried out with in-direct heating in absence of air. Air contains large amounts of inert nitrogen, that if used as oxidising medium would enlarge the whole plant considerably, and lower the efficiency in the methanol synthesis.

The gasification technologies, which have generated most operational experience on pressurised oxygen-blown biomass gasification and showed best results, are MINO, HTW and UGAS. The MINO-technology is not currently marketed, instead more or less cancelled. Therefore we have studied HTW and UGAS, where technical performances by and large do not differ significantly. Larger differences can be shown on costs and utility systems. It is difficult to decide which is best available technology, when many other factors also take part.

Gas cleaning and conditioning is best used with a sulphur tolerant catalyst in the shift unit, which is used in order to adjust the gas ratio of hydrogen and carbon monoxide. Gas shift units is a commercially available technology. To separate sulphur from syngas the new SulFerox® process from Shell Global Solutions may be beneficial to the configuration.

In order to optimise the gas to a stoichiometric gas for the methanol synthesis carbon dioxide must be separated. The commercial processes within the petrochemical industry use solvent-based absorption processes.

The methanol synthesis can be supplied from a number of companies, because when the gas has been conditioned to mimic a syngas used in petrochemical industry for methanol synthesis there is no real difference. However, the syngas contains a large content of methane, therefore a reforming step may be added in the methanol loop to increase the methanol yield.

In conclusion, there is nowhere in the world process integration demonstrated according to what described with biomass gasification to methanol production. Hence, it is difficult to optimise other process units when the produced gas differs from syngas produced from natural gas or other fossil fuels sources like oil or coal gasification.

5.5 The energy combine – configuration, technique

Work in progress....

5.5.1 The flexibility of the energy combine

The potential benefits of flexibility in time of the product-mix are desirable to improve the economic performance of the plant. In this respect the plant need a design that would make it possible to adjust the product mix over time in response to the variations in relative prices and demand. It has been noted that there are significant variations in the price of electricity at the Nordic spot-market. During the winter the need for electricity reaches the capacity level of the Swedish power production, which increase the price.

The assessment of alternatives is complicated. Not only is flexibility limited by the configuration and components in the plant that is decisive for the investment cost, but gas quality is also affecting the efficiency of the catalytic fuel synthesis providing a fraction of gas for direct combustion.

Preliminary results indicate that the best design option may be the previously studied design maximising the production of methanol/DME.

The precision of the analysis shall be improved and sensitivity assessed.

5.5.2 Size of the energy combine

5.6 Methanol and DME as motorfuels

5.6.1 Fuel properties

Some relevant fuel properties for petrol (according to EU 2005 specification), diesel fuel (Swedish Environmental Class 1), methanol, DME and propane are shown in **Table 16**. Petrol and diesel fuel are shown as reference and propane is also added as a comparison for DME, since these fuels have similar physical properties.

Some comments on the fuel properties can be made. Methanol and DME contain oxygen in comparison to the other fuels, where only petrol *may* contain a small amount of oxygen (<2,7%). In case RME is blended to diesel fuel, this fuel will also contain some oxygen. The viscosity is lower for DME and methanol than for diesel fuels, which gives lower lubricity. Differences in vapour pressure, flash point and some other properties have influence on the risk of fire and explosion. The difference in boiling point is vast, ranging from diesel fuel to the fuels in gaseous state (DME and propane) at normal temperature and pressure. DME and methanol contain less energy per mass and volume than petrol and diesel. The alternative fuels are practically sulphur-free but the sulphur content of petrol and diesel fuel has, or will be, reduced to almost zero level for these fuels as well. DME and methanol contain no olefins, aromatic or polycyclic aromatic hydrocarbons (PAH), thus implying a considerable advantage regarding the health effects from toxic emissions. One the other hand, formaldehyde, considered as an "air toxic" in the USA, might be formed with DME and methanol as fuel. However, diesel fuel also gives formaldehyde in the exhaust but in the DME case, the formation of formaldehyde seems very low. The simple molecular structure of DME and methanol implies that the formation of heavier toxic emission compounds will be less than for the conventional fuels. Since the oxygen content of DME and methanol is low, and there are no carbon-carbon bonds, the soot formation with direct injection and diffusion flame combustion of these fuels will be negligible in contrary to other fuels.

Table 16. Fuel properties (to be completed...)

Fuel property	Petrol EU 2005	Diesel fuel Swe EC1	Methanol	DME	Propane
Chemical composition					
Coal, % C	~86,5	~85,75	37,5	52,1	81,7
Hydrogen, % H	~13,5	~14,25	12,6	13,1	18,3
Oxygen, % O	0-2,7	0	49,9	34,7	0
Mole weight	~100		32,042	46,068	44,094
Viscosity @ 40°C (cSt)		1,4-4,0	0,60	0,25	
Density (gas) @ 20°C (kg/m^3)			1,35	1,92	1,88
Density (liq.) @ 20°C (kg/m^3)	730-770	810-820	795	668	501
Gas density rel. air (15°C)	3,4-4	4-5	1,11	1,59	1,52
Vapour press.@ 20°C (bar)			0,12	5,1	8,4
RVP at 37,8°C (bar)		0,0007	0,32	8	13,5
Vapour press. @ 60°C (bar)			0,77	14	20,8
Boiling point @ 1 bar(a)	30-225	180-300	65	-24,9	-42,1
Melting point (°C)		<-26	-94	-141	-190
Flash point		>50	11	-41	-100
Heat of evaporation (MJ/kg)		0,25	1,17	0,41	0,43
Heat of comb., HHV (MJ/kg)			22,65		50,3
HHV (MJ/lit.)			18,0		25,6
LHV (MJ/kg)	42,5	42,3	19,9	28,43	46,4
LHV (MJ/lit.)	32,0	35,2	15,8		23,5
CO_2 formation, LHV (g/MJ)	~74,3	~72,3	68,9	67	64,6
Autoignition temp. (°C)		~250		235-350	470
Flammability limits ($\%_{vol}$)	1,4-7,6	0,6-6,5	6,7-36	3,4-17	2,1-9,4
Water sol. @ 1 bar, 20°C ($\%_m$)			∞	5,7	0,39
Water sol. @ 4,8 bar, 20°C ($\%_m$)			∞	5,5	
Sulphur content (ppm_w, mg/kg)	50	10	0	0	0
Olefins, max (%)		n.l.	0	0	0
Benzene (%)	<1		0	0	0
Aromatics, max (%)	<42	<5	0	0	0
PAH, tri+ (%)		<0,02	0	0	0
Cetane number	n.a.	>51	~5	>55	n.a.
Octane No. (RON)	>95	n.a.	120	n.a.	112

5.6.2 Potential fuel converters for methanol and DME

5.6.2.1 Driving forces for a technology shift

Engine and vehicle development is driven today by a number of partly conflicting requirements. These are:

- Safety
- Exhaust emissions
- Reduction of climate gases (primarily CO_2)

The first issue (safety) is of significant importance for light-duty vehicles (though of somewhat less importance for heavy-duty vehicles) but it is left without further comments, while the two remaining issues are of significant interest to discuss.

Emission regulations have been passed for light-duty vehicles for the to 2005/2006 (Euro IV) and for engines used in heavy-duty vehicles to 2008/2009 (Euro V). These emission limits are reasonably well known and the technology for meeting them is being developed. Therefore, no particular analysis of the impact of the emission norms is made here. In general, alternatively fuelled engines have many advantages over conventional fuels regarding the emissions. The primary driving force for the emission development will be to meet the limits for the conventional fuels (petrol and diesel fuel). The routes chosen for engine and aftertreatment development will also have a substantial impact on the adaptation of these engines for alternative fuels. Consequently, the development on the conventional fuels must be taken into account when assessing the potential of future development of the alternative fuels.

In order to reduce climate gases from transportation, the European car manufacturer's association ACEA and the EU have agreed on voluntary future limits for CO_2 emissions for light-duty vehicles. Later, the Japanese (JAMA) and Korean (KAMA) manufacturers agreed on similar commitments but with one year delay. The limits (target and indicative targets) for ACEA are shown in **Table 18**.

Table 18. *Voluntary limits for CO_2 emissions in Europe*

Year	CO_2 (g/km)	Red. (%)	Remarks
1995	185	0%	Base level for the comparison
2003	165 – 170	-9,9%	Indicative target range
2008	140	-24,7%	Target for 2008
2012	120	-35,5%	Indicative target for 2012

It should also be noted that the voluntary agreement mentioned above is for the whole EU and for all ACEA members and it is not applicable to specific markets and car manufacturers. It is somewhat unclear how ACEA will allocate the CO_2 emissions between its members, or if some other procedure will be used. However, the means of achieving the goal is of little relevance in this respect *if* the goal is achieved. Some reservations have been made by ACEA, such as the free penetration of new technology in all member countries. This aspect will most likely be considered in the review process.

The description of the technology used in passenger cars could be begun by drawing the conclusion that a technology shift is currently taking place for both otto and diesel engines. The potential for fuel consumption and CO_2 reductions is the driving force in both cases. The technology referred to is direct injection of the fuel – both in the petrol and the diesel case. An alternative technology is to use fully variable valve actuation (both lift and timing) in the petrol case. The reduction of pumping losses is the primary objective for direct injection as well as for the fully variable valve actuation. For diesel engines, faster combustion and reduced heat release are the main contributing factors to the reduction in fuel consumption that has been shown. The necessary alterations are vast regarding the combustion system and the aftertreatment of the exhaust gases for both petrol and diesel fuel. However, most of these modifications cannot be seen from the outside the engine. It has been assumed that the technology shift will be more or less completed in the time horizon that the study is considering.

The technology shift for the diesel-fuelled engines has been proceeding for a couple of years now and it is now about to be completed. This does not necessarily imply that the full potential for a reduction of the fuel consumption is exploited yet, since the concept will presumably be further developed for several years to come. The technology shift for petrol-fuelled otto engines has just recently begun and the authors foresee a transitional period about as long as for the diesel engines also in this case. An assessment of the available data on the vehicles that already have been introduced on the market implies that there is still a vast development potential for this new technology for petrol-fuelled engines. It is likely that this development will lead to that the difference in fuel consumption between cars with diesel and otto engines will decrease in the future (seen as an average consumption for the car population in each case). The slow penetration of low-sulphur petrol and the associated problems with aftertreatment devices might have contributed to the somewhat slower–penetration as the record shows today.

During the last couple of years, significant progress has been made on fuel cells. Several light-duty vehicles have been demonstrated by various car manufacturers and technology suppliers. Limited production of vehicles is about to begin within a few years. However, a large-scale introduction of fuel cell cars is not likely during this decade. The best choice of fuel for the fuel cells has not yet been determined. Hydrogen, methanol and reformulated petrol are some of the candidate fuels being discussed. Low or zero emissions is one of the driving forces for the use of fuel cells and the potential for high efficiency is the second primary driving force.

5.6.3 Otto engine

An important question regarding the use of alternative fuels is the level of optimisation of the engines to the fuels and consequently, the question rise whether the alternative fuels have specific advantages that could be utilised in the development. It is plausible that the full potential of these fuels has not been fully exploited today. Some estimations and assumptions are used to elucidate these issues. The assessment is based on the baseline petrol-fuelled engine. Consequently, the development of an engine for this fuel is described first.

5.6.3.1 Petrol

The engine technology used for the engine in a conventional drivetrain or a hybrid-electric drivetrain does not differ very much and therefore, the improvements of the otto engine are more or less general for this engine type. The petrol-fuelled otto engine is the base alternative and therefore, it is described first.

Today, most otto engines use the three-way catalyst aftertreatment to clean the exhaust. The injection for the new generation of engines will be made directly in the cylinder instead of in the inlet manifold (or inlet port) for the conventional engines. The Japanese manufacturer Mitsubishi introduced this technology first at the Japanese market and subsequently (since 1997), this technology has also been introduced in Europe in several of the car models of this company. The European car manufacturers have also developed similar technology and they have just recently introduced this technology, or else, they will introduce this technology in the near future.

The principal advantage by using direct injection on otto engines is that the fuel consumption is considerably reduced. The primary cause for this is that the so-called pumping losses are reduced due to less throttling (excess air). The consequence of this strategy is that a conventional three-way catalyst cannot be used to reduce the NO_X emissions and this is the main drawback of the concept. The most technology that seems to have the greatest potential is based on the storage of NO_X in the catalyst. At a proper interval, the catalyst is regenerated by running the engine in a rich mode for a few seconds so that the stored NO_X can be reduced in a similar fashion as in the three-way catalyst. The main problem with this type of catalyst is that they need low-sulphur or sulphur-free fuel, since sulphates are adsorbed more easily than nitrogen dioxide in the catalyst.

The emission control concepts for direct injection that are about to be introduced on the market do in fact tolerate a certain level of sulphur in the fuel but it is clear that they could operate better with low sulphur fuel. Furthermore, new catalyst concepts with greater reduction efficiency could be introduced if low-sulphur fuel was available. The sulphur problem has most likely delayed the introduction of the new technology compared to some previous expectations. However, it is likely that several new engine generations will be introduced in the near future, which presumably implies that the technology shift is about to accelerate somewhat.

The direct injection technology, as described above, is by no means the only possible technology to reduce the fuel consumption from otto engines, although this technology has tended to attract most of the interest lately. Several of the alternatives have almost the same potential as the direct injection technology. Some of the alternatives tend to be too expensive by today's standards to be realistic, but further development will certainly lead to that those alternatives will be of interest in the future. One example is that the difference in fuel consumption between the direct injection engine with lean-burn concept and the engine with electrically actuated valves (fully variable valve control) is not great. On the contrary, the difference in cost is considerable.

Direct injection improves the fuel consumption for an engine primarily at low load. Therefore, the potential to a *relative* improvement for a hybrid drivetrain will not be as great for these engines as for the conventional otto engine. This should be taken into consideration even if we only have accounted for this impact by a rough estimation.

Electric hybrid systems of parallel and series types are conceivable for the combustion engines. The parallel hybrid version of hybrids is the concept that has the highest commercial potential in the near and mid-term future. It has also been shown that this system has a greater potential to reductions in fuel consumption. Furthermore, the parallel hybrid does not need as sizeable battery as the series hybrid and consequently, the cost is lower for the former. A special variation of the parallel hybrid system is the system that Toyota uses in the Prius. This system has at least the same potential to a reduction of the fuel consumption as the "conventional" parallel hybrid but seems to be much more expensive. The combustion engine can be scaled down to achieve the same acceleration performance target as for the non-hybrid engine.

5.6.3.2 Alcohols

It is well known that the alcohols, ethanol and methanol, have specific advantages in otto engines – these fuels are simply "natural" otto engine fuels. First, the octane number is higher than for petrol, which is advantage for an engine where the maximum compression ratio is limited (knocking) by the octane level. Second, the alcohols have a higher latent heat of evaporation than petrol and since the energy content (per litre or per kg) is lower, a total evaporation of the alcohols would give a considerably lower temperature of the air-fuel mixture than petrol. A lower temperature implies a higher volumetric efficiency although this is somewhat counteracted by the fact that the alcohol molecules are smaller than the average petrol molecule and therefore they have a greater volume than the latter. However, the air-fuel preparation is not as simple as indicated, since the evaporation is not completed in the inlet manifold (with indirect injection). Nor is it so that all energy for evaporation is taken from the air, which might be expected. A considerable contribution to the evaporation comes from the hot surfaces in the inlet system (due to evaporation from the walls) and from the hot surfaces surrounding the combustion chamber (fuel impinging on the walls). The result is a lower volumetric efficiency and increased heat transfer. It is notable that alcohol engines have a higher volumetric efficiency than petrol-fuelled engines, which implies that the physical properties of the fuel have an impact. Yet another advantage for the alcohols is a slightly increased mass flow rate per unit of energy caused by the lower energy density of the fuel. This also gives a small contribution to increased power and efficiency.

The greatest problem with alcohol fuels in otto engines today is the substantial increase in emissions when the engine is cold started at low ambient temperature. This problem should be possible to solve in the future when new engine technology (e.g. direct injection) will be available. In a direct injection otto engine, the injection at higher load is made during the inlet phase. The objective with this strategy is on the one hand to obtain a homogenous charge and on the other hand to utilise the charge cooling effect due to fuel evaporation. In direct injection gasoline engines, an increase in power and torque can be obtained with this strategy compared to conventional port injection. With port injection, some heat for evaporation comes from the hot surfaces (before inlet valve closure) and this problem is (partly) avoided by using direct injection, hence the increase in volumetric efficiency in this case. It is plausible that alcohol fuels could have a further advantage in this respect, due to the increase in latent heat of evaporation. The cooling effect of the charge by direct injection also permits a higher compression ratio compared to conventional injection. In early experiments with direct injection of alcohols, several interesting observations of potential advantages with this system have been made. The enhanced cold start ability at low ambient temperatures seems to be the most important feature.

Perhaps the most interesting question about future alcohol engines with direct injection is whether these engines can be made fuel flexible (FFV). Even if this concept is a compromise in comparison to a dedicated engine, FFV is a concept that must be used during an introduction phase. It is well known that the injection system and air-fuel preparation in a diesel engine is not particularly well suited for FFV operation, since the differences in fuel density (volume) for the fuels in mind (diesel and alcohol) are vast. Furthermore, the time allowed for the injection phase and the air fuel preparation is very short in these engines. Although the parallel to direct injection otto engines might seem far-reaching, these engines are also limited by a short period for injection and fuel preparation in the lean-burn stratified charge mode. This is not a particular problem for conventional otto engines that have indirect injection, since the period for injection and fuel preparation can be longer due to the port injection. No particular study of modern[a]

[a] The development company FEV in Aachen developed a direct injection otto engine based on an old VW-concept of an direct injection petrol-fuelled engine. However, this concept was so vastly different from the new direct injection engines that no conclusions can be drawn from that concept that can be directly applied to modern direct injection engines.

direct injection systems on an alcohol engine is known to the authors but a recently published study from the Technical University in Zwickau shows the influence of direct injection with methanol fuel. The results from this study, which were performed on petrol, methanol and mixtures of these two fuels, indicated that there should be a fair chance of success for an FFV concept with direct injection. The model tests made showed that the penetration of the spray decreases with methanol, due to the difference in physical properties in comparison to petrol fuel. In general, the penetration should increase when methanol is used but the better atomisation and the increase in evaporation counteracts this trend. This should be a considerable advantage, since wall-wetting is a particular problem in direct injection engines (especially at cold starts). In summary, we have anticipated that the future alcohol-fuelled otto engine will be equipped with direct injection and that it will be a FFV type. Instead of using M85 and E85 fuels, we have anticipated "clean" alcohols (besides denaturants), i.e. M100 and E100. The vastly improved cold start properties of the direct injection should enable blending with petrol. *By using this fuel strategy, the option of using the same fuel quality for both alcohol-fuelled diesel and otto engines is created under the condition that the diesel engines do not need blending with an injection improver.*

In the future, NO_X reduction on petrol fuelled direct injection otto engines will most likely be achieved by so-called NO_X storage catalysts. These catalysts are very sensitive to sulphur poisoning and consequently, since alcohols are sulphur-free fuels, they have a fundamental advantage in this respect over petrol and diesel fuel. A proposal for the reduction of sulphur levels in both these fuels was made by the EU prior to the publishing of this report[b]. A NO_X storage catalyst must be regenerated periodically from the stored NO_X. This is achieved by running the engine under rich condition for a short period (typically a few seconds). During this regeneration, the reduction of NO_X is accomplished by utilising CO and HC in a similar manner as for "normal" three-way catalysts. This is possible, since there is no oxygen excess during the rich "spike". It is known that the composition of the HC emissions is important to achieve a high NO_X reduction (regeneration) and the question arise whether the unburned "HC" emissions from alcohol fuels would work as a reductant. Limited results from such catalysts and lean-NO_X catalysts indicate that alcohols, and methanol in particular, has better properties than HC from petrol and diesel fuel regarding NO_X regeneration. Another advantage of alcohol fuels in direct injection otto engines would be the foreseen reduction in soot and particulate formation in comparison to petrol. The particulate formation in direct injection petrol engines is a particular problem (especially at low ambient temperatures), since these emissions are approaching those of modern diesel engines *without* particular filters.

5.6.4 Diesel engine

A diesel engine optimised for diesel fuel is the basis for diesel engines fuelled with alternative fuels. No decisive differences in efficiencies have been anticipated for the fully developed diesel engines running on alternative fuels.

5.6.4.1 Diesel fuel

More than a decade ago, direct injection was introduced in diesel engines for passenger cars but the technology is not new, since it was introduced in a larger scale in engines for heavy-duty vehicles more than 50 years ago. It could be of interest to note that of the three engines that were introduced in the 1988-1989 timeframe (Audi, Rover and Fiat), only one of these (Audi) was a commercial success. Later, the technology of this engine was passed

[b] The low-sulphur diesel fuel used in Sweden is below the future limit of 10 ppm.

on to other companies in the VW group, thus providing these car manufacturers with a lead over their competitors. However, it has not been until the last three years that the development has accelerated and this is attributable to the new high-pressure injection technology (common rail, high-pressure rotary pumps and unit injectors). It is well-known that direct injection for diesel engines demand very high injection pressure to utilise the full potential for reducing emissions and fuel consumption.

The greatest obstacle for diesel engines is still the NO_X and particulate emissions. Particulate traps are now being commercialised by one car manufacturer (Peugeot-Citroën) while other manufacturers have announced that they are developing filter systems that will be mature for production in the 2002 – 2003 timeframe. The technology for reducing the NO_X emissions will not be introduced in larger scale until low-sulphur fuel is available on several markets in Europe. Although Sweden has a diesel fuel with very low sulphur level (<10 ppm), the market for diesel cars in Sweden probably is too small to motivate the early introduction of this technology here. It could be noted that the most promising technology for NO_X removal (NO_X adsorber catalyst) is more or less similar for both otto and diesel engines in the future. Therefore, the NO_X emissions will be on a similar level for these engine types in the future.

In order to fulfil future NO_X emission limits – that are anticipated to be significantly stricter in the future for diesel-fuelled cars, presumably similar to petrol cars – a NO_X storage catalyst will be necessary. There is some increase in fuel consumption associated with the NO_X regeneration (this regeneration could be simultaneous to the regeneration of the particulate filter). An increase of the fuel consumption by 2% due to the regeneration[c] has been anticipated, although recently published data indicate that this penalty might be reduced to less than 1%, provided that the sulphur content is below 10 ppm. An increase in the fuel consumption of the same order as above (2%) has also been anticipated for the diesel engines fuelled by other fuels than diesel fuel, since these engines must use the similar type of catalyst.

5.6.4.2 Fischer-Tropsch diesel fuel (FTD)

A synthetic hydrocarbon fuel, such as the Fischer-Tropsch diesel fuel (FTD), has several properties that differ from conventional diesel fuel. The formation of NO_X and particulate emissions is reduced, although these problems remain as an inherent feature of the diesel engine. The FTD fuel is essentially sulphur-free, which is a considerable advantage regarding the use of effective exhaust aftertreatment. Furthermore, the cetane number is high for the FTD fuel, which is a considerable advantage for contemporary diesel engines. Since the fuel is also free of polycyclic aromatic hydrocarbons (PAH), olefines and cycloparaffines, the emission components (possibly) causing health hazards should (presumably) be considerably lower than for Swedish Environmental Class 1 diesel fuel (EC1) and European diesel fuel. The density for FTD is lower than for both EC1 and conventional diesel fuel, which would reduce the engine power unless countermeasures are taken. The FTD can be readily mixed with conventional diesel fuel and, possibly, it could have a higher value as a blending component in such use than used separately. Blending could also be interpreted as certain fuel flexibility for the FTD fuel.

5.6.4.3 DME

DME is a "natural" fuel for diesel engines due to the exceptionally high cetane number. Therefore, the same efficiency as for diesel fuel is possible for a diesel engine adapted for DME. DME is non-toxic and should have an inherent property of significantly reducing the

[c] Desulphatisation, however small for low-sulphur fuels, is anticipated to be included in this figure.

toxic emissions in the exhaust in comparison to conventional diesel fuel. A significant reduction of the NO_X emissions for DME in comparison to diesel fuel has been found in several studies. Particulate formation is largely avoided with DME in comparison to hydrocarbon fuels. DME also provide the opportunity for using higher rate of EGR, which further reduced the NO_X emissions compared to diesel fuel. Deducing from the limited number of studies available, it seems that the use of a NO_X reducing catalyst should be a viable solution for this fuel. Since DME is sulphur-free, the use of effective aftertreatment devices in general is more easily facilitated with DME than with sulphur containing fuels.

A particular problem with DME as a motor fuel is the fuel injection system. Several problems arise from the physical and chemical properties of DME. DME attack most elastomers and therefore, proper seals have to be developed. This problem is also evident in the distribution system. Furthermore, DME has a very low lubricity and thus, one solution would be to develop proper additives to improve the lubricity. Another solution would be to take measures to the injection system itself (surface treatment, etc.) to ensure that a fluid with very low lubricity can be tolerated. Anyway, the long-term durability of the high-pressure injection system has to be secured before an introduction on the market. Recently, new injection systems are being developed with this purpose and the results available so far appear promising. Although emission results also look very promising, much basic research is needed to utilise the full potential for emission reductions compared to diesel fuel. In summary, the large-scale commercial introduction of DME will not happen in the near future. The next objective might be to aim for a small-scale demonstration fleet with DME.

A DME engine cannot be made fuel flexible, without too large compromises and at a reasonable cost. This is of course a significant disadvantage during an introduction phase and, in particular, this is of importance for general use of this fuel, as in case of passenger cars.

5.6.4.4 Alcohols

The experience from heavy-duty vehicles has shown that ethanol and methanol could be used in diesel engines. An external ignition source, such as a glow plug, is foreseen to avoid the use of an ignition improver. Even if the development of glow plugs for diesel-fuelled passenger cars has been rapid, it is likely that further development will be necessary to increase the reliability and the useful life (i.e. the life of the engine) for the use in alcohol engines. The necessity to use an external ignition source for the alcohols is a significant disadvantage in comparison to other alternative fuels, such as DME and FTD.

The NO_X emissions will be lower for the alcohol engines than for diesel fuel and simultaneously the rate of EGR can be increased, which further reduces the NO_X emissions. In general, the soot and particulate formation is significantly reduced with alcohols, although an increase in particulate formation has been seen with high rates of EGR on a heavy-duty ethanol engine. It is not clear if the same problem will be seen for methanol but, in theory, this molecule should be better in this respect than ethanol due to the absence of carbon-carbon bonds and a higher content of oxygen. The application of a NO_X reducing catalyst should be easily facilitated on methanol according to limited test data, due to the excellent properties of methanol as a reducing agent. Ethanol should also be possible to use in combination with this catalyst technology, although ethanol is less suited as a reductant in a catalyst than methanol.

As in the case with DME, there are no practical opportunities to make alcohol diesel engines fuel flexible.

5.6.5 Fuel cells

Fuel cell drivetrains can be either of the "direct drive" or series hybrid types. A parallel hybrid system is not possible for a fuel converter that does not produce any mechanical work.

The direct fuel cell drive system has no large energy storage and therefore, the fuel cell stack has to be sized to correspond to the desired performance level for the vehicle. Furthermore, no regenerative braking can be used (due to the limited battery capacity). Therefore, the total efficiency will be somewhat lower than a hybrid fuel cell system (energy storage). There are also other concerns. If, for example, the start period cannot be sufficiently short, there are no practical possibilities to do without a larger battery capacity. Under these conditions, the direct drive fuel cell system would have to be abandoned in favour of the fuel cell hybrid. It has been shown that hybrid fuel cells provide higher efficiency than the direct drive systems and therefore, it is likely that the hybrid version will be favoured over the other version.

Hydrogen is the preferred fuel for the fuel cell stack, since no reforming of this fuel is necessary. However, the distribution, refuelling and storage of hydrogen in the vehicle is a significant problem for hydrogen. Therefore, other fuels are being considered.

Both methanol and DME could be used in a fuel cell. Today, there is almost no experience available in the public domain database about the use of DME in fuel cells so all statements must be based on theoretical considerations. Reforming is somewhat easier and more energy efficient in the methanol case. Furthermore, methanol is a liquid fuel that is less costly to distribute. A major advantage for DME is that the production can be achieved with a higher efficiency than in the methanol case.

5.6.6 Fuel cell – internal reforming (DMFC)

Today, there is little information available about direct methanol fuel cells (DMFC) and their performance. Up to now, the reported efficiency for these fuel cells has been very low (seldom more than 15%) but it could be expected that a maximum efficiency of more than 40% is possible with new breakthrough technology. Significant improvements of this system have been made recently, and therefore, this alternative cannot be overlooked. However, it is not clear whether the expectations for the DMFC fuel cell can be fulfilled. On the condition that a high efficiency can be achieved in the future, this option would be very interesting, since it is a notably simpler system than a fuel cell with reformer. The DMFC technology can only be applied on methanol and consequently, other fuels are of little interest for DMFC.

5.7 Handling, regulations and safety

Since methanol is toxic, the issues concerning handling and distribution require a specific analysis. Although both petrol and diesel fuel likewise are toxic when ingested, there is a long experience from handling and use of these fuels. Consequently, the number of fatalities is low regarding such effects. There might also be other safety issues, e.g. fire and explosion that have to be taken into account when a new fuel is introduced on the market.

DME is not toxic, as methanol, petrol and diesel fuel but, since this fuel is gaseous under normal pressure and temperature, safety issues concerning fire and explosion have to be addressed.

5.7.1 Health and environmental impact from methanol

The knowledge about health effects from methanol are reasonably well understood but the knowledge among laymen is relatively limited, since methanol is not a widespread fuel in any of the EU member countries. Therefore, it is necessary to include a short summary of these effects. In general, the public is only confronted with the problem of the toxicity of methanol when fatal ingestion of methanol has been the case. Usually, people that have been subjected to methanol have thought that they have been drinking ethanol.

Since methanol is a commodity chemical and it is traded worldwide in large quantities, the regulations for this type of handling are well developed. Therefore, it has not been considered necessary to summarise the regulations that govern this handling. Instead, the issues that might arise when methanol is distributed to the public are of main interest in this study. A similar approach has been used for methanol production. As always with technical processes, there might be issues concerning the working environment, but these issues are relatively limited and they are well taken care of today anyway.

Methanol is readily distributed more or less uniformly in the body regardless of the type of exposure. Since methanol is fully soluble in water, the distribution in the organs is directly proportional to their water content. Methanol is also formed in the body by natural metabolic processes and it is present in low concentration in the diet, as well. Consequently, there is a natural "background" level of methanol in the human body. An exposure to methanol – or other substances that can be metabolised to methanol – will increase the methanol content in the body. After exposure and distribution of methanol in the body, methanol is metabolised in the liver and thus eliminated from the body. Methanol is metabolised according to the following metabolic chain: methanol; formaldehyde; formic acid; formate; and finally to CO_2. The toxicity of methanol is due to formate. Since the metabolism of formate to CO_2 is the limiting process, the accumulation of formate will be the case when exposure levels are high. This will lead to metabolic acidosis, a process that lowers the pH of the blood. Formate can lead to ocular toxicity and metabolic acidosis might be lethal if left untreated. It should be noted that there are several possible treatments available but these methods are not referred to here. In general, it can be concluded that the mechanisms of the toxicity of methanol and its metabolisation are well understood. Methanol is neither mutagenic, nor carcinogenic.

Some typical levels of methanol in the body (calculated for a 70-kg person) due to various routes of exposure is shown in **Table 20**. As can be seen in **Table 20**, minor exposures of methanol seldom lead to any significant increase of methanol concentration in the body. As a comparison, it can be concluded that ingestion of diet that contains the aspartame sweetener also increases the methanol content in the body. A lethal dose of methanol is some 500 times higher than the other exposures shown in the table (50 000 mg compared to 100 mg).

Table 20. Exposure of methanol for a 70-kg person (source: Statoil, Methanex)

Exposure/dose	Added body burden of methanol (mg)	Reference
Background level in a 70 kg body	35[a]	Kavet & Nauss, 1990
Hand in liquid methanol, 2 min	170	IPCS, 1994
Inhalation, 40 ppm metanol for 8 hours	170	IPCS, 1994
Inhalation, 150 ppm i 15 min	42[b]	Kavet & Nauss, 1990
Aspartame sweetened products 0,8 litre diet beverage	2 – 77 42	Stegnik et al., 1984 Kavet & Nauss, 1990
Ingestion of 0,2 ml of methanol	170	
Ingestion, 25-90 ml of methanol	~21 000-71 000 (lethal)	IPCS, 1997

Notes:

Estimated from 0,73 ml/liter i blood

Assuming 100% absorption in lung (60-85% more likely)

A concluding remark about the levels of exposure is that "normal" exposures hardly could cause a lethal dose of methanol. Some unintended and intended exposure (i.e. ingestion) could result in lethal doses. Statistic information from the USA shows that of the approximately 10 cases of lethal exposure that are registered every year, about 50% are related to suicids. However, in many of the other cases, the reason is unknown, which could render an even higher percentage of suicide. Whether these fatal cases could be influenced (increased or decreased) by an increased use of methanol (i.e. widespread use) is pure speculation.

5.7.1.1 Inhalation and skin exposure

Longer exposure to methanol through inhalation and skin penetration will give similar toxic reactions as ingestion, since methanol is readily distributed in the body regardless of type of exposure. The risk of high exposure due to inhalation seems to be limited due to the low concentrations of methanol vapour in the air during normal handling of methanol. This is also a general feature for skin penetration, as only extreme carelessness would lead to high exposure.

Both petrol and methanol penetrate through the skin but the absorption is faster in the methanol case since the methanol molecule is smaller than the (average) petrol molecule. On the other hand, methanol evaporates faster from the skin, which reduces the total exposure, since the contribution from inhalation will be far less than from skin penetration. Methanol is not considered carcinogenic or mutagenic in skin exposure (or in other types of exposures). On the contrary, petrol is considered as carcinogenic, primarily due to its content of benzene[d], a known carcinogen. It should be pointed out that high exposure to petrol poses a risk of almost similar magnitude but in this case, common practice is well developed. Although the risk of "normal" exposure due to skin penetration is small, exposure for liquid methanol for a long period of time, e.g. through the use of gloves or boots soaked with methanol, might lead to high concentrations. It is not likely that the exposed people (e.g. mechanics and technicians) would tolerate such exposure to petrol

[d] It should be noted that the benzene content of petrol has been continuously decreased during the past years. However, petrol corresponding to the EU regulation for 2005 still contains benzene.

without taking countermeasures, but in the methanol case, proper information might be necessary to avoid such fates.

Inhalation of methanol is the most common exposure. Exhaust emissions from vehicles, evaporation from the tank and from spill and open containers are examples of exposures due to inhalation. A worst-case calculated exposure of 150 ppm methanol during 15 minutes, as shown in **Table 20** above, would only slightly increase the dose by 0,6 mg per kg of body weight (42 mg for a 70-kg person). This dose is on a similar level as normal ingestion of fruit, vegetables and alcoholic beverages (0,3 – 1,1 mg/kg). Most exposures to methanol vapour in the air would result in far lower doses than in the mentioned case.

5.7.1.2 Use of methanol in windshield washer fluid

The use of methanol in windshield washer fluid might be of interest to comment on. Methanol is used in this application in North America, whereas isopropanol, and in some cases ethanol, is used in Sweden and Europe. The use of alcohols in windshield washer fluid is to avoid freezing. There are few alternatives to alcohols if the requirements of primary importance in this application have to be fulfilled.

The use of methanol in windshield washer fluid is an example of widespread use of methanol by the public, although the concentration usually is less than 50%. This fluid is handled in a similar way as windshield washer fluid in Europe. It may appear obvious that windshield washer fluid should not be ingested, regardless of which alcohol is used as freeze protection, as the fluid contain other substances than methanol and water. It is evident that methanol used in this application can be handled without significant fatalities in Northern America. In addition, it seems as the handling, storage, etc. of this fluid does not pose particular problems regarding the risk of fire or explosion. Health effects of methanol from windshield washer fluid could be expected due to evaporation and inhalation. However, it appears as the concentration of methanol in urban air is very low and therefore, the exposure to methanol from this use seems to be well below a safe level.

In a Canadian report, the possible contribution from methanol from windshield washer fluid to ozone formation was investigated. Ozone is formed by the reaction of volatile organic compounds (VOC) and oxides of nitrogen (NO_X). Sunlight aids these photochemical reactions, thereby increasing the ozone levels during summertime. Although alcohols are not very reactive compared to hydrocarbons in vehicle exhaust, high concentrations *might* give a contribution to the ozone formation under certain circumstances. According to the mentioned report, windshield washer fluid might contribute to the ozone formation. However, the estimations are based on an analytical methodology only, as no direct measurements were available. It is interesting to note that ethanol and isopropanol have higher specific reactivity than methanol. Consequently, the use of methanol instead of these fluids would actually be beneficial from an ozone formation point of view.

5.7.1.3 Health and environmental risk of DME

Although DME was not the main subject of this study, it could be of interest to mention something about the health and environmental fate of this fuel. DME is not toxic, nor carcinogenic or mutagenic. DME is commonly used today as an aerosol propellant. Due to this use, comprehensive investigations have been carried out about the health effects of DME. Apparently, no health risks seem to occur. Consequently, DME has a competitive advantage over many other fuels in this respect (including methanol).

5.7.2 Fire and explosion danger

Methanol is classified in a similar class as petrol, i.e. class 1, implying that the flash point is so low (<-21°C) that fire and explosion danger must be considered. Therefore, similar regulations are enforced as for petrol but with different marking. Within the framework of the so-called PNGV programme (Partnership for a New Generation of Vehicles) in the USA, the issues of potential danger with alternative fuels has been studied. These are common issues when widespread introduction of a new fuel is being discussed. In a report by the federal laboratory ANL, the potential fate with various fuels has been investigated.

The lower vapour pressure of methanol in comparison to petrol implies that the possibility of reaching a flammable mixture in open areas is lower than for petrol. This advantage is further enhanced by a lower density for methanol vapour (1,1:1) than for petrol vapour (up to 4:1) in relation to air. Still there is a risk for ignition under these circumstances, for example in calm weather, which motivate the fire classification.

If methanol vapour is ignited, the heat release rate is significantly lower than for petrol. The lower heat of combustion and higher heat of evaporation leads to that methanol burns with a speed of only a fourth of the speed of petrol. Consequently, the energy release is only about one-fifth to one-eighth of the level for petrol.

Methanol is combusted with an almost invisible flame in sunlight, in contrast to petrol and diesel fuel that both have a yellow flame. A yellow flame indicates that soot is formed, which is not the case for methanol. The oxygen content an absence of carbon-to-carbon bonds in methanol is the reason for the "clean" burning compared to hydrocarbon fuels. A lower heat radiation in a methanol fire is the result of the less visible flame. Lower heat radiation is an advantage, since the ignition of other flammable materials near the fire is less likely. Furthermore, fire fighters can approach the fire closer. However, this also poses a certain potential risk due to the almost invisible flame, as fire fighters might be attempt to get too close to the fire. Additives to increase the flame luminosity have been discussed, but it is uncertain if such additives are necessary for vehicle applications. In a vehicle fire, there are many other materials that burning simultaneously with methanol will create a visible flame.

Methanol is fully soluble in water and this is of an advantage from a fire fighting point of view. In contrast, petrol and diesel fuel will float on top of water, with the potential for steam explosions and further spread of the fire. Some previously used foams were not effective with alcohols. However, new types of multipurpose foams work both with alcohols and petroleum fuels.

The properties of methanol regarding fire hazard have been considered an important feature in motor sports, e.g. in the US CART series, where methanol is the prescribed fuel. The US EPA calculated in a report carried out in 1990 that the substitution of petrol by pure methanol (M100) could give a 95% reduction of the hazards by fire. The question remains whether this figure would still be valid for the vehicle fleet of today.

Petrol storage (tanks, depots, etc.) generally gives such a high vapour pressure (except at very low ambient temperatures) that the mixture is richer than the rich flammable limit. For diesel fuel, the vapour pressure is lower than the lower flammable limit and consequently diesel fuel pose no risk of explosion under these conditions. In contrast to the two other fuels, methanol (as well as ethanol) has a vapour pressure that could cause an explosion in the fuel container at "normal" ambient temperatures. However, since alcohols are more polar fluids than petrol, the risk of ignition by static electricity is considered very small. An explosion initiated by an ignition source outside the tank is possible. Although such explosions have *not* been shown particularly dangerous in experiments, countermeasures have to be taken to avoid such risks. Flame arresters in the pipes to and from tanks are necessary. This technology is well developed and thus, methanol storage can be considered safe regarding the risk of explosion. However, it is essential that countermeasures, as described, be used to avoid public perception of methanol as a dangerous fuel in this respect.

In the ethanol-fuelled city buses used in Sweden (e.g. Stockholm), fires in the engine compartment have been frequent. This is in contrast to the situation for passenger cars where the general opinion is that the risk of fire in a vehicle is less for methanol than for petrol. Without conducting a thorough analysis of the causes of fire in buses, two factors could be of importance to note. First, diesel fuel is the reference in the bus case is diesel fuel and this fuel is generally safer than petrol in such applications. Second, ethanol fuel pipes have been prone to leaks, primarily due to cavitation of the pipes. The hazard for a fire if a high-pressure fuel pipe is leaking is obvious. Consequently, buses are usually equipped with automatic fire extinguishers. However, there is no reason to believe that the experiences from buses are applicable to cars and consequently, the conclusions above that methanol used in passenger cars with otto engines would be safer than petrol are still valid. It could be hypothesised that methanol-fuelled diesel engines would behave in a similar way as the city buses mentioned above regarding fire hazard. However, one also has to note that modern high-pressure fuel injection systems have changed. In the future, common rail injection and unit injectors will replace rotary pumps for cars with diesel engines. These injection systems do not have the problems with cavitation, as the systems used in the buses have experienced. Consequently, there is no reason to believe that methanol-fuelled diesel engines should pose any specific hazards for fire in future passenger cars.

DME has not been investigated thoroughly in this study regarding its hazards for fire and explosion, since no experience is available from widespread public use of this fuel but some comments are nevertheless included. DME has similar physical properties as LPG and consequently, some of the experiences from LPG can be applied to DME as well. DME burns with a visible flame and has less flame radiation than petrol. Containers (tanks) for DME are stronger than petrol tanks and therefore, the risk of leak in a collision and due to other damage is less. The dispersion of DME is faster than petrol due to the low vapour density (1,5:1), but on the other hand, the formation of vapour clouds is faster. Likewise, the persistence of clouds in still-air is more likely than for petrol. DME is likely to have a greater explosion hazard than petrol if it is spilled, due to the wide detonability limits. The flammability risk is higher than for petrol. In summary, it is somewhat difficult to assess whether DME would pose higher or lower risk for explosions and fire compared to petrol. It is likely that DME must be treated as a more dangerous fuel than petrol in this respect.

5.8 Distribution

5.8.1 Release of methanol during distribution

The distribution of methanol in general could include various different transportation modes. In general, methanol of fossil origin is produced at remote sites. Thus, the distribution could include sea, rail and truck transport. Pipeline distribution is not likely other than in rare occasions. During distribution methanol could be spilled to surface water, ground water, soil and evaporate into the atmosphere.

Spill of methanol to land, water and the air evidently occur, since methanol is one of the mostly traded chemicals in the world (No. 3). Calculations have been carried out in the USA to estimate the total release of methanol. Some results for USA have been compiled by AMI (American Methanol Institute) and these results are shown in **Table 22**.

Table 22. *Estimated release of methanol in the USA (recalculated in SI units)*

Release to:	1992[a] (ton/år)	1993[b] (ton/år)
Atmosphere	88 500	77 900
Underground injection	12 200	12 700
Land	1 500	800
Water	7 400	4 500
Total releases	***109 600***	***95 900***

Notes:

[a] Source: US EPA, 1994

[b] Source: Zogorski, et al. 1997

The results in **Table 22** show that the release to the atmosphere dominate over the other releases. In a spill to land and water, the evaporation will be less and in this case, the distribution of the release is shifted. An increased use of methanol would of course increase the releases of methanol. On the other hand, the release of conventional fuels of fossil origin would decrease if these products were substituted by methanol. As will be shown below, the health- and environmental impact would presumably decrease is this substitution was carried through. The emissions from vehicles are not discussed in this section.

Table 23. *Estimated half-lives for methanol and benzene*

Medium	Methanol (days)	Benzene (days)
Air	3-30	2-20
Soil	1-7	5-16
Surface water	1-7	5-16
Ground water	1-7	10-730

Note:

[c] Original source: Howard el al., 1991

Methanol molecules are ubiquitous (naturally present) in the environment as a result of various biological processes in plants, microorganisms and animals. Consequently, the biodegradation of methanol is generally faster than for fuels of crude oil origin, as these substances are not naturally present in the nature. In **Table 23**, a comparison between the half-lives for methanol and benzene, a common element in petrol. Since petrol and diesel fuel are mixtures of various hydrocarbons, data on the (average) half-life on these fuels are scarce, so data for benzene are generally used instead. The results in **Table 23** show that the half-lives in general are significantly shorter for methanol than for benzene in most cases, except for release to air. It should be noted that benzene is a rather reactive chemical compound in the air (i.e. contribution to ozone formation).

The release of crude oil or oil products (such as petrol and diesel fuel) to water and soil generally cause great impact on the environment (at least on a local scale). Catastrophic oil spills are regularly occurring on a smaller or greater scale and the environmental impact is sometimes great, as for a spill in a sensitive area (e.g. Exxon Valdez in Alaska). Accidents with tank trucks and rail cars can happen and in such cases, spill to soil and water is often the case. The question is what the consequences of a methanol spill would be in similar cases, as described previously.

Methanol is readily soluble in water in contrast to oil products that have a very limited solubility in water. Therefore, the acute toxicity will be noted in direct association to the spill area only, but below a certain concentration methanol is not toxic. Instead, some life forms will metabolise methanol, i.e. use the methanol as nutrition. Such an example is that methanol is used today for just this purpose, i.e. as nutrition for the microorganisms used in wastewater treatment (denitrification, i.e. removal of nitrates).

Spill of methanol to surface water will result in a fast dispersion due to the infinite solubility in water. At a concentration level of less than 1%, it is no longer toxic and therefore, the acute effect is only local. Estimations of a spill of 10 000 ton of methanol in the sea show that a concentration would be less than 0,36% within less than one hour. A similar release from a coastal pier would result in a concentration less than 1% after 2 hours and 0,13% after 3 hours. The impact is relatively small and local in both cases. One can easily envision the ecological consequences if similar spills of oil products would occur.

Methanol is dissolve very fast in the ground water after *a spill on land*, and this might be a drawback in comparison to petrol and diesel fuel, where the diffusion is not as fast. In a worst-case situation, this could lead to a faster contamination of water supplies. However, it is not likely that the diffusion would be so fast that precautionary measures could not be taken to avoid the distribution of contaminated drinking water. Again, the advantage of faster biodegradation limits the damage to a local scale. Similar situation might occur for spill in surface water but in this case methanol is dissolved and diluted even faster.

There is always some *release (evaporation) of methanol to the air* from spill to water and soil. The question is whether this could pose any risk for health and environment. Since the equilibrium between air and water is shifted towards the water, vaporisation is minimal in this case. The vaporisation from spill to (dry) soil tends to be significantly greater than from water and in this case, this is a faster release than for petrol. The vapour pressure is lower than for petrol and likewise, the vapour density is lower for methanol vapour than for petrol vapour. Consequently, methanol vapour is dispersed faster in the atmosphere than petrol vapour. Although methanol vapour most likely has a greater acute toxicity than petrol vapour at the same concentration, this is compensated by the faster diffusion.

In summary, methanol should have significant advantages compared to petrol regarding releases to soil, water and air (and compared to diesel fuel in the two first cases).

5.8.2 Material compatibility and cost issues

Issues regarding material compatibility and associated cost have been investigated in earlier studies by the author's organisation. One example is a study by Ecotraffic for the Swedish Governmental Agency KFB (today part of the agency Vinnova). Another example is a study by the consultant company EA Engineering that was carried out for AMI.

The relatively new report by EA Engineering provides an overview of the distribution of methanol and identifies the necessary measures compared to the distribution of petrol. The report concentrates on the cost for upgrading an existing distribution system. The authors concluded that a new refilling unit (replacement of a petrol tank of 10 000 gallon) could be installed for a cost of approximately 10 000 USD. Upgrading of an existing unit could cost 19 000 USD. In both cases, the authors concluded that the incremental cost was relatively low. In Sweden, several oil companies have rebuilt existing tanks to be compatible with motor alcohols. This is now a common procedure in rebuilding tanks (new tank linings, etc.) and when new refilling stations are built, they are made alcohol compatible. However, the policy between companies is slightly varying, since some distributors upgrade to tolerate *both* ethanol and methanol while others are satisfied with ethanol compatibility alone. The extra investment to be able to tolerate methanol as well is considered small.

A Swedish company of fuel dispensers, Identic, is currently developing a new dispensing system for methanol. In a press release from this company and from the partners in the Methanol Fuel Cell Alliance (MFCA), this work is briefly described. Besides the press release, not much information is available about this development yet. Within the framework of a contract between MFCA and Identic, the AT-1 dispensing system currently used for diesel buses and other heavy-duty vehicles will be further developed for the use of methanol. A prototype system has been installed in the Necar 5 prototype fuel cell car by DaimlerChrysler. It is interesting to note that if a fleet test on methanol-fuelled vehicles is initiated in the near future, the proper tank and dispensing system will be available.

It could be of interest to show the potential incremental cost of distributing methanol in comparison to petrol distribution. Evidently, there is an additional cost related to methanol, as the discussion above has indicated. First, this is due to the use of more expensive materials in the methanol case. Second, an increase in the fuel volume has to be taken into account, as methanol has low energy density. In comparison to petrol, the volume increase would be some 40% for ethanol and 85% for methanol. Some of the associated cost is related to the volume increase but some cost in the distribution is independent of the volume and will not be affected by fuel switching. In a previous study by Ecotraffic, the incremental cost of distributing ethanol and methanol was estimated. Since this work was completed in 1996, the cost was representative for the situation in mid 1990's. Presumably, the cost would be somewhat higher today, primarily due to inflation. It should also be noted that the cost was estimated for a fully developed system. For rebuilds and during an initial phase, the cost will most likely be higher but on the other hand, such cost is not relevant.

The results from the mentioned study are shown in **Table 24** but in Euro (€) compared to Swedish crowns (SEK). The conversion factor from SEK to Euro has been set to 10. As can be noted in **Table 24**, the distribution cost for substituting one litre of petrol is 11,3 €c for methanol and 10,3 €c for ethanol, i.e. an advantage of 1 €c for ethanol. As reference, the cost of distributing petrol was estimated to 8,5 €c per litre. Consequently, the incremental cost of distributing methanol is 2,8 €c per litre petrol substituted. If the fact that the engine efficiency can be increased by using an optimised methanol engine in comparison to a petrol engine would be taken into account, the incremental cost could decrease marginally.

Table 24. Distribution cost for alcohols (€c per litre petrol equivalent)

Distribution stage	Methanol	Ethanol
Sea transport	1,1	0,85
Depot	1,7	1,6
Land transport	1,3	1,0
Refuelling station	2,7	2,35
Charge, distributor	2,0	2,0
Charge, station	2,5	2,5
Total distr. cost	***11,3***	***10,3***

The incremental cost of substituting petrol (or diesel fuel) with DME is significantly higher than for methanol simply because DME has to be handled under pressure. The cost of DME distribution was calculated in a previous report by Ecotraffic. Since DME is a fuel for diesel engines, the comparison was made with diesel fuel. However, as the previous figures for motor alcohols were compared with petrol, the results in the mentioned report have been recalculated for a substitution of petrol. The same conversion factor of 10 between € and SEK has also been used. The recalculation gives a cost of 14,2 €c per litre of substituted petrol. This is almost 3 €c higher than for methanol and nearly twice (5,7 €c) the difference between methanol and petrol. As diesel engines are more efficient than otto engines, the comparison with petrol would be more favourable if this was taken into account. The comparison with methanol depends on whether the methanol engine is of the otto type or diesel type. As shown above, diesel engines can be adapted to methanol as well as otto engines. If the comparison between DME is made with diesel fuel, the difference amounts to 7,1 €c. The greater difference in this case is due to the higher energy content of diesel fuel in comparison to petrol. This give a lower distribution cost per energy unit for diesel fuel compared to petrol and therefore, the comparison between DME is less favourable for DME than the previous comparison with petrol.

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6.3 Abbreviations and acronyms

ATK: Aviation Turbine Kerosene

CGP: Co-generation plant

DHC: District heating central

EB: Electric boiler

HFO: Heavy fuel oil

HP: Heat pump

HW: Hot water boiler

HX: Heat exchanger

LN: Light naphtha

LFO: Light fuel oil

LPG: Liquid petroleum gas

NG: Natural gas

ODt: Oven Dry tonne (= dry biomass)

VF: Vattenfall (a Swedish energy company)

WRD: Wide range distillate

Appendix 1. Steering committee protocols

Notes from the meeting of the steering committee no 2 of the BioMeeT-II Project

The meeting was held at Hotel Swania, Trollhättan, May 28th 2001, from 11.00 – 14.00.

Present at the meeting were:

Gert-Inge Andersson,	Trollhättan kommun
Maria Gerd,	Trollhättan kommun
Barbara Sandell,	Trollhättan kommun
Bengt Sävbark,	Ecotraffic ERD[3]
Tomas Ekbom,	Nykomb Synergetics
Clas Ekström,	Vattenfall, Stockholm
Einar Bjarne,	Vattenfall, Trollhättan
Claes Fredriksson,	University College Trollhättan/Uddevalla
Tommy Björkqvist,	SAAB
Lars Thoreson,	SAAB

§ 1 Introduction
Maria Gerd and Gert-Inge Andersson introduced the meeting, greeted the participants welcome to Trollhättan. The meeting in particular greeted Tomas Kåberger welcome as a new co-ordinator from Ecotraffic. The meeting further acknowledged that the meeting had been properly called and agreed on the proposed agenda.

It was noted that Henrik Landälv, Mats Johansson, Roland Ax, Lars Niklasson, and Gunnar Gidestam had announced they were unable to attend this meeting.

§ 2 Background
Bengt Sävbark explained the recent history of the project application and why the decisions had been delayed and the project had fallen behind the original time schedule. The project has been placed into a cluster of related projects. In the cluster is a project from Ireland, University of Limerick, aiming to "demonstrate the use of blends of waste cooking oil with biodiesels and mineral fuel for engines and heating the county council at Mallow Country Cork". There is also a project from Austria in the cluster, Abwasserverband Hall in Tirol –Fritzens (AWV HTF), entitled "Energy from waste fats-pilot project of waste fat recycling and synergetic processing into biodiesel and biogas as renewable energy sources in the Alpine regions of the Tyrol, South Tyrol and in Catalonia.

§ 3 The conditions and tasks for the project
Tomas Kåberger started by summarising the results of the previous studies that had shown that there were technological possibilities to build a plant for fuel and heat co-generation and that there were opportunities to add electricity generation to such a plant. In the previous studies it was also shown that there were biomass resources in the region that were available for energy purposes. There were potential markets for heat and gas in the region, and electricity could be sold to the Scandinavian electricity market.

However, the studies had also shown that the existing price relations were not favourable enough to make a plant sufficiently profitable to justify the required investments.

However, some developments during the recent year have strengthened to attraction of the envisioned energy conversion plant:

- IPCC has published its most recent findings during the last months, increasing the certainty of human influence on the climate in increasing the predicted temperature increase due to changes in the atmosphere. (Reduced particle emissions appearing to be an important factor increasing the effects of the greenhouse effect.) [www.ipcc.ch]
- New legislation on waste management introduced in Sweden and Europe will increase the supply of waste-fuels and bio-fuels thereby increasing the resource base for a plant like BioMeeT's.
- Several EU-documents calls for increased attention to technologies like those of BioMeet
  - Proposed directive supporting electricity from renewable energy, (Com (2000) 279).
  - Commission green paper on emission trading, (Com (2000) 87).
  - Commission proposal of environmental action programme, (Com (2001) 31).
  - Commission proposal on action plan for energy efficiency, (Com (2000) 247).
  - Commission green paper on security of energy supply, (Com (2000) 769).
  -
- There are market developments like the increased world-market oil price level.
- The electricity price levels have also increased at Nord-pool, the Scandinavian electricity exchange. [www.nordpool.no]
- The variation of electricity spot-market price has also increased, increasing the value of flexible plants like those envisioned in BioMeet. [www.nordpool.no]

Thus, the prices of the products – fuel, heat, gas and electricity – appear to have increased, while the new supply of wastes to the fuel markets makes more biomass available as raw material for the plant. The general attitude from the policy-making bodies in Europe appears generally favourable.

On the other hand the policy change that appears to take place in the United States may indicate that there are counter currents.

- The U.S. president has declared the U.S. will not ratify the Kyoto protocol.
- The policy document the president has presented includes reduced environmental restrictions on oil-extraction, and increased support for non-sustainable energy alternatives.

In Sweden there are statements made favouring that all available biomass should be used to substitute fossil fuels in heat- and electricity-production, as the costs of reducing carbon emissions in these applications are generally lower than when substituting automotive fuels. (E.g. see Azar, Lindgren & Andersson: *Hydrogen or methanol in the transportation sector?*
[www.frt.fy.chalmers.se])

§ 4 The Technological opportunities

Tomas Ekbom described the technological concept of gasifying biomass to produce electricity heat and fuels. He also described the Technologies available on the market and the contribution to technology development of a project of the kind envisioned. He recalled the BAL project where fuel-grade methanol and heat were the products, with an methanol energy yield of almost 50%.

The BioMeet concept included the potential to export fuel-gases. In present project we shall consider the economic costs and benefits of increasing the flexibility of a biomass-based energy combine in the region. We shall study the technological and economic opportunities to adapt the combine the interests of the actors in the region.

Some potential technological issues presented were:

1. Gasification optimisations, cost calculations, possible increased drying step and investigations of tar handling
   Identify alternative CO_2 separation techniques
2. Optimise methanol synthesis on efficiency (level of looping, shift) and flexibility
3. Handling of trace elements
4. Investigate possibilities of upgrading the fuel gas to methane for biogas applications or as a feed for the natural gas grid
5. Identify status of commercialisation of all process steps

In the discussion, the costs of using different kinds of fuels were discussed. The management of different energy-rich waste fractions was becoming important in the region, and the potential for gasification technologies handle waste was of interest. Tomas Ekbom responding by referring to a plant producing large amounts of methanol from waste in eastern Germany.

§ 5 The perspectives of the participants

- Claes Ekström pointed out the economic importance of the age of existing plants in the region. When new investments are required the willingness to participate in a project of this kind will be significant. If existing plants may continue to operate at low marginal costs there will be little interest in engaging capital in new plants.
- Maria Gerd noted that the district-heat demand could increase if the industries such as SAAB, now relying on carbon taxes lower than the nominal, would be convinced to discontinue fossil use. Not only taxation of automotive fuels, but the general energy taxation system provide economically important conditions for an energy combine of the envirioned kind.
- Tommy Björkquist noted that for SAAB as an investor, there are at present many opportunities to invest at better rates of return then bioenergy investments.
- Einar Bjarne reported that, as a result of the new waste legislation, Trollhättan was investigating the potential generate electricity and heat from waste.
- Claes Ekström described the knowledge collected by Elforsk on new electricity generating technologies. Here, too, the energy taxation regimes is decisive in ordering the economic competitiveness of generating technologies.
- Tomas Ekbom described some of the solid fuel gasifications technologies demonstrated in the world.
- Tommy Björkqvist told about the technologies for methanol-use that SAAB had. These technologies were to be tested in the U.S.A. SAAB in Sweden would benefit from the local feed back of a local test fleet in Trollhättan. SAAB/Fiat is responsible for european engine development within General Motors. But other conditions were needed to justify efforts in Sweden.

- SAAB also reported that their interest was sufficient to justify financing two PhD students working on alternative fuels.
- Claes Fredriksson reported that from the point of view of the University College, energy systems analysis integrating electricity, heat and fuel production was of great interest. His ambitions was to increase the activities in this field.
- Maria Gerd reported the project to demonstrate methane fuels in Trollhättan that now engages a part of the Taxi fleet in Trollhättan. Parallel demonstration projects may be seen as competing in a negative sense, but they may also be viewed as mutually supporting justifying common support measures while the competition between them may appear as a constructive force.

§ 6 Next meeting

The next meeting of this committee was to take place on September 28th at 12.00-15.00 in Trollhättan.

Notes from the meeting of the steering committee no 3 of the BioMeeT-II Project

The meeting was held at Hotel Swania, Trollhättan, September 28th 2001, from 11.00 – 14.00.

Present at the meeting were:

Maria Gerd	Trollhättan kommun
Barbara Sandell	Trollhättan kommun
Bengt Sävbark	Ecotraffic ERD³
Tomas Kåberger	Ecotraffic ERD³
Henrik Boding	Ecotraffic ERD³
Claes Fredriksson	Högskolan i Trollhättan/Uddevalla
Tomas Ekbom	Nykomb Synergetics
Tommy Björkqvist	SAAB
Nils-Gunnar Svensson,	SAAB
Clas Ekström	Vattenfall, Stockholm (via telephone)
Einar Bjarne	Vattenfall, Trollhättan
Ulf Olsson	Volvo Aero Corporation
Roland Ax	Västtrafik

§ 0 The meeting was opened by Tomas Kåberger.

Clas Ekström was present via telephone, as he was ill at home. The participants all introduced themselves to Clas.

Tomas Kåberger reported that interviews held since the last meeting had revealed that there were three important issues that appeared vital to the stakeholders considering committing themselves to a project of this kind.

The actors in the project all have capacity to contribute to establishing a plant that produce electricity, fuel and gas from biomass. However, none of the users of the products see that there is an economic potential under present conditions. Three important ideas that appear crucial:

1. EU policy development may be decisive in creating economic conditions to facilitate the introduction of biofuels in the transport sector. Present tax-regulations are excluding fuels of this kind, but with the ambitions stated one may expect economic condition forcing biofuels into the market.

2. There are arguments suggesting that biofuels never shall be a significant energy source for the transport sector. Biomass resources are limited, and these small resources are more easily utilised to substitute fossil fuels in stationary applications. If correct, this is an important issue as short-term profits induced by favourable taxes are not sufficient to justify development efforts.

3. Waste available for energy recovery at negative cost is increasing dramatically due to new legislation. Environmental requirements are stringent, and gasification may be a

competitive technological option. This, in turn, would make the production of fuels possible at costs of the same order as production of electricity.

§ 1 The proposed agenda was agreed upon with the addition of the following three reports:
1. Progress of the parallel project of biofuel in Värnamo,
2. Ecotraffic report of efficiencies of a large number of fuel chains from resource to motion, and
3. A demonstration of a methanol fuel cell brought to the meeting by Claes Fredriksson.

§ 2 Notes from the previous meeting of the steering committee were confirmed after the correction of one name on the list of people present.

§ 3 Henrik Boding described the ideas in the proposal for a new EU-directive on alternative automotive fuels. The strategy conceived includes quotas for total share of biofuels as well as total share of biofuels in dedicated vehicles different years. The total yearly amount of biofuels required would be some 17 Mton within a decade.

The proposal is enclosed to these notes.
Another important proposal is a change of the EU rules in order to allow a general reduction in taxation of biofuels in the transport sector.

§ 4a) Bengt Sävbark reported the main results of the life-cycle, "Well-to-wheel", efficiency study carried out by Ecotraffic showing that both DME-diesel-hybrid, hydrogen and methanol-FC-hybrid chains were among the most efficient fuel chain possible within a ten year horizon.

MIT and GM have performed a similar study. Differences between the studies illustrate the importance of assumption brought into the analysis. The US study is criticised for not using the modern technologies for all alternatives.

§ 4b) Tomas Ekbom reported the progress of our colleagues preparing a reconstruction of the biomass IGCC build half a decade ago in Värnamo. Sydkraft, who owns the plant has mothballed the plant as the energy prices were not considered sufficient to justify continued operation after the technologies were demonstrated during 8000 hours of gasification and some 4000 hours of integrated operation. Now a consortium including TPS, Topsø, Daimler Chrysler, Växjö, Volvo are preparing to use the site and some of the equipment as a basis for a biomass-to-DME demonstration plant. They have acquired some funding for a feasibility study.

Kåberger brought up the issue of how to exchange information with the Värnamo project. The issue was left on the table until the next SC-meeting.

§ 4c) Tomas Ekbom described the methanol production from waste fuels operating at Schwarze Pumpe in Germany. The plant produced some 0,1 Mton of methanol per year. A system including several different gasifiers are used to gasify a wide range of waste fuels with good environmental performance.

In relation to the discussion at the previous steering committee meeting, we learn that methanol production from waste is indeed possible with economic soundness of operation. However, the cost of building such a plant cannot be justified by the operating surplus, Schwarze Pumpe was a result of a city-gas grid supply effort during the DDR era.

A discussion followed regarding the distinction between biomass and waste and the relevance in interpreting the EU ambitions on biofuels for the transport sector.

It was also described that parallel projects are developed to further develop biofuel production technologies from black liquor as well as solid waste.

§ 5 Working groups.
In order to have on ongoing dialogue comparing the strategies of the actors in the project there was a decision to form working groups to take on the important issues identified:

Group 1, to deal with the issue whether biomass should only be used is stationary applications as a solid fuel or if biomass should also be utilised as an automotive fuel.

Group 2, to assess the relative advantages of waste versus fresh biomass as raw material for fuel production.

Group 3, to assess the costs and benefits of flexibility in the production.

And, finally

Group 4 to assess the local demand

Grouping

		Group 1	Group 2	Group 3	Group 4
Gert-Inge Andersson	Trollhättan kommun				
Maria Gerd	Trollhättan kommun		x		x
Barbara Sandell	Trollhättan kommun		x		
Mats Johansson	Trollhättan Energi		x		
Lars Niklasson	Trollhätteåkarnas Last				
Bengt Sävbark	Ecotraffic ERD[3]	x	x	x	x
Tomas Kåberger	Ecotraffic ERD[3]	x			
Henrik Boding	Ecotraffic ERD[3]		x	x	x
Claes Fredriksson	Högskolan i Trollhättan/Uddevalla	x			
Tomas Ekbom	Nykomb Synergetics		x	x	
Tommy Björkqvist	SAAB				
Nils-Gunnar Svensson	SAAB	x			
Clas Ekström	Vattenfall, Stockholm	x			
Einar Bjarne	Vattenfall, Trollhättan				x
Ulf Olsson	Volvo Aero Corporation				
Henrik Landälv	Volvo Lastvagnar Sverige	x	x		
Roland Ax	Västtrafik	x			

§ 6 Next meeting was set to take place on January 25, 2002 from 11.00 – 14.00 at Swania in Trollhättan.

§ 7 Claes Fredriksson demonstrated the direct methanol fuel cell he had brought from the university. We had all learned it worked in theory, but the demonstration attracted the great interest that only real demonstration can get.

§ 8 The meeting was closed.

Notes from the meeting of the steering committee no 4 of the BioMeeT- II Project

The meeting was held at Hotel Swania, Trollhättan, January 25th 2002, from 11.00 – 14.00.

Present at the meeting were:

Gert-Inge Andersson	Trollhättan kommun
Maria Gerd	Trollhättan kommun
Barbara Sandell	Trollhättan kommun
Mats Johansson	Trollhättan Energi
Bengt Sävbark	Ecotraffic ERD^3
Tomas Kåberger	Ecotraffic ERD^3
Henrik Boding	Ecotraffic ERD^3
Claes Fredriksson	Högskolan i Trollhättan/Uddevalla
Tomas Ekbom	Nykomb Synergetics
Nils-Gunnar Svensson	SAAB
Clas Ekström	Vattenfall, Stockholm
Einar Bjarne	Vattenfall, Trollhättan
Peter Danielsson	Volvo Bus Corporation

1. Opening and welcome

Tomas Kåberger opened the fourth steering committee meeting of BioMeet-II project. All members present were greeted welcome, in particular Peter Danielsson, representing Volvo Bus Corporation, who has taken over the position of Henrik Landälv.

2. Agenda

The preliminary agenda was agreed with the addition of two points:

i) Information from the seminar on automotive fuels organised by the National Energy Administration 2002-01-17.

ii) Information on the parallel projects preparing bio-gasification-to-fuel plants in Värnamo and Hagfors.

3. Notes from previous meeting

Notes distributed from the previous meeting were summarised, and agreed upon by the committee, after the error in date in the first distributed version was explained.

4. Reports from the working groups

i) Strategic arguments on automotive fuels from biomass versus stationary applications. The group is facilitated by Tomas Kåberger.

The cost efficiency of automotive fuels has been questioned in some studies lately. Short-term marginal efficiency of reducing carbon emissions is higher when substituting electricity for heating and for co-generation of electricity and heat then by producing automotive fuels. That has been easily documented. And it is the result of a project organised by the academy of engineering sciences with active contributions from Ekström and Kåberger in our group.

However, the more important and questionable result is concerning the role of automotive fuels from biomass as a component in an ambitious global carbon mitigation strategy. The participants agree that confidence of a role for automotive biofuels in that context is vital for the interest of the parties to this project to continue. A report refusing such a role has been discussed for almost a year but has been under continuous rewriting by the authors Azar and Andersson. The last version of the report has just been prepared and is being electronically distributed to the group members. The group will try to get access to the computer model to perform a sensitivity analysis

i) The potential of waste-fuels instead of forest fuels as feedstock for the gasification and liquid-fuel production. The group is facilitated by Henrik Boding.

The group has investigated the quantities of waste available and found that there are large quantities available in relation to the requirements of a plant of 20 MW discussed in this project. Due to the legislation and taxes on waste dumps, the fuel is available at a negative price.

Because of the time lag in building a plant the immediate waste problems will find other solutions in the mean time, possibly in the form of other investments or long term contracts.

Despite the impression given by the presentation at the previous steering-committee meeting on the large-scale methanol production of methanol from waste at Schwarze Pumpe, there are economically significant disadvantages of using waste-fuels instead of forest fuels for the production of methanol or DME.

A critical technological component is the filter system used to clean the synthesis gas. The design and operation of that system is dependent on the composition of the fuel gasified. The designs are easier for homogenous forest fuels then for a plant that shall be prepared to cope with waste fuels showing variations in composition.

To take on waste fuels, demands would have top be placed on the composition of the fuel that would imply costs increasing the price of the fuel. A quantitative analysis of such a cost increase is difficult.

However, the robust conclusion of the group is that the increased availability of waste fuels will increase the supply side of the solid fuel marked and therefor tend to decrease the solid fuel prises. Even if waste-fuels are not used for the production of automotive biofuels it will indirectly improve the conditions of such a plant by decreasing the price of forest fuels.

It was also noted that a more detailed analysis of the potential of using waste as a feed-stock for automotive fuel production will be made in the Altener-project

RENEWA-Renewable Energy from Waste, in the near future. In anticipation of what that study will reveal, no more efforts will focus on waste feedstock in BioMeet II.

ii) The potential benefits of flexibility in time of the product-mix. The group is facilitated by Henrik Boding.

It has been noted that there are significant variations in the price of electricity at the Nordic spot-market. The group has assessed the potential for improving the economic performance of the plant by a design that would make it possible to adjust the product mix over time in response to the variations in relative prices.

The assessment of alternatives is complicated. Not only is flexibility limited by the configuration and components in the plant that is decisive for the investment cost, but gas quality is also affecting the efficiency of the catalytic fuel synthesis providing a fraction of gas for direct combustion.

Preliminary results indicate that the best design option may be the previously studied design maximising the production of methanol/DME.

The precision of the analysis shall be improved and sensitivity assessed.

iii) Re-assessment of demand structure in the region. The group facilitated by Henrik Boding.

The group has no new results to report at this moment.

5. Other reports

i) The automotive fuel conference of the National Energy Administration

On January 17th the Swedish National Energy Administration organised a conference on automotive-fuel projects in the country. The BioMeet-II project was presented at the meeting by Bengt Sävbark and Henrik Boding. They also presented the study on the conditions of a large scale introduction of motor-alcohols as automotive fuel in the Swedish market.

The national energy administration is now actively seeking advice to govern their future priorities. In the end of the meeting there was a clear view that biological methane production had a small potential but that the support historically given to such systems had been high. These technologies were now ready to operate without support, according to the energy administration.

At the same meeting the National Road Administration, that has a sector responsibility for the sustainability of the road-transport sector, expressed an interest in significant efforts to demonstrate fuels produced from biomass via thermal gasification. These systems have greater potentials in annual contributions to the fuel sector.

The Swedish authorities – The Energy Administration, the Road Administration, The Environmental Protection Agency and Vinnova (the research council for industial development) – are co-operating to develop a common strategy for introducing sustainable automotive fuel systems in Sweden.

ii) Tomas Kåberger reported on the reactions to the proposed directive in support of alternative fuels.

There are several motives for the proposed directive. Security of supply, meeting Koyto commitments and reducing costs of meeting local environmental criteria are among them but also agricultural support ambitions.

In large parts of Europe, there is substantial opposition to the proposal. While the Swedish debate is based on cost-efficiency, in other parts of Europe there are fears that support for alternative fuels will lead to more pesticide intensive and subsidised agriculture causing financial and environmental harm to the people of Europe and their environment. The European Environmental Bureau, an umbrella organisation of European environmental organisation has expressed very strong opposition.

From the Swedish perspective the proposal do open up for bad agricultural practices and the risks are that the results will be economically inefficient and with bad environmental consequences.

However, another risk is that such features of the proposal will be seen as a reason to discharge the whole idea of turning towards sustainable automotive fuels.

An important role for the future of the directive will be the process in the European Parliament. In the process of selecting the member to draft parliamentary positions Swedish member Anders Wijkman is one of the candidates.

A successful decision making process in Brussels will be necessary for the continued investments, but the process will go on for at least about one year.

iii) Information on the feasibility study of DME-production from biomass in Värnamo.

Peter Danielsson reported that the Värnamo project is stalled waiting for a possible opportunity to continue with the support of the 6th framework programme. The Project-budget is in the order of 450 MSEK.

Peter pronounced that Volvo was interested in the BioMeet II as another option, as they would like to achieve a complete supply chain from biomass to DME fuelled Volvo vehicles.

Their vehicle development is proceeding in a project called AFFORHD, Alternative Fuel FOR Heavy Duty vehicles.

iv) Information on Värmland-methanol in Hagfors

Tomas Ekbom informed about the plans for a demonstration plant of methanol production by biomass gasification in Hagfors. The project is headed by well-known environmentalist Björn Gillberg. The purpose is to demonstrate the technology in a small plant of about the same size as the Värnamo plant.

Tomas Ekblom also reported that there is a project on gasification of black liquor in progress in Piteå. This feed stock has high quality for synthesis of methanol or DME. The total quantity of black liquor available in Sweden would be sufficient to supply about 20% of the Swedish use of automotive fuels.

6. Intermediate report

Henrik informed about the work on the intermediate report to the commission. The report is to be submitted in early February. All participants will receive the document.

7. Discussion

Preliminary conclusions were discussed openly regarding the following steps in passing the obstacles on the road to full scale production of automotive fuels from biomass.

Clas Ekström said that with uncertainties regarding political decisions the robust step to take would be to prove gasification and gas purification. The remaining steps are commercially available and minimisation of investment risks would yield that conclusion. The testing may cost 150 MSEK during one year

Mats Johansson said that it would be easy to find use for 20 MW heat in the area.

Claes Fredriksson called for more activity by Trollhättan to prove their role in the development.

Gert-Inge Andersson described the over-all strategy of Trollhättan to achieve diversification in the fuel sector and the role of this project in that context. Trollhättan has other activities to involve customers and distributors in other projects going on.

He also pointed to the need for this project group to present the results and strategy in such a way that politicians, distributors as well as customers voters could understand the project.

8. Next meeting

Next meeting will take place May 24th, at 11.00-14.00, in Hotel Swania in Trollhättan.

Secretaries

Henrik Boding and Tomas Kåberger

Appendix 1

Group structure

		Group 1	Group 2	Group 3	Group 4
Gert-Inge Andersson	Trollhättan kommun				
Maria Gerd	Trollhättan kommun		x		x
Barbara Sandell	Trollhättan kommun		x		
Mats Johansson	Trollhättan Energi		x		x
Lars Niklasson	Trollhätteåkarnas Last				
Bengt Sävbark	Ecotraffic ERD^3	x	x	x	x
Tomas Kåberger	Ecotraffic ERD^3	x			
Henrik Boding	Ecotraffic ERD^3		x	x	x
Claes Fredriksson	Högskolan i Trollhättan/Uddevalla	x			
Tomas Ekbom	Nykomb Synergetics		x	x	
Tommy Björkqvist	SAAB				
Nils-Gunnar Svensson	SAAB	x			
Clas Ekström	Vattenfall, Stockholm	x			
Einar Bjarne	Vattenfall, Trollhättan				x
Ulf Olsson	Volvo Aero Corporation				
Henrik Landälv	Volvo Lastvagnar Sverige	x	x		
Roland Ax	Västtrafik	x			

Group tasks:

1. Strategic arguments on automotive fuels from biomass versus stationary biofuel applications

2. The potential of waste-fuels instead of forest-fuels as feedstock for the gasification and fuel production

3. The potential benefits of flexibility in time of the product-mix.

4. Reassessment of demand structure in the region

To be translated to English in the final report.

Appendix 2. Biometanolproduktion i Schwarze Pumpe i Tyskland

1. Allmänt om anläggningen

1.1 Bakgrund

Redan 1955 byggdes en brunkolsanläggning vid orten Schwarze Pumpe i nordöstra Tyskland (130 km från Berlin), för produktion av främst stadsgas, men också elektricitet och brunkolsbriketter. Anläggningen bestod av 24 fastbäddsförgasare för brunkolsbriketter och 4 medströmsförgasare för de oljor och tjäror som producerades av fastbäddsförgasarna. Detta komplex försåg dåvarande Östtyskland till 80% med stadsgas.

I och med det sedermera samgåendet med Västtyskland minskade behovet av dessa produkter och efter 1995 då stadsgasproduktionen lades ner, har anläggningen istället anpassats efter förgasning av avfall för produktion av främst metanol och elektricitet. Se Bild 1 nedan.

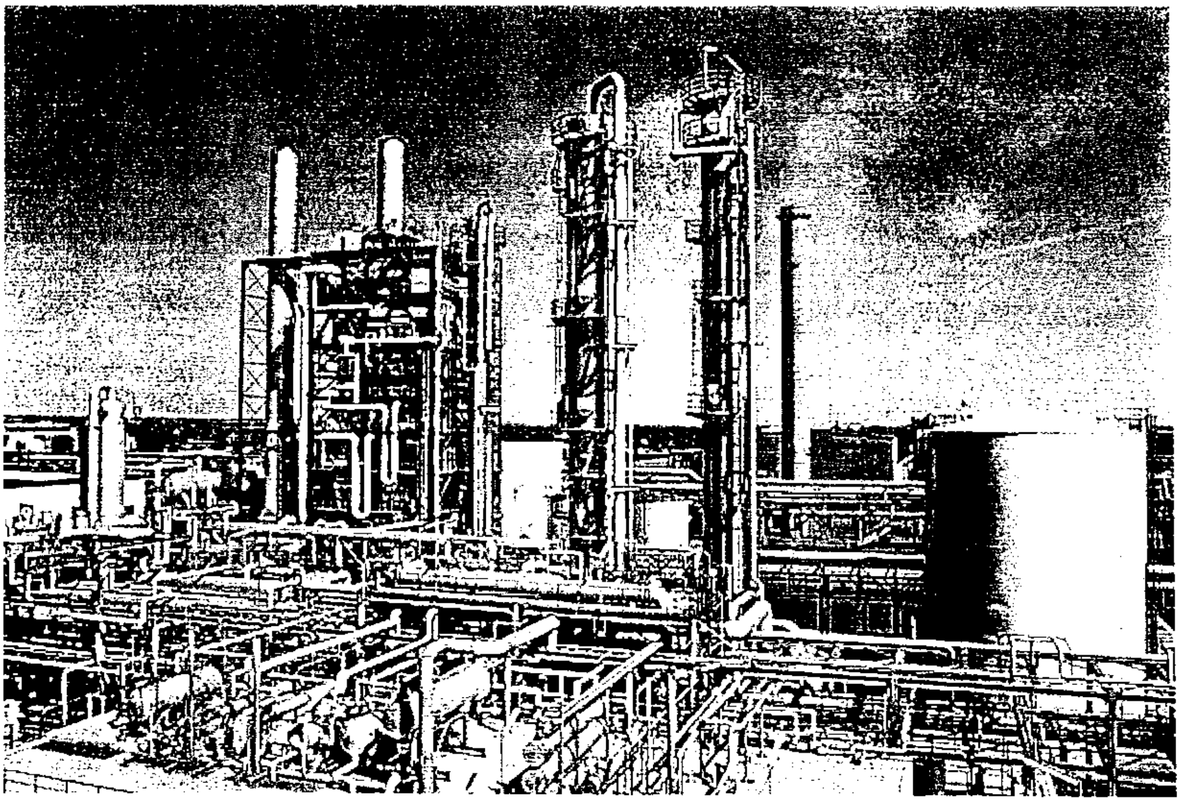

Bild 1. Sekundärrohstoff- Verwertungszentrums (SVZ) anläggning för metanolproduktion genom avfallsförgasning vid Schwarze Pumpe, nordöstra Tyskland. SVZ Copyright © 1998

Sekundärrohstoff- Verwertungszentrum (SVZ) Schwarze Pumpe GmbH med 370 medarbetare står sedan 1995 som ägare till anläggningen och som i sin tur ägs sedan juli 2000 till 100% av Global Energy Inc. i Cincinnati, Ohio, USA. Totalt har efter renoveringstarten 1995 omkring en halv miljard DEM (tyska mark) investerats.

1.2 Kapacitet

Anläggningen består idag av 7 stycken fastbäddsförgasare, som vardera har en kapacitet på 15 ton/h, 2 stycken medströmsförgasare på 45.000 m^3/h syntesgas och en slaggande förgasare på 30 ton/h. Bränslet prepareras i en särskild del av anläggningen och kan hantera 5 ton/h plast, 5 ton/h trä, 200 ton/d flytande avfall och 20 ton/h kommunalt avfall. Totalt har anläggningen en årlig kapacitet av cirka 450.000 ton fast avfall (330.000 ton/år avfall, 110.000 ton/år kol $\approx$50 ton/h) och 50.000 ton flytande kontaminerad olja och vatten-oljeemulsioner.

Idag produceras 100.000 - 120.000 ton metanol per år och netto cirka 340 GWh el (med effekt om 40 - 50 MW). Det finns planer på att bygga ut anläggningen med en ny generationsserie av förgasare för att utöka metanolproduktionen med hundra tusentals ton per år och för närvarande söker SVZ avfallsföretag i Tyskland som kan leverera mer bränsle till anläggningen i Schwarze Pumpe. Ett första genombrott blev att Abfallwirtschaftsverband Chemnitz skrev på ett avtal i slutet av år 2000 om att låta SVZ bygga en prepareringsanläggning i Chemnitz-Bernsdorf.

Anläggningen ska stå färdig 2005 och ska sortera och pressa 100.000 ton hushållssopor årligen till pellets och briketter som sedan ska sedan förgasas vid anläggningen i Schwarze Pumpe för vidare syntes till ytterligare 50.000 ton metanol per år. Dessutom finns möjligheter att ta emot djurfett och köttmjöl för förgasning, bland annat från Irland, och sedan 1999 har redan 3.000 ton djurfett och köttmjöl förgasats och vidare syntetiserats till metanol. Av två ton djurfett produceras cirka ett ton metanol.

2. Processteknologi

2.1 Processkoncept

Anläggningen baseras på förbehandling av avfall till fasta pellets och briketter, samt flytande avfall till en pumpbar vätska. Det finns kriterier för hur mycket föroreningar som får finnas i det avfall som tas emot, vilket kontrolleras ständigt. Avfallet som sedan blivit till bränsle matas sedan in i de 10 stycken förgasare som finns. Dessa producerar en syntesgas där 95% renas i en Rectisolprocess som effektivt tar bort föroreningar och resterande 5% som avsvavlas i en gipsanläggning.

Den renade gasen går sedan till en metanolsyntesanläggning där oreagerad syntesgas går vidare till en kombicykelanläggning för el- och värmeproduktion. Den producerade metanolen renas i en destillationskolonn till ren metanol och är kvalitetsklassad som övrig metanol på världsmarknaden. Den färdiga metanolen används idag till 25% för MTBE och 75% som baskemikalie för tillverkning av bland annat:

- läkemedel och vitaminer
- färger och som formaldehyd i hartser, konserverings- och disinfektionsmedel
- lösningsmedel för hartser, vaxer, oorganiska salter, polymerer etc.
- kylarvätska och andra kylsystemsmedia
- etansyra
- denatueringsmedel
- gasreningsmedium för lågtemperaturprocesser
- synteskemikalier för produktion av bekämpningsmedel, explosiva material, smakämnen och aromater, plexiglas med mera.

2.2 Processteknologi

Fastbäddsförgasare

De första förgasarna var av konventionell fastbäddstyp för enbart kol. Dessa byggdes om vid anpassningen och efter 1997 kan de ta en avfallshalt av upp till 50% vid kontinuerlig drift. Senaste åren har moderniseringsarbetet koncentrerats till att höja fraktionen till 75%. Varje förgasare har en kapacitet av 15 ton/h och arbetar vid 25 bar i ett temperaturintervall om 800 - 1300 °C.

Det fasta bränslet med en medelstorlek 60 mm matas in via ett slutet magasin ovanifrån och torkas först i en temperaturavgränsad zon för att sedan förgasas med hjälp av värmen från underliggande förbränningszon. Förgasarmedium är syre och ånga som blåses in underifrån. Resterande aska sorteras ut i botten genom ett galler. Den orenade gasen tas därefter ut till en vattenskrubber som kyler och kondenserar ut högre kolväten som tjäror samt oförbrända partiklar (se Bild 2).

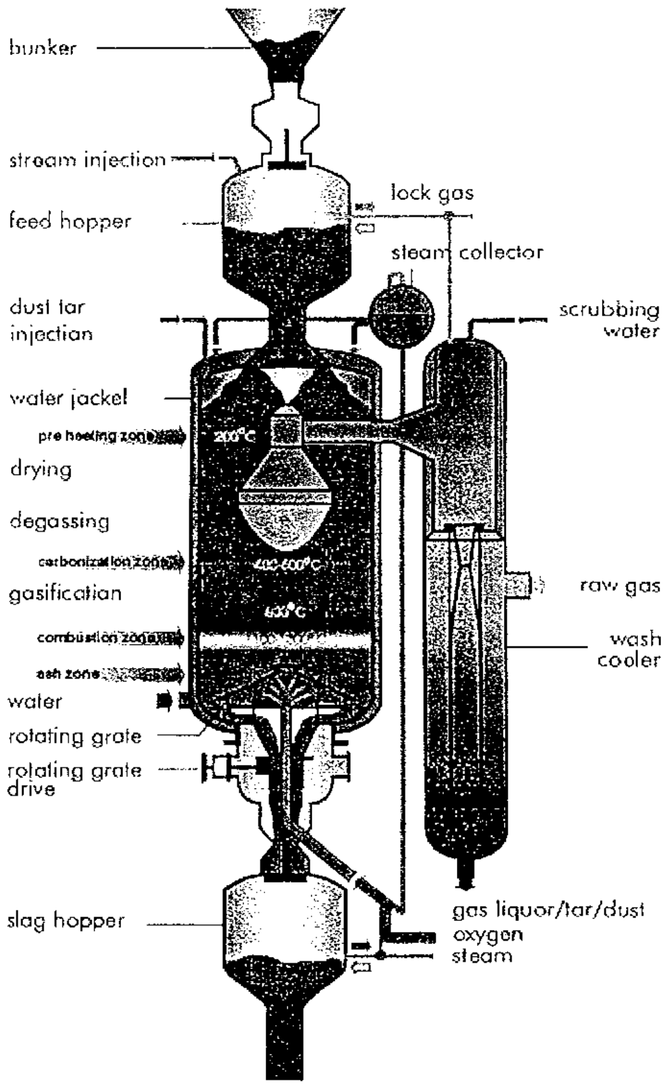

Bild 2. Schematisk bild över fastbäddsförgasare, Schwarze Pumpe. SVZ Copyright © 1998

Slaggande förgasare
Den slaggande förgasaren är senaste tillskottet och av en nyare typ (British Gas Lurgi - BGL) av avfallsförgasare med en speciell störtkylare "quench". Förgasaren har en kapacitet av 30 ton/h och arbetar vid 25 bar och upp till 1600 °C.

Det fasta bränslet matas in via dubbla lufttäta magasin ovanifrån och förgasas med syre och ånga som blåses in underifrån. Askan tas ut som flytande slagg, vilken störtkyls i underliggande "quenchen" till granuler (kulor) där alla föroreningar inneslutes utan risk för utlakning. Den orenade gasen tas därefter ut till en vattenskrubber som kyler och kondenserar ut högre kolväten som tjäror samt oförbrända partiklar (se Bild 3).

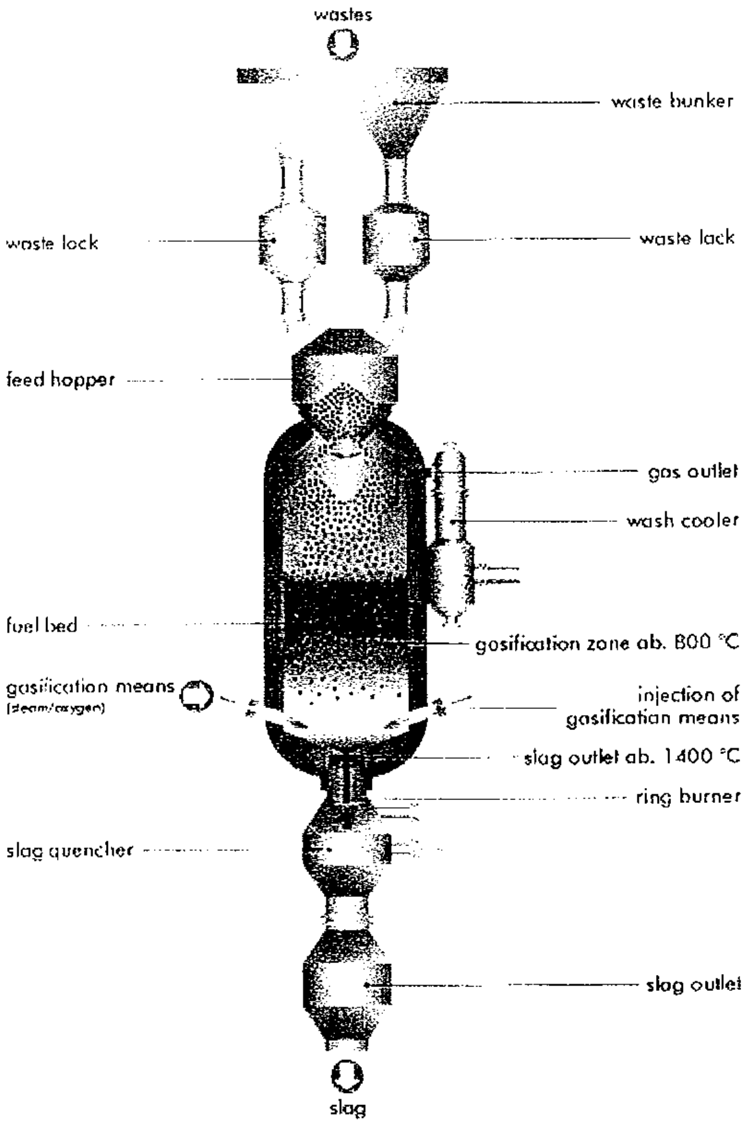

Bild 3. Schematisk bild över slaggande British Gas Lurgi, BGL-förgasare, Schwarze Pumpe. SVZ Copyright © 1998

Medströmsförgasare
Medströmsförgasaren är avsedd för rena flytande bränslen, men också för slurry-bränslen. Förgasaren har en kapacitet av 7 - 10 ton/h för oljor och upp till 9 ton/h för slurry-bränslen. Förgasaren arbetar vid 25 bar och mellan 1600 - 1800 °C.

Det flytande bränslet förs in till en brännare med ånga där bränslet konverteras till en syntesgas. Den höga temperaturen säkerställer att alla organiska ämnen blir sönderdelade. Den efterföljande störtkylningen förhindrar oönskade vidare reaktioner och tungmetaller försluts i ett laksäkert slagg, vilket as ut i botten (se Bild 4).

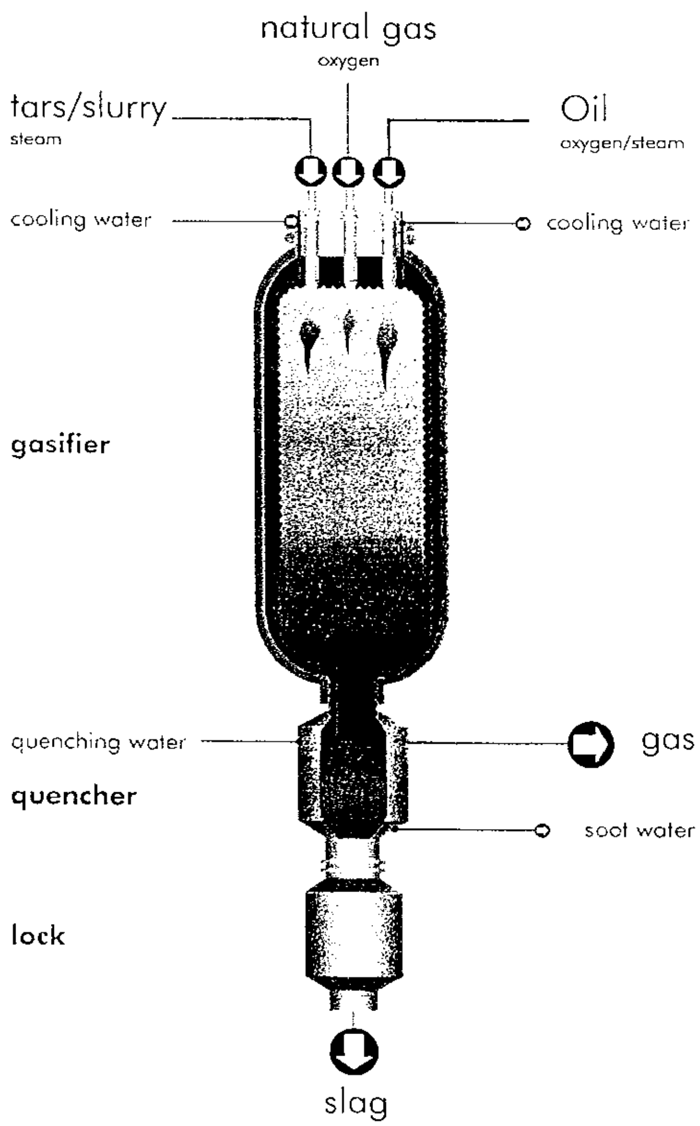

Bild 4. Schematisk bild över medströmsförgasare, Schwarze Pumpe. SVZ Copyright © 1998

3. Teknisk beskrivning

För en sammanfattande tabell över hela anläggningens tekniska prestanda, se Bilaga Teknisk beskrivning.

3.1 Bränslepreparering

Det mottagna avfallet avpassas och mixas till att kunna förgasas med brunkol, där en del avfall behöver försortering och preparering. En halt av 75% avfall och 25% brunkol kan numera uppnås för det fasta bränslet. I en första sortering separeras metall- och glasföremål samt stenar bort så att endast organiskt material återstår.

Träavfall som tas emot rivs och krossas till 60 mm stora bitar. Plastförpackningar komprimeras med extruders till briketter. Avloppslam torkas och briketteras och resterande avfallstyper torkas, krossas och pelleteras.

3.2 Förgasning

Det färdiga bränslet transporteras via transportband till lagringsmagasin vid förgasarna. Därefter matas bränslet in i de trycksatta reaktorerna och förgasas motströms med syre och ånga. Förgasningen ger en rågas med huvudkomponenterna H_2 (vätgas), CO (kolmonoxid), CO_2 (koldioxid) och CH_4 (metan). De efterföljande processtegen störtkylning, värmeåtervinning med ångproduktion och kondensering separerar medryckta partiklar, återvinner latent värme och kyler gasen till 30 °C.

Flytande bränslen transporteras via bilar till speciella tankar där en första analys görs av materialet för klassificering. Från tankarna transporteras sedan bränslet via pipelines till medströmsförgasarna för konvertering till syntesgas.

3.3 Gasrening

Syntesgasen från fastbäddsförgasarna går från lågtemperaturskrubbning där viss anpassning sker i gassammansättning över till en till en Rectisolprocess där gasen kyls ner till -60 °C och renas med metanol i en trestegsskrubber. Därmed kondenseras ut resterande vatten och lätta kolväten. Metanolen tvättar också bort CO_2 (koldioxid), H_2S (divätesulfid) och COS (karbonylsulfid) samt andra organiska svavel- och kväveföreningar.

3.4 Metanolproduktion

Den renade gasen förs vidare till en multistegs gasrening och en metanolsyntesprocess bestående av en metanolsyntesreaktor med återcirkulerande gaskomprimering, trestegs destillation och efterföljande lagring. Metanolreaktorn arbetar vid 38-40 bar och vid en temperatur om 250 °C. Produktionen har sedan 1997 stigit från omkring 35.000 ton/år till över 100.000 med planer på en utbyggnad för en närliggande produktionshöjning av 50.000 ton/år.

Dessutom ska utbyggnaden i ett tredje investeringssteg av anläggningen med ny generation förgasare kunna öka produktionskapaciteten flera gånger, vilket kan komma realiseras inom närmsta tio åren. Förutsättningarna är baserade på att mer avfall ska kunna tas emot från ett större område.

3.5 Kraft- och ångproduktion

För att tillgodose delprocessernas behov av ånga samt el i anläggningen produceras ånga i tre tryckkokare, varav största delen, 240 t/h, produceras i en avgaspanna i en kombicykelanläggning. Kombicykelanläggningen består av en PG 6551 B gasturbin (45 MW el) och en kondenserande ångturbin (31 MW el) med en avgaspanna om maximal effekt 215 MW.

Elproduktionen uppgår årligen till cirka 340 GWh. För att kunna bli nettoproducent av el tas ren syntesgas upp till 50.000 Nm^3/h med ett värmevärde av 12 - 16 MJ/Nm^3 från gasproduktionen förbi metanolanläggningen för mer kraft- och ångproduktion. Vidare används den överskottsgas upp till 20.000 Nm^3/h med ett värmevärde av 17 MJ/Nm^3 som inte kan generera mer metanol i metanolprocessen till kombianläggningen för mer kraft- och ångproduktion.

4. Produktspecifikation

SVZ Schwarze Pumpe anläggningen är kvalitetsäkrad efter DIN EN ISO 9002 och den producerade metanolen håller samma klass som övrig metanol handlad som bulkkemikalie över hela världen för alla dess applikationer. Idag säljs cirka 75% av den metanol som produceras för vidare kemikalieproduktion och resterande 25% för MTBE.

5. Leverans av drivmedel

Metanol levereras idag på kontrakt till kunder och prissätts mot gällande världsmarknadspris på råvarumarknaden i Rotterdam. Under andra kvartalet 2001 låg priset, FOB, på €255/tonne. SVZ kan idag garantera framtida leverans 2003 och framåt om minst 5.000 ton/år av ren metanol till ett flottförsöksprojekt i Trollhättan.

För att säkra en framtida leverans bör ett Letter of Intent skrivas mellan båda parter och förhandlingar ske över deras standardkontrakt mot kund. Då råvarubränslet till metanol-anläggningen baseras på trä- och hushållsavfall, oljor samt brunkol är graden av förnybarhet på metanolen mer svårdefinierad, dock är själva metanolprodukten densamma oavsett råvara den är baserad på.

6. Kontaktinformation

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Bilaga: Teknisk beskrivning

Allmänt	
Plats	Schwarze Pumpe, Saxen, Tyskland
Ägare	SVZ GmbH
Produktion	
El, netto	340 GWh, 40-50 MW
Metanol	100.000-120.000 ton/år
Gips	12.000 ton/år
Teknologi	
Bränsleberedning:	Fast, flytande och slurryavfall
-Kapacitet (förgasare med fast bädd):	350.000 ton/år industriellt avfall, 120.000 ton/år kommunalt avfall, 80.000-130.000 ton/år industriellt plastavfall, 80.000 ton/år torkat avloppsslam 40.000 ton/år kontaminerat trä, 10.000-60.000 ton/år andra fasta sopor, 60.000-100.000 ton/år kol
-Kapacitet (medströms-förgasare):	50.000 ton/år restoljor, tjäror, lösningsmedel och laboratoriekemikalier, 50.000 ton/år slurry
Luftseparation:	AGA, oxygen 20.000-24.000 m^3/h
Förgasare:	7 fastbädds- och 2 medströmsförgasare samt en slaggande förgasare med störtkylare "quench"
-Tryck/temperatur	Fast bädd: 25 bar/800-1300 °C Medströms: 25 bar/1600-1800 °C Slaggande: 25 bar/1600 °C
-Syntesgas, LHV	12-16 MJ/Nm^3
-Restgas, LHV	17 MJ/Nm^3
Gasrening:	Rectisol 95% och avsvavling med gipsproduktion 5% av gasen.
Gasturbin:	General Electric PG 6551B, 1 x 45 MW
Ångturbin:	1 x 31 MW
Metanolsyntes:	Multistegsrening med cirkulerande gaskompression och trestegsdestillering
-Tryck/temperatur	38-40 bar/250 °C
-Kapacitet	21 m^3/h, 100.000-120.000 ton/år
Prestanda	
LHV verkningsgrad	45.3%
Tillgänglighet	80-90%
Status	
Projektstart	1991
Storskaliga tester	1992-1994
Drift av befintlig anläggning	1995
Till- och ombyggnad	1995-1997
Kommersiell drift (steg 1)	juli 1997
Tillbyggnad (steg 2)	1997-1999
Kommersiell drift (steg 2)	1999