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RENEWA

Renewable energy from waste through gasification or incineration for heat, power or fuel production. A project on increased market-share through stakeholder group networks.

FINAL REPORT

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Ecotraffic ERD^3 AB
Henrik Boding
Peter Ahlvik

Nykomb Synergetics AB
Daniel Ingman
Tomas Ekbom
Mikael Blomgren

Western Norway Research Institute
Otto Anderssen

NYKOMB SYNERGETICS

Ecotraffic
ENERGY RESEARCH, DEVELOPMENT, DEMONSTRATION, AND DEPLOYMENT
ENVIRONMENTAL CONSULTANTS

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SUMMARY

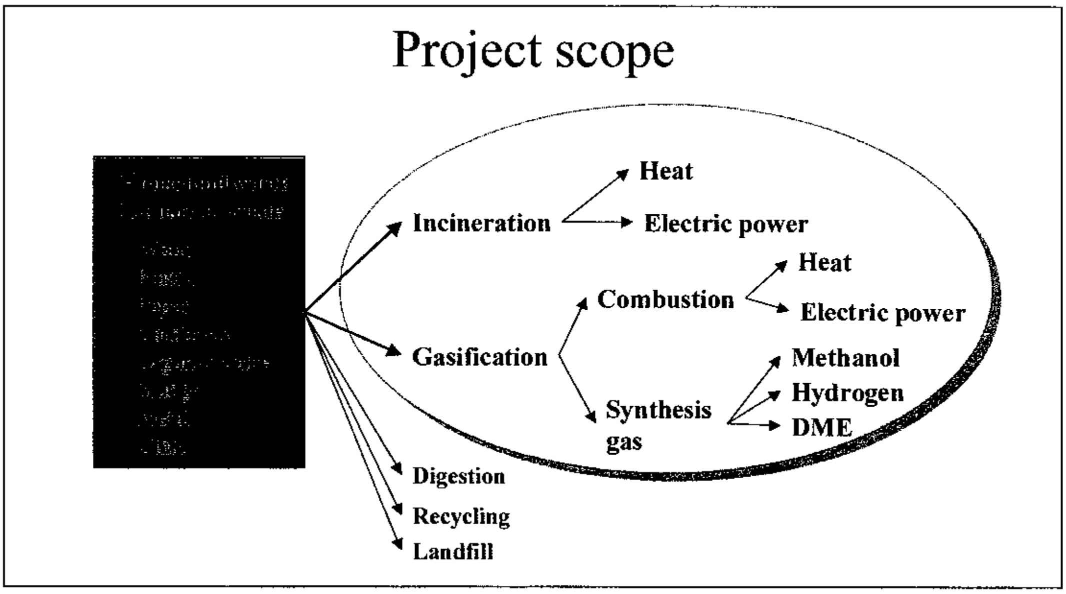
Introduction

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 could be considered as biofuel. The fossil part has in investigations been estimated to 15-20% depending on the level of recovery. Other wastes emerge from erection and demolition of buildings, from parks and gardens and from industries, agriculture and forestry.

There are at present large quantities of household and industrial waste available for energy recovery. Due to the legislation and taxes on landfilling in some countries, the fuel is available at a negative price.

The interest in biofuels has increased during the recent years and the reason for that are 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.

Scope and work organisation



The scope of the project is to identify and assess the most important barriers for using bioenergy from waste through incineration or gasification. This will be carried out by investigating the possibilities for eliminating these barriers with the purpose of increasing the market share for this form of renewable energy in the EU, with the focus on motor fuels. The work will be carried out in a network comprising stakeholders in the whole chain; from the collection of the waste to the energy production and end use in the vehicles. The project has a primary focus on the conditions in Northern Europe, but the aim is also to compile and distribute knowledge within the whole of EU. The basis for the study is that an efficient utilisation of bioenergy from waste, using incineration or gasification, needs a pan-European view. This refers to the source of waste, the composition of waste, local and global energy demand as well as the co-operation with the involved stakeholders, such as governmental agencies, municipalities, suppliers of energy and the automotive industry.

The basic hypothesis in the project is that a network of stakeholders is necessary to reach a consensus with the aim of increasing the utilisation of bioenergy from waste. The stakeholder network is also important for a quick dissemination of the results of the project.

Purpose

- To gain knowledge about the most important barriers for an increased utilisation of energy from biomass from waste through incineration or gasification.
- To gain knowledge about the barriers for the utilisation of bioenergy from waste as motor fuels.
- To gain knowledge about the conditions to remove the barriers in order to increase the market share for bioenergy from waste.
- Present a proposal for a future network with the purpose of achieving an increased market share for bioenergy from waste.

Methodology

The work in the project consisted mainly of 5 phases:

Phase 1:	Survey of stakeholder groups
Phase 2:	Survey and analysis of arguments against incineration and gasification of waste
Phase 3:	Survey of barriers regarding technology, economy, legislation, environmental impact and transport logistics including a cost estimation for a plant producing motor fuel from waste
Phase 4:	Assessment of the market opportunities and production potential of energy from waste in Sweden, Norway, Germany and the EU
Phase 5:	Proposal for the utilisation of a network in order to achieve an increased market share of bioenergy from waste

The reference group

In the first phase key actors were identified and a reference group were formed including these experts. The members of the reference group are listed below.

First name	Surname	Company/organisation/Institution
Wlodzimierz	Blasiak	Royal Institute of Technology, Department of Material Science and Engineering/Metallurgy.
Henrik	Boding	Ecotraffic ERD^3 AB
Björn	Dahlroth	KSL, Stockholm County Association of Local Authorities
Björn	Ejner	Swedish Environmental Protection Agency
Tomas	Ekbom	Nykomb Synergetics AB
Daniel	Ingman	Nykomb Synergetics AB
Åsa	Hagelin	RVF - The Swedish Association of Waste Management
Tore	Hagen	Norsas AS
Erik	Herland	LRF Federation of Swedish Farmers
Gunnar	Herlö	Organic Power ASA
Karl-Georg	Høyer	Western Norway Research Institute
Sven	Järås	Royal Institute of Technology, Chemical Engineering and Technology
Friedemann	Mehlhose	Future Energy GmbH
Göran	Petersson	Chalmers University of Technology, Chemical Environmental Science
Lennart	Ryk	Söderenergi
Peter	Schmidt	Methanex Europe S.A./N.V
Jan-Olov	Sundqvist	IVL Swedish Environmental Research Institute
Lars	Waldheim	TPS Termiska Processer AB
Staffan	Ågren	The Ragnar Sellberg Foundation

Arguments for and against incineration and gasification of waste

The strongest arguments for energy recovery from waste are connected to energy demand. Putting waste on landfills is seen as a waste of useful energy and an inefficient use of land and nature. Also the high biomass content is an important argument. The argumentation is focused on the problems concerning waste volumes today and in a near future. The spokesmen for incineration consider the emissions from incineration are no longer problematic for modern plants and that pollutants in ashes are stable and stay in the ash. In comparison with composting and anaerobic digestion the problems with toxic substances and metals in the waste still remain after treatment and may even be more complicated. Gasification has the advantage of not causing dioxins.

The arguments against thermal treatment of waste are almost entirely focused on emissions and toxic substances, mainly dioxins, in the ash. Also not regulated, unknown emissions and substances in the gases and the ash, are pointed out as risks for human health. The need for landfilling is still considered as a problem since the increasing waste volumes require landfill facilities for the ashes. The campaigns against incineration are adressed to people's emotions and fear of the unknown (which has a strong effect). An argument on energy is the loss of energy used in manufacturing when a product is combusted.

The opponents on incineration have a more long-term view with a change in waste handling system promoting increased reuse and recycling.

Consequently, both sides have good and important arguments and one opinion they have in common is; the need for reduction of pollutants and toxic substances in society.

The problematic issues within thermal conversion of waste

Definition of the "waste" refers to a large variety of materials with well distinguishable differences in their elemental composition, physical and chemical properties, ash and moisture content and energy content. Wastes from industries are normally homogeneous materials having a well-defined composition. Municipal solid waste (MSW) on the other hand consists of different fractions. The amount and properties of each fraction are usually household- and site specific. Too high content of moisture and non-combustible materials, such as glass and metals in the waste makes it a less attractive material as an energy source and in extreme cases energy must be supplied for its destruction.

Emission control and flue gas cleaning systems are necessary equipment within waste combustion for elimination of the risks of emitting environmental pollutants. There is a clear relationship between the amount of the pollutant released during combustion and the content of the pollutant precursors in the raw material. Because of variations in the quality of the raw material and uncertainties upon the amount pollutant precursors the capacity of the gas cleaning systems must be dimensioned in a manner for being able of handling a maximum possible emission, i.e. a worst case scenario. Generally the most problematic issues in thermal treatment of waste concerns two main categories:

a) Environmental aspects

b) Plant and process specific aspects

The environmental aspects include questions such as emission of hazardous compounds to air, water and in solid by-products. The plant specific questions are the low efficiency relative other fuels, high erosion and corrosion rates and problems related to the disposal of by-products.

The major barriers within thermal treatment of waste are non-technical. More stringent demands can technically be achievable to almost any level, penalised by a rapidly increasing treatment cost. However, alternative treatment procedures (composting, anaerobic digestion) entail the risk of even higher costs of treatment, as large masses of residues requiring post-treatment are generated. Incineration of these can become a necessary part of such Waste-to-Energy (WtE) installations.

A techno- economic barrier is presently the low efficiencies for power production due to corrosion. In the waste minimising hierarchy (preventing, recycling, energy recovery, disposal) adopted by the EU, a breakthrough in the complex of superheater corrosion reduction could move energy recovery one full step up from recycling in this hierarchy.

DME production through gasification

A principal specification and a cost estimation for a conceivable plant producing motor fuel from waste have been made. The gasification plant setup is focused on the waste pretreatment and the gasifier technique, as well as the gas cleaning processes. These processes are identified as the most important, whereas processes as DME or methanol production from synthesis gas can be regarded as well-proven technology and therefore given lower priority in the report.

It should be emphasised that the uncertainties in the results ultimately depends on the site conditions and what agreements that may be contracted. If slag may be approved as building material, to be used in roads for instance, this may constitute revenues instead of the cost shown. Furthermore, the process may be configured for additional power production.

The total cost as well as the operating costs associated with the implementation of this waste-to-motor fuel plant could be handled differently. The main argument for using this approach is that when a municipality is discussing to erect an incineration plant, it is the incremental cost for choosing the gasification plant instead that is relevant. That is, the same functions are delivered with the gasification plant as with the incineration plant; the total amount of waste to be deposited is reduced and heat could be produced. Above these features, automotive fuel is delivered. The cost per unit DME or methanol produced is therefore calculated with respect to the complete plant cost and the *additional* cost for the gasifier choice, as well.

Since the district heat production in this specific configuration is smaller than for the incineration alternative, there is a negative sign on the district heating revenue.

The estimated cost for a reference incineration plant handling 22 tonnes of waste per hour is EUR 110 million. To compare this with the gasification plant, the cost is scaled relative the waste capacities resulting in a total investment cost of EUR 180 million. The incremental capital cost for the gasification plant is the difference in capital costs between the waste-to-motor fuel plant investment cost of EUR 346 million and the EUR 180 million for the reference incineration plant.

The comparison to the incineration plant, as well as the absolute costs and revenues associated with the waste-to-motor fuel plant, is shown in the table below. It is noticed that the total incremental cost for building a gasification plant, instead of an incineration plant, exceeds the absolute cost. This is related to the large revenues from the waste, which naturally is the same for both the incineration and gasification alternatives, and the revenues from district heating sales that is less for the gasification alternative.

When comparing the revenues for the absolute and the incremental part, a price has been put on the DME calculated from the current price on diesel fuel. The price on the DME therefore equals the diesel price on energy terms, which is taken as EUR 0.76/litre diesel equivalent. The production cost marginally exceeds this diesel equivalent price. Considering the "worst case" scenario and most of the costs taken on their conservative boundary, this small difference is not frightening. The sensitivity study shows the large influence from a relatively small increase in tipping fee. A gradually increasing fuel price for conventional fossil fuels will decrease the difference further and make the waste-to-motor fuel concept indeed viable.

The production of automotive fuels via gasification of waste is a technically feasible process, generating a DME yield of 31% on an energy basis. The single process layout investigated, given a certain waste composition with high inert content, results in a production cost for DME of EUR 0.82/litre diesel equivalent.

The waste-to-motor fuel plant fulfils, in principle, the same targets as the incineration plant, to a higher cost. This is compensated by an additional, higher quality product stream. This also results in a higher exergy efficiency for the gasification configuration than for the incineration alternative, calculated as 34 and 23% respectively. The gasification alternative has a lower energy efficiency than the incineration plant, but the flexibility is higher, as well as the utilisation of waste as feedstock for an automotive fuel is exergetically favourable.

Production cost divided into cost components, shown in MEUR. Left column shows total plant cost and right column shows incremental costs compared to reference incineration plant

	MEUR/y *(tot)*	MEUR/y *(incr)*
Revenues		
Gate fee (a)	17.5	0
DME (b)	35.3	35.3
District heating ©	4.0	-17.5
Sulphur revenue (d)	0.068	0.068
Total revenues:	**56.9**	**17.9**
Costs		
Capital (e)	32.7	17.0
Operation and maintenance (f)	13.5	4.8
Electrical power consumption (g)	6.9	5.5
Slag (h)	7.0	0
Total costs:	**60.1**	**27.3**
Gross profit	-3.2	-9.3
Daily DME production [tpd]	170.3	170.3
Production cost DME [EURc/kWh]	8.7	10
Production cost DME [EUR/tonne]	679	787
Production cost per diesel equivalent [EUR/l] (i)	0.82	0.95

The results of this study show that production of automotive fuels from waste has potential to be an environmentally and economically good solution in the future. With a gate fee of fully 50 EUR/ton the cost for the automotive fuel is in parity with the price of diesel oil. By further optimisation this can be improved to give margins to profit and fuel tax. Since the produced fuel is based mainly on biomass this part should be exempted from fossil fuel taxes.

Improvements would also be possible with a higher quality of the waste. A well specified waste raw material with small variations in composition make a more effective plant design possible with improved overall economy. Studies on automotive fuel production by gasification in a full scale demonstration plant using pure wood waste (forest residues), a much better raw material than waste, gives a cost of 6.2 EURc/kWh compared to 8.7 EUR/kWh in this study. This indicates the potential in possible cost reductions by increased waste quality.

Questionnaire survey on barriers

A survey of barriers for the utilisation of bioenergy from waste was carried out. These barriers comprise of a variety of different areas, such as technology, economy, legislation and environmental impact. The Reference Group has had an essential role in the accomplishment of this work. Questionnaires were sent to members of the reference group and other important persons in the field of waste management.

The survey of barriers to incineration/gasification of waste revealed that, among the stakeholders in the project, there are many different views on the importance of the various barriers. This is reflected through the answers to the questions, where in total, almost all answer alternatives were chosen by the respondents altogether. However, there were also some trends in the stakeholder groups, which could be seen by the ranging of the answers.

A wide range of issues presented for the Reference Group were considered as constituting very important barriers for the increased use of gasification/incineration of waste. These covered all three sub-systems 1) input material, 2) gasification/ incineration process and 3) products. The important barriers are also of different kinds, either in the form of 1) environmental, 2) regulative/legislative, or 3) economical barriers.

It is thus possible to conclude that the barriers to incineration/gasification of waste are not limited to one or a few key barriers. It is on the contrary a large set of barriers that must be overcome for increased utilisation of waste by incineration/gasification. Neither is it possible to conclude that the most central barriers are connected to one single part of the overall system for incineration/gasification of waste. There are important barriers present in many areas, connected to the various sub-systems.

Barriers of high importance:

- Poor quality of input material (waste) is a barrier for making gasification economically feasible.
- The requirement of very homogenous input material (waste) can be a limitation of the gasification technology.
- Gasification is a high-risk technology for investors due to its complicity, requiring large-scale production in order to be commercially feasible.
- The fact that the gasification technology is not well known, with just a few demonstration plants worldwide, in contrast to incineration technology that is well known, might constitute a barrier to gasification.
- The cost of products from gasification is too high for competitiveness with products obtained by other routes.
- Increases in number of incineration plants might out-compete gasification regarding available waste material.
- The EU taxation act, which allows tax-exemption for pilot tests only, is an important barrier for increased use of biofuels.

- Electricity and heat from gasification can be produced cheaper by incineration.
- Waste incineration/gasification may be in conflict with goals of waste reduction, increased product reuse and material recycling.
- The necessary technology is not yet developed for use of biofuels from gasification.
- The EU definition of input material as waste, and not as resource, may imply restrictions for incineration/gasification.

Market opportunities and production potential

The analysis aims at determining the amount of waste that could be utilised as raw material, and their potential for producing fuel, electricity and heat production in Norway, Sweden, Germany and Europe. Using the conversion rate ranges for the use of state-of-the-art technology, it is possible to estimate the production potentials for these forms of renewable energy from waste material. Three different cases for the utilisation of waste energy are applied:

Case 1: Heat production only

Case 2: Production of electricity plus heat

Case 3: Production of motor fuel plus heat

The summary of the result from the analysis of potentials for energy from waste in Norway, Sweden, Germany and Europe is shown in the table below.

Potential of not utilised energy from waste in Norway, Sweden, Germany and Europe.

	Norway	Sweden	Germany	Europe
Available waste (million tons)	0.5	2.1	19.5	117.3
MeOH production potential (million tons)	0.1	0.4	4.0	23.9
MeOH replacement potential (%)	1.7	3.3	3.6	4.5
Electricity production potential (TWh)	0.4	1.7	16.2	97.7
Electricity replacement potential[1] (%)	0.4	1.3	0.3	3.9
Heat alone (TWh)	1.3	5.8	54.6	328.5
Heat in combination with el. (TWh)	0.9	3.9	36.9	222.0
Heat in combination with fuel (TWh)	0.2	1.0	9.9	59.8

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[1] The calculations of electricity replacement potential for Norway and Sweden are based on total electricity consumption, while the cooesponding figures for Germany and Europe are based on total electricity production.

Network

The objective is to propose the utilisation of a network in order to achieve an increased market share of bioenergy from waste in the future. The work has been carried out by interviews, questionnaires and workshop discussions.

There is one main reason why large amounts of waste are put on landfills instead of energy recycled. Landfilling is cheaper! That implies that alternative energy sources can be used to produce power and heat to a lower cost. There is also a strong public opinion against waste incineration in many countries due to its bad reputation concerning emissions. This may affect politicians and decision-makers to be more interested in other solutions than incineration. Gasification is in this aspect a more unknown technology having possibilities to get attention but it is not enough demonstrated and the high investment costs are a hindrance.

The demand for heat is less in the southern Europe than in the northern parts. That may be one reason why energy from waste in combination with district heating has been so successful in Sweden. A demand for heat is an important condition to a good plant economy even if power is produced. In general there are few waste-to-energy plants in Europe.

Participants in a network for increased use of energy from waste should represent waste management, energy companies, municipalities, governments, politicians and the EU-administration. Even the manufacturing industry should be represented.

The main task for the network should be to clarify conditions and data as a source of information and open discussions. Politicians and the public need more information. Politicians need tools and facts to be able to make correct decisions on waste and energy issues. Therefore trustworthiness and reliability should be fundamental. The network should work for exchange of reliable information and support and fund research and cooperation between the waste sector and energy sector. Gasification technology for solid biofuels needs support for further development.

The network should also work for equal market conditions for energy from waste by the following activities:

- Stimulate more commercialism and private enterprises.
- Stimulate internal trade within the EU
- Create stable political conditions
- Make it possible to utilise waste as mainly a biofuel
- Question the waste hierarchy
- Include power from waste in the system for Green certificates for electric power
- Introduce equal emission regulations for different energy plants
- Clearly define the difference between recycling and destruction
- Introduce landfill tax to direct waste quantities from landfills to recycling alternatives, e.g. incineration.

Automotive fuels from waste

The gasification technology enables production of fuels suitable for automotive purposes. Several studies on fuel production from gasification of biomass have pointed out methanol, DME (Dimethyl ether) and FTD (Fischer-Tropsch Diesel) as the most economically and environmentally best fuels in a well-to-wheel perspective. Even hydrogen can be produced but are a much more expensive fuel.

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 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[2], which further reduce the NO_X emissions compared to diesel 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. 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. Although emission results also look very promising, much basic research is needed to utilise the full potential for emission reductions compared to diesel oil.

Alcohols, methanol and ethanol, 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 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.

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.

Methanol and ethanol 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 in the fuel. 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.

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Conclusions

Waste recovery should be encouraged, primarily through sorting at source. Waste segregation at an early stage simplifies recycling of products and materials as well as the use of waste as raw material for motor fuel production. The latter is considerably simplified if the waste composition is well known with small variations in constitution.

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[2] Exhaust Gas Recirculation

Sorted waste fractions make high quality requirements possible by continuos mixing the fractions to a suitable raw material.

The main reason why waste with energy content still is put on landfills is economical. As long as landfilling is cheap there are no incentives for large investments in thermal treatment plants. The situation is, however, not the same all over Europe. In Sweden for example incineration in combination with district heating is well established.

The strongest arguments for energy from waste are connected to energy demand such as demand for biobased energy and security of energy supply. Even the opposition to waste incineration agrees on that energy utilising is better than landfilling but the anxiety over pollutants formed by incineration is a stronger argument against. The opposition advocates reuse and recycling. Since gasification is not well known by people in general it is regarded as incineration even though it has the benefit of not creating dioxins. Consequently, both sides have good and important arguments and they have one argument in common; reduction of pollutants and toxic substances in society.

Incentives must be created in order to make recycling and energy recovery more attractive then landfilling. Taxes are one way, regulations another. This study shows that both ways are necessary. There also has to be a demand for the products. The demand for heating is less in southern Europe than in the northern parts but electric power and automotive fuels are requested all over the world. The results of this study show that production of automotive fuels from waste has potential to be an environmentally and economically good solution in the future. With a gate fee of fully 50 EUR/ton the cost for the automotive fuel is in parity with the price of diesel oil. The assumed gate fee is not very high and in some countries waste fees of 100 EUR or more are common. By further optimisation these results can be improved to give margins to profit and fuel tax. Since the produced fuel is based mainly on biomass this part should be exempted from fossil fuel taxes.

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The gasification technology for solid biofuels need to be further developed and the high investments required and the lack of demonstration plants are important barriers. The growing interest for gasification of pure biomass, such as forest residues, for automotive fuel production might though lead the way for waste as well.

Changes in the waste regulations are requested. For example, MSW is not accepted as a biofuel even though typically 80% of the content is biomass. This needs to be changed.

The major barriers within waste thermal treatment are non-technical. More stringent demands can technically be achievable to almost any level of the penalty of rapidly increased cost of treatment. However, alternative treatment procedures (composting, biogas) entail the risk of even higher costs of treatment, as large masses of residues requiring post-treatment are generated. Incineration of these can become a necessary part of such WtE installations.

The not utilised energy in MSW and industrial manufacturing waste put on landfills in Europe is estimated to have a potential to replace 4.5% of the diesel and petrol fuel in Europe. This is a large potential and could be increased in a long term if new waste-to-motor fuel plants replace old incineration plants.

Participants in a network for increased use of energy from waste should represent waste management, energy companies, municipalities, governments, politicians and the EU-administration. Even the manufacturing industry should be represented as they are in FEAD. The main task for the network should be to clarify conditions and data as a source of information and open discussion. Politicians and the public need more information. Politicians need tools and facts to be able to make correct decisions on waste and energy issues. Therefore trustworthiness and reliability should be fundamental. The network should work for exchange of reliable information and support and fund research and cooperation between the waste sector and energy sector. Gasification technology for solid biofuels needs support for further development

The network should also work for equal market conditions for energy from waste by the following activities:

- Stimulate more commercialism and private enterprises.
- Stimulate internal trade of waste within the EU
- Create stable political conditions
- Make it possible to utilise waste as mainly a biofuel
- Question the application of the waste hierarchy
- Include power from waste in the system for Green certificates for electric power
- Introduce equal emission regulations for different energy plants
- Clearly define the difference between recycling and destruction
- Introduce landfill tax to direct waste quantities from landfills to recycling alternatives, e.g. incineration.

Sammanfattning (Summary in Swedish)

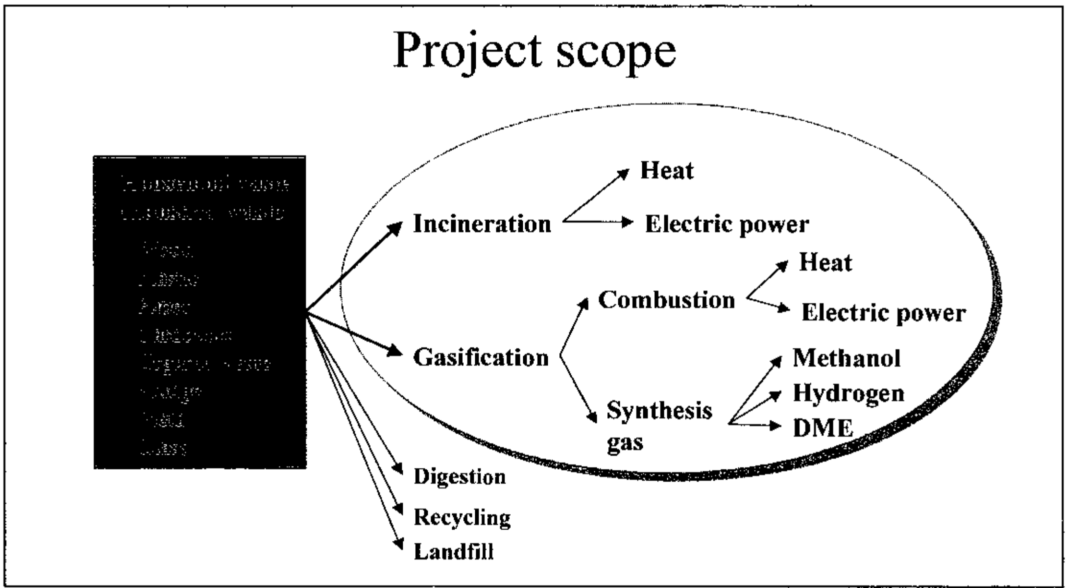
Introduktion

Brännbart avfall i samhället är delvis sådant som är kommunens ansvar men också sådant som härrör från industriell verksamhet. I den förra kategorin ingår hushållsavfall som efter utsortering av papper, förpackningar, glas och metall och kan anses utgöra ett biobränsle. Den fossila andelen har vid flera undersökningar visats vara 15-20% beroende på grad av källsortering. Annat brännbart avfall utgörs exempelvis av bygg- och rivningsavfall, park- och trädgårdsavfall samt från industrier, jord- och skogsbruk.

Det finns för närvarande stora mängder brännbart avfall tillgängligt. Genom lagstiftning och deponiskatter är avfallet tillgängligt till ett negativt pris i vissa länder.

Intresset för biodrivmedel har ökat starkt de senaste åren och ett skäl till detta är den internationella ambitionen att minska utsläppen av växthusgaser. Det är också en fråga om att trygga energiförsörjningen och inte enbart av det skälet att Sverige och EU är alltmer beroende av importerad fossil energi utan också att oljetillgångarna är begränsade. Oljan kommer inte att ta slut helt men kostnaderna kommer att stiga till nivåer där biobaserade drivmedel kan konkurrera prismässigt.

Omfattning och organisation



Projektet omfattar identifiering och fastställning av de viktigaste hindren för utnyttjandet av bioenergin i avfall genom förbränning eller förgasning. Möjligheterna att eliminera dessa hinder kommer att undersökas i syfte att öka marknadsandelen för förnybar energi inom EU med ett särskilt focus på drivmedel. Arbetet kommer att genomföras i nätverksform som omfattar intressenter i hela kedjan från avfallsinsamling via energiproduktion till slutanvändning i fordon. Projektet är vidare inriktat på förhållandena i norra Europa men målsättningen är att också att sprida kunskap inom hela EU. Utgångspunkten är att ett effektivt utnyttjande av bioenergin i avfall genom förbränning eller förgasning kräver ett EU-perspektiv. Inverkar gör faktorer som; avfallets ursprung och sammansättning, lokalt och globalt energibehov så väl som samarbete med intressenter som tex myndigheter, kommuner, energibolag och fordonsindustrin.

Den grundläggande hypotesen i projektet är att ett nätverk av intressenter är nödvändigt för att nå samsyn i målsättningen att öka användningen av bioenergin i avfall. Nätverket är också viktigt för att snabbt sprida projektresultaten.

Syfte

- Att skaffa kunskap om de viktigaste hindren för ett ökat utnyttjande av energi från biomassa från avfall, genom förbränning eller förgasning.
- Att skaffa kunskap om de hinder för att utnyttjande av bioenergin i avfall som drivmedel.
- Att skaffa kunskap om förutsättningarna för att undanröja hinder i syfte att öka marknadsandelen för bioenergi från avfall.
- Ge förslag till utformningen av ett framtida nätverk med syfte att erhålla ökad marknadsandel för bioenergi från avfall.

Metodik

Det huvudsakliga arbetet är uppdelat på 5 faser:

Fas 1:	Genomgång av intressentgrupper
Fas 2:	Genomgång och analys av argument för och emot förbränning och förgasning av avfall.
Fas 3:	Genomgång av hinder avseende teknik, ekonomi, lagstiftning, miljöpåverkan och transportlogistik inklusive en uppskattning av kostnader för en anläggning för produktion av drivmedel ur avfall.
Fas 4:	Bedömning av marknadsmöjligheter och potentialen för energi ur avfall i Sverige, Norge, Tyskland och EU.
Fas 5:	Lämna förslag på utformningen av ett nätverk för att öka marknadsandelen för bioenergi från avfall.

Referensgruppen

I den första fasen identifierades nyckelpersoner och en referensgrupp inehållande dessa experter bildades. Medlemmarna i gruppen framgår av nedanstående lista..

Förnamn	Efternamn	Företag/organisation/Institution
Wlodzimierz	Blasiak	Kungliga Tekniska Högskolan, Avdelningen för Materialvetenskap och metallurgi
Henrik	Boding	Ecotraffic ERD^3 AB
Björn	Dahlroth	KSL, Kommunförbundet i Stockholms Län
Björn	Ejner	Svenska Naturvårdsverket

Tomas	Ekbom	Nykomb Synergetics AB
Daniel	Ingman	Nykomb Synergetics AB
Åsa	Hagelin	RVF - The Swedish Association of Waste Management
Tore	Hagen	Norsas AS
Erik	Herland	LRF Lantbrukarnas Riksförbund
Gunnar	Herlö	Organic Power ASA
Karl-Georg	Høyer	Vestlandsforsking
Sven	Järås	Kungliga Tekniska Högskolan, Kemiteknik
Friedemann	Mehlhose	Future Energy GmbH
Göran	Petersson	Chalmers tekniska högskola, Kemisk Miljövetenskap
Lennart	Ryk	Söderenergi
Peter	Schmidt	Methanex Europé S.A./N.V
Jan-Olov	Sundqvist	IVL Svenska Miljöinstitutet
Lars	Waldheim	TPS Termiska Processer AB
Staffan	Ågren	Ragnar Sellbergs stiftelse

Argument för och emot förbränning och förgasning av avfall.

De starkaste argumenten för energi ur avfall är kopplade till energibehovet. Att deponera avfall ses som ett slöseri med energi och ett ineffektivt utnyttjande av mark och natur. Den höga andelen av biomassa i avfallet är ett viktigt argument. Argumentationen utgår ifrån problemen med dagens och framtidens avfallsmängder. Förespråkarna för förbränning anser att emissioner från förbränning inte är ett problem i dagens anläggningar och att farliga ämnen i askan är stabila och är låsta i askan. Som jämförelse nämns att problemen med farliga ämnen och metaller i avfallet även är ett problem vid kompostering och rötning. Kanske till och med ett större problem. Förgasning har fördelen att dioxiner inte bildas.

Argumenten mot termisk behandling av avfall är nästan uteslutande fokuserade mot emissioner och farliga ämnen, huvudsakligen dioxiner, i askan. Även oreglerade emissioner och ämnen i rökgaserna och i askan pekas ut som hälsorisker. Behovet av deponering anses utgöra ett problem även vid förbränning på grund av de ständigt ökande avfallsmängderna eftersom askan och slaggen måste deponeras. Anti förbränningskampanjer tar alltid fasta på mänskliga känslor och rädslan för det okända. Energifrågan finns med i motargumenten men då som en förlust av den energi som går åt då en vara produceras.

Motståndarna har en mer långsiktig, visionär, syn innefattande ett förändrat system för avfallshantering som gynnar ökad återanvändning och återvinning.

Således har både förespråkarna och motståndarna bra och viktiga argument och en åsikt som de har gemensamt är; behovet av minskade föroreningar och farliga ämnen i samhället.

Svårigheter med termisk energiutvinning ur avfall

Definitionen av avfall innefattar en vid flora av material med var för sig väl definierade skillnader i sammansättning, fysiska och kemiska egenskaper, askinnehåll, fukthalt och energiinnehåll. Industriavfall omfattar vanligen homogena material med väl definierad sammansättning. Hushållsavfall däremot är sammansatt av olika fraktioner. Mängden av varje fraktion och sammansättningen varierar mellan olika hushåll och områden. Höga fukthalter och obrännbara material, som t.ex. glas och metaller, gör avfallet mindre attraktivt för energiutvinning och i extrema fall måste energi tillföras för att avfallet ska kunna destrueras. Kontinuerlig emissionsövervakning och rökgasreningssystem är nödvändiga för att eliminera riskerna för utsläpp av föroreningar. Det finns ett tydligt samband mellan mängden föroreningar i rökgaserna och mängden föroreningar, och ämnen som kan bilda föroreningar, i det ingående avfallet. Eftersom mängden föroreningar efter förbränning varierar måste rökgasreningssystemen dimensioneras för att klara det högsta möjliga halterna av föroreningar. Generellt kan problemområdena för termisk avfallsbehandling delas in i två kategorier:

a) Miljöpåverkan

b) Anläggnings- och processpecifika problem

Miljöpåverkan omfattar t.ex. emissioner av farliga ämnen till luft, vatten och fasta restprodukter. De anläggnings- och processpecifika problemområdena låg energieffektivitet i förhållande till andra bränslen, förslitning och korrosion samt problemställningar kring deponering av restprodukter.

Problemen för termiska behandling av avfall är icke-tekniska. Högre krav på rening t.ex. klaras rent tekniskt men till snabbt stigande kostnader. I jämförelse med andra behandlingsmetoder (kompostering, rötning) är risken för ännu högre kostnader för efterbehandling av stora mängder förorenade restprodukter som kan behöva att förbrännas i efterhand.

Ett tekniskt/ekonomiskt problem är låg verkningsgrad för elproduktion pga korrosionsproblem. Skulle man kunna lösa problemen med korrosion i överhettaren skulle lyfta flytta energiåtervinning ett steg upp i EU:s avfallshierarki (förebygga, återanvända, återvinna, energiutvinna, deponera).

Produktion av DME genom förgasning

En principiell anläggning för produktion av DME har skisserats i syfte att göra en kostnadsuppskattning för drivmedel från avfall. Arbetet har fokuserats på förbehandling av avfallet, förgasningsteknik och gasrening. Dessa processteg har bedömts vara de viktigaste att studera då DME- och metanolproduktion från syntesgas redan är väl utprovad teknik.

Det bör betonas att det finns en osäkerheten i resultaten och att dessa påverkas av en var en anläggning lokaliseras och vilka avtal som kan tecknas. Om slaggen t.ex. kan användas som byggnadsmaterial (vägar) så kan det medföra intäkter eller lägre kostnader. Anläggningen kan också kompletteras med produktion av elkraft.

De totala kostnaderna såväl som driftskostnaderna för en anläggning kan analyseras ur olika synvinklar. Huvudskälet till detta är att när exempelvis en kommun avser att uppföra en förbränningsanläggning är det skillnaden i kostnad för att uppföra en förgasningsanläggning som är intressant. Det innebär i för jämförelsen i detta fall att förbrännings- respektive förgasningsanläggningen har samma kapacitet för mängden avfall som ska tas emot och att värme produceras. Utöver detta produceras i förgasningsfallet även drivmedel. Kostnadsberäkningarna avser därför den totala kostnaden för anläggningen och dels merkostnaden för en förgasningsanläggning.

Eftersom värmeproduktionen blir lägre i drivmedelsfallet måste detta kompenseras vilket innebär en extra kostnad för förgasningsanläggningen.

Kostnaden för en motsvarande förbränningsanläggning har beräknats utgående från en befintlig anläggning för behandling av 22 ton avfall per timme. Kostnaden för denna har uppgetts till EUR 110 miljoner. Denna kostnad har skalats upp med en exponent på 0.6, motsvarande samma kapacitet som förgasningsanläggningen, till EUR 180 miljoner.

Kostnaderna och intäkterna för de två fallen redovisas i tabellen nedan. Det framgår att den totala merkostnaden för förgasningsanläggningen jämfört med förbränningsanläggningen överskrider totalkostnaden. Detta beror på de stora intäkterna från dels avfallet och dels värmeförsäljningen. De sistnämnda är dock lägre för förgasningsanläggningen.

I jämförelsen mellan intäkterna i det absoluta fallet och merkostnadsfallet har priset på DME beräknats utifrån en aktuell prisnivå på dieselolja och antagits till EUR 0.76/liter dieselekvivalent. Som framgår av tabellen är produktionskostnaden något högre än drivmedelspriset. Denna merkostnad är dock inte avskräckande hög om man beaktar att beräkningarna utgår från "pessimistiska" värden. Känslighetsanalysen visar vilken stor inverkan intäkterna från avfallet har. Ett successivt ökande oljepris kommer också att minska denna merkostnad.

Drivmedelsproduktion ur avfall via förgasning är en genomförbar process med ett drivmedelsutbyte på 31% på energibas. Denna studie, utgående från ett relativt sett dåligt råmaterial och utan några gjorda optimeringar, ger en DME-kostnad på EUR 0.82/liter dieselekvivalent. Både investeringskostnaderna och personalkostnaderna är högre i förgasningsalternativet vilket innebär att förgasningsalternativet lever upp till samma mål som förbränningsalternativet men till en högre kostnad. Detta kompenseras av att DME är en mer högkvalitativ produkt. Det resulterar också i en högre exergi effektivitet i förgasningsfallet på 34% jämfört me 23% i förbränningsfallet. Energieffektiviteten är dock lägre i förgasningsalternativet men flexibiliteten är större såväl som att drivmedelsproduktion ur avfall är att föredra ur exergisynpunkt.

Produktionskosnader i MEUR uppdelade på komponenter. Den vänstra kolumnen visar den totala anläggningskostnaden och den högra kolumnen visar merkostnaden jämfört med en motsvarande förbränningsanläggning.

	MEUR/år	MEUR/år
	(tot)	*(ökning)*
Intäkter		
Mottagningsavgift	17.5	0
DME	35.3	35.3
Fjärrvärme	4.0	-17.5
Svavel	0.068	0.068
Intäkter totalt:	**56.9**	**17.9**
Kostnader		
Kapital	32.7	17.0
Drift och underhåll	13.5	4.8
Elanvändning	6.9	5.5
Slagg	7.0	0
Kostnader totalt:	**60.1**	**27.3**
Bruttomarginal	-3.2	-9.3
DME produktion per dag [tpd]	170.3	170.3
Produktions kostnad DME [EURc/kWh]	8.7	10
Produktions kostnad DME [EUR/ton]	679	787
Produktions kostnad per diesel ekvivalent [EUR/l] (i)	0.82	0.95

Resultatet av studien visar att drivmedelsproduktion ur avfall har potential att bli ett miljöanpassat och ekonomiskt bra alternativ i framtiden. Med en mottagningsavgift på drygt EUR 50/ton blir produktionskostnaden för drivmedel i nivå med dagens pris på dieselolja. Genom optimeringar kan detta förbättras och ge utrymme för vinstmarginal och drivmedelsskatt. Drivmedlet ska inte belastas med samma skatter som för fossila drivmedel eftersom biomassaandelen är normalt sett ca 80%.

Förbättringar är också möjliga genom att använda ett avfall med högre kvalitet. Ett avfall med väl specificerat innehåll och med små variationer i sammansättning möjliggör ett mer kostnadseffektivt utförande på anläggningen. Tidigare studier på en fullskalig demonstrationsanläggning för drivmedelsproduktion som använder ren biomassa (skogsavfall) som råvara ger en produktionskostnad på EURc 6.2/kWh jämfört med EURc 8.7/kWh för avfall i denna studie.

Enkätundersökning

Som en del i att kartlägga hinder för utnyttjande av bioenergi i avfall har en enkätundersökning genomförts. Dessa hinder omfattar ett flertal olika områden som t.ex.

teknik, ekonomi, regelverk och miljöpåverkan. Referensgruppen har haft en aktiv roll i detta arbete. Enkäter har skickats till referensgruppen och ytterligare några nyckelpersoner.

Enkätundersökningen visar att uppfattningen vad som är viktiga hinder varierar kraftigt inom svarsgruppen. Detta återspeglar sig genom att nästan samtliga svarsalternativ i undersökningen har valts någon gång. Det gick dock att utläsa vissa trender bland svaren vilket visar sig när svaren rangordnas efter hur många personer som valt ett visst svar.

En stor mängd svar ansågs av gruppen utgöra viktiga hinder för ökat energiutnyttjande av avfall. Dessa hinder omfattar alla tre delsystemen 1) råmaterial, 2) förgasning/förbränning och 3) produkter. Dessa väsentliga hinder är också av olika karaktär; 1) miljö, 2) regelverk/lagstiftning och 3) ekonomi.

Man kan dra slutsatsen att hinder för förbränning/förgasning inte utgörs av några enstaka hinder. Det är tvärtom ett stort antal hinder som måste övervinnas för ökad energiutvinning. Det är däremot inte möjligt att dra några slutsatser om att de viktigaste hindren är kopplade till någon särskild del av förbrännings/förgasningssystemdelen. Viktiga hinder finns inom många områden i de olika delsystemen.

Viktiga hinder:

- Låg kvalitet på råvaran (avfallet) utgör ett ekonomiskt hinder för förgasning.
- Kravet på en homogen råvara kan utgöra en begränsning för förgasningstekniken.
- Förgasning är investeringsmässigt en hög-risk teknik på grund av dess komplexitet som innebär att endast storskalig produktion kan motiveras ekonomiskt.
- Det faktum att förgasningstekniken inte är väl etablerad, med endast ett fåtal demonstrationsanläggningar världen över, jämfört med förbränning, kan utgöra ett hinder.
- Kostnader för produkter framställda genom förgasning är inte konkurrenskraftiga jämfört med andra produktionssätt.
- Det ökande antalet förbränningsanläggningar kan komma att konkurrera ut förgasning med hänsyn till tillgängligt avfall.
- EU:s drivmedelsbeskattning, som endast tillåter skatteundantag för tillfälliga pilotprojekt är ett hinder för ökad användning av biodrivmedel.
- Elkraft och värme kan produceras billigare genom förbränning än genom förgasning
- Förbränning/förgasning av avfall kan motverka mål för avfallsminimering, ökad återanvändning och materialåtervinning.
- Fordonstekniken för användning av biodrivmedel för förgasning är inte fullt utvecklade (metanol-korrosivt och kallstartsproblem, bränslecellsfordon- långt till kommersialisering)
- EU:s definition på råmaterialet som ett avfall och inte som en resurs kan utgöra en begränsning för förbränning/förgasning

Marknad och produktionspotential

Målsättningen har varit att fastställa mängden avfall som inte utnyttjas samt potentialen för produktion av drivmedel, elkraft och värme i Norge, Sverige, Tyskland och Europa. Utgående från prestanda hos moderna anläggningar har är det möjligt att uppskatta produktionspotentialerna för dessa förnybara energiformer. Tre olika fall har beräknats:

Fall 1: Enbart värmeproduktion

Fall 2: Produktion av elkraft och värme

Fall 3: Produktion av drivmedel och värme

En sammanställning av potentialerna visas i tabellen nedan.

Potentialen för outnyttjad energy i avfall i Norge, Sverige, Tyskland och Europa.

	Norge	Sverige	Tyskland	Europa
Tillgängligt avfall (miljoner ton)	0.5	2.1	19.5	117.3
MeOH produktionspotential (miljoner ton)	0.1	0.4	4.0	23.9
MeOH ersättningspotential (%)	1.7	3.3	3.6	4.5
Elkraft produktionspotential (TWh)	0.4	1.7	16.2	97.7
Elkraft ersättningspotential (%)	0.4	1.3	0.3	3.9
Enbart värme (TWh)	1.3	5.8	54.6	328.5
Värme i kombination med elkraft (TWh)	0.9	3.9	36.9	222.0
Värme i kombination med drivmedel (TWh)	0.2	1.0	9.9	59.8

Nätverk

Syftet är att föreslå utnyttjandet av ett nätverk för att uppnå en ökad marknadsandel för bioenergi från avfall i framtiden. Arbetet har utförts genom intervjuer, frågeformulär och diskussioner i seminarier (Workshops).

Det finns en huvudsaklig orsak till varför stora kvantiteter av avfall deponeras på avfallsdeponier i stället för att återvinnas. Avfallsdeponier är billigare! Detta medför att de alternativa energikällorna kan användas för att producera el och värme till en lägre kostnad. Det finns också en kraftig opinion mot förbränning av avfall och i många länder beror detta dåliga rykte på emissionerna. Detta kan påverka politikerna och beslutsfattarna till att bli mer intresserade i andra lösningar än förbränning. Förgasning är i detta avseende en mer okänd teknik som har möjligheter att erhålla ökad uppmärksamhet men den har inte blivit tillräckligt demonstrerad och de höga investeringskostnaderna är ett hinder.

Behovet av värme är mindre i södra Europa än in de nordliga delarna. Detta kan vara en orsak till varför energi från avfall i kombination med fjärrvärme har varit så framgångsrik i Sverige. Ett behov av värme är en viktig förutsättning för en god ekonomi i anläggningen även om el produceras. I allmänhet finns det få anläggningar som producerar energi från avfall i Europa.

Deltagare i ett nätverk för en ökad användning av energi från avfall borde representera avfallshantering, energileverantörer, kommuner, administration på nationell nivå, politiker och EU-administrationen. Även tillverkande industri borde vara representerad.

Huvuduppgiften för nätverket borde vara att tydliggöra förutsättningar och fakta som en källa till information och för öppna diskussioner. Politikerna och allmänheten behöver mer information. Politikerna behöver verktyg och fakta för att kunna fatta rätt beslut i frågor som gäller avfall och energi. Därför är trovärdighet och tillförlitlighet fundamentala begrepp. Nätverket skall arbeta för ett utbyte av tillförlitlig information och stöd och skall finansiera forskning och samarbete mellan avfalls- och energisektorerna. Förgasningstekniken för fasta biobränslen behöver stöd för fortsatt utveckling.

Nätverket skall också arbeta för rättvisa marknadsförutsättningarna för energi från avfall genom följande kriterier:

- Stimulera affärsmässighet och privata företag
- Stimulera intern handel inom EU
- Skapa stabila politiska förutsättningar
- Skapa möjligheter att utnyttja avfall främst till biodrivmedel
- Ifrågasätta hierarkin inom avfallshanteringen
- Inkludera el från avfall i systemet för Gröna certifikat för elkraft
- Introducera likvärdiga emissionskrav för olika energiproduktionsanläggningar
- Klart och tydligt definiera skillnaden mellan återvinning och destruering
- Introducera skatter för deponering för att omdirigera avfall från deponier till återvinningsbara alternativ, t.ex. förbränning.

Drivmedel från avfall

Förgasningstekniken möjliggör produktion av drivmedel som är användbara till fordon. Flera studier av drivmedelsproduktion från förgasad biomassa har pekat ut metanol, DME (dimetyleter) och FTD (Fischer-Tropsch diesel) som de mest ekonomiska och miljömässigt bästa drivmedlen i ett livscykelperspektiv (well-to-wheel). Även vätgas kan produceras på detta sätt men det är ett mer kostsamt drivmedel.

DME är ett ”naturligt” drivmedel för dieselmotorer på grund av det exceptionellt höga cetantalet. Därför är samma effektivitet som för dieselolja möjlig för en dieselmotor som anpassats för drift med DME. DME är icke-toxisk och bör ha en inneboende möjlighet att signifikant minska de toxiska emissionerna i avgaserna i jämförelse med konventionella dieselbränslen. En signifikant reduktion av NO_X emissionerna för DME i jämförelse med dieselolja har konstaterats i ett flertal studier. Partikelbildningen kan i stort sett undvikas med DME i jämförelse med kolvätebränslen. DME kan också medföra en möjlighet att använda högre halter av EGR[3], vilket ytterligare minskar NO_X emissionerna jämfört med dieselolja. Eftersom DME är svavelfritt blir användningen av effektiva efterbehandlingssystem enklare med DME än med drivmedel som innehåller svavel.

Ett speciellt problem med DME som drivmedel är bränsleinsprutningssystemet. DME angriper de flesta elastomerer och därför måste fungerande tätningar utvecklas. Detta

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[3] Exhaust Gas Recirculation

problem är också uppenbart i distributionssystemet. Dessutom har DME en mycket dålig smörjförmåga och därför kunde en möjlighet vara att utveckla fungerade additiv för att förbättra smörjförmågan. Även om emissionsresultaten ser mycket lovande ut är mer grundläggande forskning nödvändig för att utnyttja den fulla potentialen till emissionsreduktioner jämfört med dieselolja.

Alkoholer, som metanol och etanol, har specifika fördelar i ottomotorer – dessa drivmedel är helt enkelt ”naturliga” ottomotorbränslen. För det första är oktantalet högre än för bensin, vilket är en fördel för en motortyp där det maximala kompressionsförhållandet är begränsat (knackning) av oktantalet. För det andra har alkoholerna ett högre förångningsvärme än bensin och eftersom energiinnehållet är lägre skulle en total förångning av alkoholerna ge en väsentligt lägre temperatur för bränsle-luft blandningen än bensin. En lägre temperatur medför en högre volymetrisk verkningsgrad.

Det största problemet med alkoholbränslen i ottomotorer i dag är den påtagliga ökningen av emissionerna när motorn kallstartas vid låg omgivningstemperatur. Detta problem bör vara möjligt att lösa i framtiden när ny motorteknik (t.ex. direktinsprutning) blir tillgänglig.

Metanol och etanol kan användas i dieselmotorer. En extern tändkälla, som t.ex. ett glödstift, förutsätts för att undvika användningen av en tändförbättrare i bränslet. Nödvändigheten att använda en extern tändkälla för alkoholerna är en påtaglig nackdel i jämförelse med andra alternativ som DME och FTD.

Slutsatser

Återvinning av avfall genom källsortering bör stimuleras. Sortering av avfall i ett tidigt skede underlättar såväl återanvändning, materialåtervinning och energiutvinning och drivmedelsframställning. Det senare underlättas väsentligt om avfallet är väl specificerat med små variationer i sammansättning. Sorterade avfallsfraktioner möjliggör att högt ställda kvalitetskrav kan realiseras genom att fraktioner kan blandas till önskade kvaliteter.

Skälen till att stora mängder avfall fortfarande deponeras är ekonomiska. Så länge deponering är billigt i relativ bemärkelse finns inte anledning till stora investeringar i termiska behandlingsanläggningar för avfall. Situationen är dock inte lika i hela Europa. I Sverige till exempel, är förbränning i kombination med fjärrvärme väl etablerat.

De viktigaste argumenten för energiutvinning ur avfall är kopplat till dels behovet av energi och bioenergi och dels till tryggad energiförsörjning. Även motståndare till avfallsförbränning anser det bättre att utnyttja energin i avfallet än att deponera det men oron över föroreningar som bildas vid förbränning sprids, är ett starkare argument mot. Motståndarna förespråkar återanvändning och återvinning. Förgasning som teknik är inte lika allmänt känt som förbränning vilket gör att förgasning, trots att t.ex inte dioxiner bildas, uppfattas som och likställs med förbränning. Sammanfattningsvis har både förespråkare och motståndare till termisk energiutvinning ur avfall både bra och viktiga argument och en sak har de gemensamt. Behovet av minskad spridning av föroreningar och farliga ämnen i samhället.

Incitament måste till för att energiåtervinning ska bli mer attraktivt än deponering. Skatter är ett sätt, regler och bestämmelser ett annat. Denna studie visar att båda är nödvändiga. Det måste också finnas en marknad för produkterna. Behovet av värme är mindre i södra Europa än i de norra delarna men elkraft och drivmedel efterfrågas världen över.

Resultatet av denna studie visar att drivmedelsproduktion ur avfall har potential att bli ett miljöanpassat och ekonomiskt bra alternativ i framtiden. Med en mottagningsavgift på drygt EUR 50/ton blir produktionskostnaden för drivmedel i nivå med dagens pris på dieselolja. Genom optimeringar kan detta förbättras och ge utrymme för vinstmarginal och drivmedelsskatt. Drivmedlet ska inte belastas med samma skatter som för fossila drivmedel eftersom biomassaandelen är normalt sett ca 80%.

Förgasningstekniken behöver utvecklas vidare och de höga investeringsnivåerna och bristen på demonstrationsanläggningar är utgör viktiga hinder för förgasningsteknikens utveckling. Det ökande intresset för förgasning av ren biomassa, t.ex. skogsavfall, för drivmedelsproduktion kan dock leda väg för även avfall som råmaterial.

Förändringar i regelverken för avfall efterfrågas. Hushållsavfall består t.ex. av ca 80% biomassa men räknas ändå i vissa avseenden som biobränsle. Detta måste ändras.

Problemen för termiska behandling av avfall är icke-tekniska. Högre krav på rening t.ex. klaras rent tekniskt men till snabbt stigande kostnader. I jämförelse med andra behandlingsmetoder (kompostering, rötning) är risken för ännu högre kostnader för efterbehandling av stora mängder förorenade restprodukter som kan behöva att förbrännas i efterhand.

Den outnyttjade energipotentialen i hushållsavfall och industriavfall som deponeras i Europa beräknas ha en energipotential att ersätta 4.5% av nuvarande användning av bensin och diesel. Detta är en stor potential som kan utökas ytterligare om äldre förbränningsanläggningar ersätts med moderna drivmedelsanläggningar.

Deltagare i ett nätverk för ökad energiutvinning ur avfall bör bestå av representanter från avfallsbolag, energibolag, kommuner, myndigheter, politiska partier och EU-administrationen. Tillverkningsindustrin bör också finnas med såsom de är idag i FEAD. Nätverkets huvuduppgift bör vara att klarlägga förutsättningar och fakta som informationsunderlag. Politiker och allmänhet behöver mer information. Politiker behöver också verktyg för och fakta för att kunna fatta riktiga beslut kring avfall och energifrågor.

Trovärdighet och pålitlighet ska vara fundamentalt för arbetet i nätverket. Nätverket ska arbeta för utbyte av tillförlitlig information och stödja forskning och samarbete avfalls- och energisektorn. Förgasningstekniken för avfall behöver stöd för fortsatt utveckling.

Nätverket ska också verka för att avfallsenergi ska få likvärdiga marknadsvillkor genom följande aktiviteter:

- Stimulera kommersialism och privat företagande
- Stimulera intern handel med avfall inom EU
- Skapa stabila politiska förutsättningar
- Göra det möjligt att utnyttja avfall som biobränsle
- Ifrågasätta tillämpningen av EU:s avfallshierarki
- Inkludera elkraft från avfall i systemet för Gröna certifikat
- Införa lika emissionskrav på olika typer av energianläggningar
- Klargöra skillnaderna i definition mellan återvinning och destruering
- Införa deponiskatt för att styra över avfall från deponering till återvinning t.ex genom förbränning

1 INTRODUCTION

1.1 Introduction and background

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, agriculture and forestry.

There are at present large quantities of household and industrial waste available. Due to the legislation and taxes on waste dumps, the fuel is available at a negative price. Taking the whole EU in consideration there are even more available in energy terms due to the not incinerated waste on one hand and the energy surplus of the incinerated waste on the other hand.

The interest in biofuels has increased the recent years and the reason for that are 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 Swedish National Energy Administration has calculated the potential of energy in waste in Sweden to 16 TWh. Today, 5.2 TWh is utilised in incineration with the main purpose of heat generation. As a comparison, the total energy use in the transportation sector is some 108 TWh. It is assumed that the potential from waste for the whole of EU would amount to 5-10% of the energy use in the transportation sector.

To increase the energy use further, the Swedish National Energy Administration had dedicated about 1.1 million Euro for research in the in the programme -Energy from waste- which is in progress year 2000-2003.

From year 2002 it is prohibited in Sweden to put sorted combustible waste on landfills but during 2002 exemptions from this legislation were made. The deposition of organic waste is prohibited from 2005 as a consequence of the EU landfill directive.

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.

1.2 Scope and work organisation

The scope of the project is to identify and assess the most important barriers for using bioenergy from waste through incineration or gasification. This will be carried out by investigating the possibilities for eliminating these barriers with the purpose of increasing the market share for this form of renewable energy in the EU, with the focus on motor fuels. The work will be carried out in a network comprising stakeholders in the whole chain; from the collection of the waste to the energy production and end use in the vehicles.

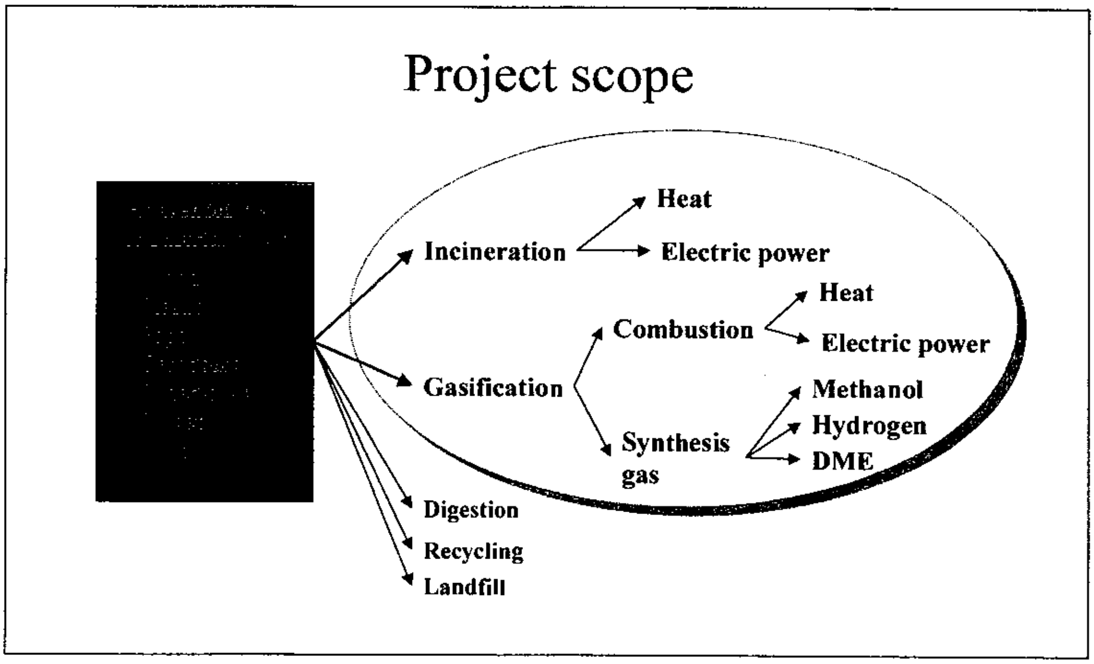

Figure 1. Project scope

The project comprises analytical studies of the barriers for:

- different types of waste suitable for recovery of bioenergy;
- methods of energy conversion from different types of waste;
- energy forms for various production processes and
- energy production for the use as motor fuel in vehicles.

The work in the project comprises various activities, e.g. legislation, economy, socio-economic effects, environmental impact, health effects, energy efficiency, life cycle assessment, transportation, logistics, storage and security.

The project has a primary focus on the conditions in Northern Europe, but the aim is also to compile and distribute knowledge within the whole of EU. In the project, representatives from Germany, Sweden and Norway participate but the basis for the study is that an efficient utilisation of bioenergy from waste, using incineration or gasification, needs a pan-European view. This refers to the source of waste, the composition of waste, local and global energy demand as well as the co-operation with the involved stakeholders, such as Governmental Agencies, municipalities, suppliers of energy and the automotive industry.

The basic hypothesis in the project is that a network of stakeholders is necessary to reach a consensus with the aim of increasing the utilisation of bioenergy from waste. The stakeholder network is also important for a quick dissemination of the results of the project.

1.3 Purpose

The project has several purposes:

To gain knowledge about the most important barriers for an increased utilisation of energy from biomass from waste through incineration or gasification.

A widespread understanding of the different ways of extracting renewable energy from waste through incineration or gasification using different types of waste would help to increase the use of the unused potential of renewable feedstock. In a short term, it will also help solving the increasing problems according to landfills and waste treatment. An increased utilisation of bioenergy from waste will contribute to the reduction of climate change. Especially, issues concerning pollutants from incineration plants are one of the main barriers in waste treatment and this impact could be significantly reduced with a better quality of the waste.

To gain knowledge about the barriers for the utilisation of bioenergy from waste as motor fuels.

In the future, the anticipated use of fuel cells as drivelines in road vehicles, will increase the interest in fuels particularly suited for these vehicles, such as methanol, DME and hydrogen. These fuels could be produced from biomass using gasification processes.

To gain knowledge about the conditions to remove the barriers in order to increase the market share for bioenergy from waste.

The consensus in how renewable energy from waste should be utilised, which is one of the main goals in this project, is necessary to increase the market share of bioenergy.

Present a proposal for a future network with special focus on participants, function, and areas of work with the purpose of achieving an increased market share for bioenergy from waste.

The understanding of the complexity of the whole waste handling and treatment chain among all stakeholder groups will reduce the take-off time for utilising the unused potential of biomass in waste.

1.4 Methodology

Phase 1: Survey of stakeholder groups

The objective of this phase is to identify the key actors, who will form a Stakeholder/Reference Group and the experts who should represent these organisations.

The members of the group are listed in section 1.5.

Phase 2: Survey and analysis of arguments against incineration and gasification of waste

The objective of this phase is to carry out a survey of the arguments against incineration and gasification of biomass from waste. This has been done through interviews of influential persons, environmental movements and authorities and members of the Reference Group.

The outcome of the work is a comprehensive analysis of the opposition to utilising energy from waste.

Phase 3: Survey of barriers regarding technology, economy, legislation, environmental impact and transport logistics including a cost estimation for a plant producing motor fuel from waste

The objective of this phase is to carry out a survey of the barriers for the utilisation of biomass from waste. These barriers could comprise of a variety of different areas, such as technology, economy, legislation, environmental impact and transport logistics. The Reference Group will also have an essential role in the accomplishment of this phase.

This phase also include a principal specification and a cost estimation for a conceivable plant producing motor fuel from waste. For this work a fuel specification has to be made.

The outcome of the work will be a comprehensive analysis of the barriers of utilising energy from waste.

Phase 4: Assessment of the market opportunities and production potential of energy from waste in Sweden, Norway, Germany and the EU

The objective of this phase is to assess the market opportunities and production potential of energy from biomass from waste in Sweden, Norway, Germany and the EU.

The outcome of the work will be an estimation of the potential on the national level for the participating countries and for the EU.

Phase 5: Proposal for the utilisation of a network in order to achieve an increased market share of bioenergy from waste

The objective of this phase is to propose the utilisation of a network in order to achieve an increased market share of bioenergy from waste in the future. The Reference Group will have an important role in this phase.

The outcome of the work will be the identification of the said network and a proposal in which way this network should be used in the future to achieve the long-term objective of the EU to decrease the use of fossil energy and to increase the use of renewable energy.

Phase 6: Preparation of project reports

The objectives of this phase are to ensure the quality of reports made in the project according to both substance and time of delivery.

Phase 7: Dissemination of the project results

The objective of this phase is to disseminate the outcome of the project according to the dissemination plan. The outcome of the work will be spread as much as possible to organisations and companies representing the target groups.

1.5 The reference group

First name	Surname	Company/organisation
Wlodzimierz	Blasiak	Royal Institute of Technology, Department of Material Science and Engineering/Metallurgy.
Henrik	Boding	Ecotraffic ERD3 AB
Björn	Dahlroth	KSL (STOSEB The Greater Stockholm Energy Company Ltd)
Björn	Ejner	Swedish Environmental Protection Agency
Tomas	Ekbom	Nykomb Synergetics AB
Åsa	Hagelin	RVF - The Swedish Association of Waste Management
Tore	Hagen	Norsas AS
Erik	Herland	LRF Federation of Swedish Farmers
Gunnar	Herlö	Organic Power ASA
Karl-Georg	Høyer	Western Norway Research Institute
Sven	Järås	Royal Institute of Technology, Chemical Engineering and Technology
Friedemann	Mehlhose	Future Energy GmbH
Göran	Petersson	Chalmers University of Technology, Chemical Environmental Science
Lennart	Ryk	Söderenergi
Peter	Schmidt	Methanex Europe S.A./N.V
Jan-Olov	Sundqvist	IVL Swedish Environmental Research Institute
Lars	Waldheim	TPS Termiska Processer AB
Staffan	Ågren	The Ragnar Sellberg Foundation

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[illegible]

Åsa [illegible]

2 ARGUMENTS FOR AND AGAINST INCINERATION AND GASIFICATION OF WASTE

This chapter gives an overview over arguments for and against incineration and gasification of waste. The arguments are taken from literature, websites, journals, seminars etc. The arguments against incineration are well structured due to the fact that there is a well-organised campaign against waste incineration arranged by Greenpeace. There are no such similar pro-incineration organisations.

2.1 Arguments for

Security of energy supply

The energy use continues to grow inexorably and fossil fuels continue to dominate the global energy mix. World energy use will increase steadily through 2030 projected to increase by 1.7% per year. The increase will be equal to two thirds of current demand. Fossil fuels will remain the primary sources of energy, meeting more than 90% of the increase in demand. Global oil demand will rise by about 1.6% per year to 2030. Oil resources are ample, but more reserves will need to be identified in order to meet rising oil demand to 2030. Most of the projected increase in global oil demand in the next three decades will be met by OPEC producers, particularly those in the Middle East. EU will be increasingly dependent on external fossil energy especially in the transport sector. Fossil oil should of that reason be used as little as possible for heat and power production and replaced by energy from waste.

There is a large not utilised energy potential in household and industrial waste.

The Swedish Energy Agency has calculated a not yet utilised energy potential in waste of 10 TWh in Sweden. The produced energy from waste in 2001, amounts to some 8 TWh in the form of heat and electricity. This means that only 45% of the energy in waste is utilised in Sweden. This figure is assumed to be much lower for EU as a whole since the energy recovery share is much lower.

Well-developed district heating systems give Sweden a unique situation compared with many other countries in Europe. Some 95% of the heat generated is used for district heating, covering roughly 10% of the total need in Sweden.

The need for heat in central and south Europe are less than in the northern parts but green electric power are in great demand and could be produced anywhere.

RDF (Refuse Derived Fuel) makes storage possible and the fuel can be used in less complex plants than designed for waste.

Gasification in combination with gas cleaning can be used to radically improve the efficiency of generating electricity compared to incineration of wastes.

Combustible waste is a domestic resource

Combustible waste appears everywhere human activities are taken part. This is also the case with human need for energy. Thus, fuel is available close to the consumer and no long transports are necessary to utilise the energy in the waste.

Incineration of household waste contributes only marginally to an increase in the greenhouse effect since it mostly consists of renewable material – biofuel.

Meeting Kyoto objectives waste and recovered fuels can replace fossil fuels in heat and power production. The biomass content in household varies among the European countries and amounts to 50-90% by weight. A lot of plants originally built for coal as fuel has been rebuilt to use recovered fuels instead.

The increasing waste volumes must be taken care of.

Waste volumes in the European Community are projected to continue to rise in the foreseeable future unless new initiatives are taken. Waste generation is still coupled to economic growth. The increasing waste volumes bring pressure on waste treatment facilities and make it difficult for countries to raise the recycling rate and reduce landfilling. Even with increasing shares of waste being reused or recycled there will still be considerable amounts only suitable for incineration or gasification with energy recovery.

The growing waste amount underlines the importance of building up additional treatment capacity for recycling, composting, incineration etc., if the waste landfilled quantities are to be stabilised or reduced.

There are no indications that waste generation will be stabilised in the near future. An ETC/W study published in September 1999 clearly indicates that the quantities of municipal waste would continue to increase in the coming 10 years.

Incineration decreases landfill demand.

Wastes that can be incinerated, material recycled, anaerobically digested or composted should not be landfilled. This is valid even if landfill gas is extracted and utilised, and the leachate is collected and treated. This is due to that the resources in the waste are inefficiently utilised when landfilled, making it necessary to produce materials, fuels and nutrients from virgin resources [10].

The Council directive 1999/31/EC on the landfill of waste stipulates great reductions of biodegradable municipal waste going to landfills. This can be achieved by increased waste incineration with energy recovery.

Incineration is an established and well functioning method for waste treatment and energy recovery.

The technology for waste incineration has been developed during over 100 years. Plants have been more and more complex in order to meet more stringent environmental demand. Today's incineration plants with combined heat and power production consists of advanced well functioning processes.

Modern waste management is an integrated system combining different methods of treatment such as; recovery and recycling, thermal treatment, biological treatment and landfilling.

Incineration is one necessary part in an integrated waste management system. There will always be amounts of waste where incineration offer the best treatment alternative.

Good economy

Incineration with energy recovery shows good economic outcome compared to other treatment methods. Though waste is available at a negative price a large part of the waste flow is still too expensive to be recycled.

Lower environmental impact than other treatment alternatives.

In an LCA perspective, incineration is the best alternative concerning environmental impact. Societal studies on waste management considering different waste treatment alternatives reveal incineration as a method with low total environmental impact.

Contamination present in the waste will also be present after composting or anaerobic digestion.

Contamination such as heavy metals and chemicals present in the waste will also be present after composting or anaerobic digestion. The residual product is therefore hard to find applications for other than landfilling. Farmers do not accept compost earth and sludge as fertiliser for food production due to the risk of getting the soil contaminated.

Emission levels from waste incineration are low

Strict levels on emissions from waste incineration are regulated in an EU-directive.

The waste incinerated today is in different degrees pre-sorted in the meaning that hazardous waste, batteries, electronic waste etc are only present in the waste in low levels.

Modern flue gas cleaning systems consist of different steps each one removing even other pollutants than designed for. This makes the system low emitting even if one step will stop function.

The problem of dioxin emissions attracted attention in the mid-1980s. Since then, the plants have cut dioxin emissions by 98%, which means that they now account for a smaller share of the total emission of dioxins into the air. In 2000 the plants together emitted 1.7 grams of dioxin. A major RVF study conducted in 2001 has shown that dioxins generated by incineration are above all bound closely to the residue, including ashes, that is deposited as hazardous waste. This therefore does not cause environmental damage. Since the mid-1980s there has also been a reduction by 90–99% of a number of other emissions that impact the environment, such as hydrogen chloride, mercury, cadmium, lead, and dust. The EC directive regulates these emissions as well as the emission of wastewater. All the plants where wastewater arises are already within the limits today.

Emissions from today's waste incineration are thus very low, and the existing Swedish plants are already adjusted to many of the coming requirements. However, there will still be a need for supplementation of, for example, flue gas treatment in order to a further reduce of emissions to comply with all the limits in the directive.

An expansion in incineration capacity will not make the society dependent on waste as a fuel.

Incineration plants can handle a wide range of different solid fuels. A lack of combustible waste due to future change in waste treatment can be solved by using other solid fuels.

2.2 Arguments against

This section is mainly based on information from Greenpeace.

Society continues to generate more waste and those who are against waste incineration sees incineration as a part of the world's waste problems, not a solution. Incinerators may reduce the volume of solid waste, but they do not dispose of the toxic substances contained in the waste. They create a source of dioxins, which is one of the most toxic chemicals known to science. Incinerators emit a wide range of pollutants in their stack gases, ashes and other residues. The filters used to clean incinerator stack gases produce solid and liquid toxic wastes, which also need to be disposed. The way to improve the situation is to avoid toxic waste production by improving our products and processes. There is no room for the incineration of waste in a sustainable society

2.2.1 Types of incineration

Municipal incinerators

Municipal waste incineration is still the first cause of dioxin pollution, according to a 1999 UNEP study. Over the past few years, many countries have updated their old incinerators or built new ones. In doing so, they have taken advantage of improved technologies for air pollution control. This has resulted in a substantial reduction in toxic emissions. Although this is an improvement, toxic waste production is still a serious global issue. In fact, the problem has now shifted, and more dioxins and other toxic substances are appearing in the ashes, therefore creating new disposal and pollution problems. Studies conducted in Europe have reported that emission measurements from some European incinerators fall within the new proposed EU emissions levels, but others exceed this limit.

Industrial/hazardous waste incineration

Only a few recent studies on emission testing of industrial incinerators are published in scientific literature. A study undertaken in Japan performed point measurements on nine industrial waste incinerators. Dioxin emissions were below the new EC limit for two of the incinerators and above this level for the remaining six.

In the US, one study reported on dioxin emissions of mobile soil burning incinerators. On-site remediation of soils, contaminated by these incinerators, is employed where sites contain compounds that are difficult to destroy. Data collected primarily from the trial burns of 16 incinerators, showed that 10 of the incinerators failed to meet the proposed EPA standard.

Medical waste - useful waste into hazardous waste

Only 10% or less of a typical hospital's waste stream is potentially infectious. It is possible to sterilise this waste with heat, microwaves and other non-burn disinfecting technologies. The remaining waste is not infectious and often includes paper, plastic and food waste. This is similar to the waste coming from hotels, offices and restaurants, as hospitals serve all of these functions. Incineration of medical waste has become a formidable chemical pollution problem, that is costly to manage and difficult to contain. Fortunately, there are alternative technologies available to ensure the appropriate sterilisation of medical waste.

Waste to energy schemes

The generation of energy from waste has increased. It is now used extensively by governments and industry, to “green” incineration, thereby making it more acceptable to the public. However, all the negative impacts of incineration also apply to “waste to energy” facilities. Moreover, the energy used to produce the product is lost and only a fraction of the intrinsic energy content of the materials can be recovered. Reuse and recycling, even from an energy perspective, are the preferred options.

Refuse-derived fuel (RDF)

Refuse-derived fuel (RDF) typically consists of pelletized or fluff waste that remains after the removal of non-combustible materials such as ferrous materials, glass, grit, and other non combustible materials. The remaining material is then sold as RDF and used in dedicated RDF boilers or co-incinerated with coal or oil in a multi-fuel boiler. However, the environmental concerns of incineration also apply to RDF combustion facilities.

Pyrolysis/thermal gasification

Pyrolysis and thermal gasification are related technologies. Pyrolysis is the thermal decomposition of organic material at elevated temperatures, in the absence of gases such as air or oxygen. The process, which requires heat, produces a mixture of combustible gases (primarily methane, complex hydrocarbons, hydrogen and carbon monoxide), liquids and solid residues.

Thermal gasification of waste is different from pyrolysis in that the thermal decomposition takes place in the presence of a limited amount of oxygen or air. The generated gas can then be used in either boilers or cleaned up and used[4] in combustion turbine generators.

Both of these technologies are at the development stage, with a limited number of units in operation. Most of the environmental concerns for incineration also apply to pyrolysis and thermal gasification facilities.

Cement kilns

Throughout the world some 60 cement kilns have been modified so that various wastes can be burned along with conventional fuels. However, cement kilns are designed to make cement and not to dispose of waste. A study by the US Centre for the Biology of Natural Systems, found that emissions of dioxins are eight times higher from cement kilns that burn hazardous waste than those that do not burn it.

2.2.2 The problem

Burning was once considered the most effective method for disposing waste materials. However, since industrialisation the nature of waste has changed dramatically. Mass production of chemicals and plastics means that burning or incinerating today’s waste is a complex, costly and highly polluting method of disposal.

The myth that burning makes waste disappear has lead to incineration emerging as a widely used method for disposing many kinds of waste, including hazardous wastes.

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[4] The gas could be cleaned and upgraded to a synthesis gas for production of chemicals or automotive fuels e.g. methanol, DME, Fischer-Tropsch Diesel oil or hydrogen.

Rather than making waste disappear, incinerators create more toxic waste that poses a significant threat to public health and the environment.

Incineration is often touted as an alternative to land filling. However, what many people do not realise is that incinerator ashes are contaminated with heavy metals, unburned chemicals and new chemicals formed during the burning process. These ashes are then buried in landfill or dumped in the environment.

Incineration is a method where industry can break down its bulk waste and disperse it into the environment through air, water and ash emissions. It is a convenient way for industry to mask today's waste problems and pass them onto future generations.

Incineration impacts - emissions

Existing data shows that burning hazardous waste, even in "state-of-the-art" incinerators, will lead to the release of three types of dangerous pollutants into the environment:

1 Heavy metals;

2 Unburned toxic chemicals

3 New pollutants - entirely new chemicals formed during the incineration process.

Toxic Metals

Metals are not destroyed during incineration and are often released into the environment in more concentrated and dangerous forms.

High temperature combustion releases toxic metals such as lead, cadmium, arsenic, mercury and chromium from waste products containing these substances, including batteries, paints and certain plastics. These metals are released as tiny gas particles, which increase the risk of inhalation and yet further amounts will be found in residual ashes and liquids. Pollution control equipment can remove some but not all heavy metals from stack gases. However, the metals do not disappear; they are merely transferred from the air into the ash, which is then land filled.

Subsequently, metals in the ash may leach into and contaminate soils and potentially groundwater. Presently, ash from incinerators is sometimes used in construction material such as asphalt and cement. This practice can also have implications for the environment and for human health, as metals can leach out of these construction materials. Ash from a municipal waste incinerator in Newcastle, UK, was used on local allotments and paths between 1994 and 1999. Recently, it was removed, as was found to contain unacceptably high levels of heavy metals and dioxins.

Unburned toxic chemicals

No incineration process operates at 100% efficiency. Unburned chemicals are emitted in the stack gases of all hazardous waste incinerators.

While incinerators are designed to burn wastes, they also produce more waste in the form of ash and effluent from wet scrubbers and/or cooling processes. Incinerator ash carries many of the pollutants that are emitted as stack gases. Studies have identified up to 43 different semi-volatile, organic chemicals in incinerator ash, and at least 16 organic chemicals in scrubber water from hazardous waste incinerators. Ash is commonly buried in landfill, while effluent is often treated before being discharged into rivers or lakes.

New pollutants - dioxins and furans

One of the most insidious aspects of incineration is the new and highly toxic chemicals formed during combustion. Fragments of partially burned waste chemicals recombine within incinerator furnaces, smokestacks, and/or pollution control devices. Hundreds, possibly thousands, of new substances are created, and many of these substances are more toxic than the original waste.

Very little research exists on the multitude of pollutants emitted from incinerators. One study identified 250 volatile organic compounds, many of which are known to be highly toxic or carcinogenic. It is likely that many other compounds are emitted during incineration that are yet to be identified.

Among the possible compounds are dioxins and furans, often referred to as just dioxins. These are a class of chemical compounds widely recognised to contain many highly toxic compounds including Dichlorodiphenyltrichloroethane (TCDD). TCDD has been described as the most toxic chemical known to man. Dioxins are created when materials containing chlorine are burned. They have no useful purpose and are associated with a wide range of health impacts including, cancer, altered sexual development, male and female reproductive problems, suppression of the immune system, diabetes, organ toxicity and a wide range of effects on hormones.

Fugitive emissions

Some waste is accidentally released when:

- Chemicals are removed from storage containers at the incinerator site;
- It is moved to transportation vehicles;
- It is shipped to and moved about within the incineration facility.

According to the US Environmental Protection Authority: “Fugitive emissions and accidental spills may release as much, or even more toxic material into the environment than direct emissions from incomplete waste incineration.” There is also the risk of catastrophic waste releases in fires and explosions.

Incinerator ash is hazardous waste

Leftover incinerator ash is extremely toxic, containing concentrated amounts of lead, cadmium and other heavy metals. It can also contain dioxins and other toxic chemicals. Toxic ash disposal in an environmentally sound manner is problematic and expensive. If handled improperly it poses short and long-term health and environmental dangers. The better the pollution-trapping device in an incinerator smokestack, the greater the quantity and toxicity content of the residues. A hundred times more dioxin may leave an incineration facility via ash, than in air emissions. Some experts recommend burying this ash in a landfill equipped with a plastic liner to prevent leaching into groundwater. However, all landfill liners will eventually leak.

Impacts of incineration - health and environment

Increased cancer rates, respiratory ailments, reproductive abnormalities and other health effects are noted among people living near some waste-burning facilities, according to scientific studies, surveys by community groups and local physicians. Cancer, birth defects, reproductive dysfunction, neurological damage and other health effects are also known to occur at very low exposures to many of the metals, organochlorines and other pollutants released by waste-burning facilities.

Many pollutants released in incinerator air emissions have been shown to accumulate in and on food crops. This is most notable on crops where the edible portion is exposed such as leafy vegetables. While thorough washing of produce may remove a portion of pollutants on crop surfaces, a significant amount (typically from 15 to 50%) will remain.

Incineration - theory versus practice

In theory, a properly designed incinerator should convert simple hydrocarbons into nothing other than carbon dioxide and water.

Practical experience, however, has shown that even the best combustion systems usually produces Products of Incomplete Combustion (PICs), some of which highly toxic.

Even under the most stringent standards, incinerators emit chemicals that have escaped combustion as well as newly-formed PICS. Newly formed products refer to the thousands of different chemicals, which only a small fraction has been identified.

Different countries monitor and measure incinerator performance in various ways and to different degrees. Actual incinerator performance can deviate radically due to combustion upsets such as:

- Equipment failure;
- Human error;
- Rapid changes in the type of waste fed to an incinerator.

Only a small fraction of the waste needs to experience a combustion upset for there to be significant deviations from the targeted destruction efficiencies.

Pollution control devices

Pollution control technologies for different pollutants are often incompatible. Scrubbers designed to filter out particulate and heavy metals will cool the exhaust gas to the ideal range for dioxin formation. This means that decreasing the emission of one pollutant often increases the emissions of others and no pollution control device can eliminate dioxin or heavy metal emissions completely.

Incineration removes the incentive to recycle and reuse

Incinerators with pollution control equipment are prohibitively expensive, and once authorities have invested in incineration they often do not have the money to invest in waste reduction. In this way, incineration directly competes with efforts to reduce and recycle waste.

Incineration actually perpetuates the use of landfills because of the large quantities of leftover ash produced by incinerators. It is estimated that for every three tons of waste that is incinerated, one tonne of ash is generated. This ash might be very toxic, containing concentrated amounts of heavy metals and dioxins which, when buried, will eventually leach into the soil, potentially polluting groundwater.

Very few jobs are created in return for the huge economic investment in incineration. A large incinerator may employ about 100 workers. Whereas, community efforts into waste separation, reuse and repair as well as recycling and composting, can create more jobs, both in the handling of the waste and in secondary industries using recovered material.

Recycling saves more energy than incineration yields. Incineration can only recover some of the calorific value contained in the waste. It cannot recover any of the energy invested in the extraction, processing, fabrication and chemical synthesis involved in the manufacture materials present in the waste stream. However, re-use and recycling can do this. In fact, a cost-benefit study conducted for the European Commission in 1997 concluded that even land filling was better and more energy efficient than incineration, for managing household waste.

2.2.3 Alternatives to incineration

Municipal and hospital waste incinerators are the largest dioxin sources in industrial countries. PVC plastic is probably the most significant source of dioxin generating chlorine in these incinerators. Incinerators that burn hazardous waste from industry are also point sources of dioxin.

Strategies to prevent generating incinerable waste streams currently exist by:

- Toxic use reduction planning within industries;
- Waste reduction and alternative forms of sterilisation in hospitals; and
- Efficient reduction, recycling and compost actions at community level for household waste.

Incinerators and cement kilns that burn hazardous waste will never solve toxic waste problems. A clean production approach, which substitutes safe materials and processes to stop the generation of hazardous waste in the first place, is needed.

Alternatives to municipal waste incineration

Although PVC only accounts for approximately 0.5 percent of municipal waste by weight, PVC provides over 50 percent of available chlorine - the element essential to dioxin formation. According to the majority of incineration studies, when all other factors are held constant, there is a direct correlation between input of PVC and output of dioxin. For this reason the Danish government policy is to avoid the presence of PVC in incinerators.

"Cleaner production is as much about attitudes, approaches and management as it is about technology. This is why it is called cleaner production and not cleaner technology." Cleaner Production in the Mediterranean Region, 1995.

If all the PVC and chlorinated wastes were eliminated from the waste stream, incineration would still be a poor solution due to high costs, loss of jobs in the recycling industry, lost profits from secondary resale and on-going contamination from heavy metal, hydrocarbon and other air emissions.

Cost effective and eco-efficient waste management alternatives to incineration exist

Glass, metals and paper can be easily recycled and reused. Organic waste fractions can be composted at household or community level. Some plastics such as polyethylene and polypropylene can be efficiently recycled if collection and recycling systems are based within the region.

Recycling is not the answer to waste reduction however. We need to reduce our use of packaging and products and advocate reusable, returnable packaging and better product design for durability and reparability.

Alternatives to medical waste incineration

In medical waste incinerators, the dominant chlorine donor is PVC plastic, which enters these facilities as packaging and in many disposal medical products. An estimated 9.4% of all infectious waste is PVC, and virtually all available chlorine fed to medical waste incinerators comes from PVC.

In reality there are dioxin-free means of disposing of 99.7% of the medical waste stream. Because medical waste incinerators are major point sources of dioxins some countries have brought in more stringent regulations. This has resulted in many hospitals closing their own on-site incinerator and shipping waste to a commercial incinerator with more pollution control devices.

However, this is increasingly seen as an inadequate solution. Increasingly hospitals in Austria, Germany and Denmark are reducing the amount and nature of wastes by switching to reusables, which can be sterilised. Substitution of PVC products go with programmes to prevent waste and separate for recycling. Reasons for phasing out PVC in these hospitals:

- municipal incineration plants either did not accept wastes where the chlorine content exceeded the determined percentage, or would do so only at a considerably increased price;
- incineration plants had to be closed due to more stringent emission regulations;
- repeated complaints from the community.

Currently there are often increased costs for PVC alternatives (often 20-30% more expensive). However these costs must be balanced against the cost of ongoing incineration fees and dioxin emissions.

Non PVC hospital products

In general, 85% of the total medical waste stream in hospitals consists of the same mixture of discarded paper, plastic, glass, metal and food waste that is found in ordinary household waste. The remaining 15 percent are defined as infectious and these wastes must be sterilised before disposal.

A small percentage of this waste or 0.3 percent of the total medical waste stream, can only be incinerated, in part for cultural or aesthetic reasons, but also because it is difficult to sterilise in any other way. Thus there are dioxin-free means of disposing of 99.7 percent of the medical waste stream. Non hazardous waste can be recycled within a household waste-recycling plan.

For disposing of infectious waste there are several alternative dioxin-free methods that are cost comparative. Three of these are autoclaving, microwave disinfection and superheated steam sterilisation.

Alternatives to hazardous waste incineration

There are European researchers that estimate that 70 percent of all current waste and emissions from industrial processes can be prevented at source by using technically sound and economically profitable procedures.

No country should contemplate a commercial hazardous waste incinerator without a national programme of cleaner production. Policy measures to achieve this have been well documented by UN agencies and cleaner production initiatives have achieved significant results particularly within small and medium scale industries.

Once an incinerator is built, ongoing toxic waste generation is legitimised and there is little incentive to investigate process changes within industry even if cleaner production methods are more profitable. For this reason, mandatory toxic use reduction plans should be prepared by each facility currently generating toxic waste.

2.3 Conclusions

The strongest arguments for energy from waste are connected to energy demand. Putting waste on landfills is seen as a waste of energy and an inefficent use of land and nature. Also the high biomass content is an important argument. The argumentation is focused on the problems concerning waste volumes today and in a near future. The spokesmen for incineration consider the emissions from incineration is no longer a problem with new plants and that pollutants in ashes are stable and stays in the ash. In comparison with composting and anaerobic digestion the problems with toxic substances and metals in the waste still a problem after treatment and even a worse one. Gasification has the advantage of not causing dioxins.

The arguments against thermal treatment of waste are almost entirely focused on emissions and toxic substances, mainly dioxins, in the ash. Also not regulated, unknown emissions and substances in the gases and the ash, are pointed out as risks for human health. The need for landfilling is still considered as a problem since the increasing waste volumes requires landfill facilities for the ashes. The campaigns against incineration are adressed to people's emotions and fear of the unknown wich has a strong effect. Even energy is an argument but in this case the loss of energy while the energy used in manufacturing is lost when a product is combusted.

The opponents have a more long-term view with a change in waste handling system promoting increased reuse and recycling.

Consequently, both sides have good and important arguments and they have one argument in common; reduction of pollutants and toxic substances in society.

3 THE PROBLEMATIC ISSUES WITHIN THERMAL CONVERSION OF WASTE

Definition of the "waste" refers to a large variety of materials with well distinguishable differences in their elemental composition, physical and chemical properties, ash and moister content and energy content. Wastes from industries are normally homogeneous materials having a well-defined composition. Municipal solid wastes (MSW) on the other hand consist from different fractions. The amount and properties of each fraction are usally household- and site- specific. Too high content of moisture and non-combustible materials, such as glass and metals in the waste makes it a less attractive material as an energy source and in extreme cases energy must be supplied for its destruction. Emission control and flue gas cleaning systems are the necessary equipments within waste combustion for elimination of the risks of emission of environmental pollutants. There is a clear relationship between the amount of the pollutant released during combustion and the content of the pollutant precursors in the raw material. Because of variations in the quality of the raw material and uncertainties upon the amount pollutant precursors the capacity of the gas cleaning systems must be dimensioned in a manner for being able of handling a maximum possible emission. Generally the most problematic issues in thermal treatment of waste concerns two main categories:

c) Environmental aspects

d) Plant and process specific aspects

The environmental aspects include questions such as emission of hazardous compounds to air, water and in solid by-products. The plant specific questions are the low efficiency relative other fuels, high erosion and corrosion rates and problems related to the disposal of by-products.

3.1 Environmental aspects

3.1.1 Emissions

Inorganic pollutants

Although associated with low overall efficiency and high cost, the combustion of untreated waste is a well-established technique. Compared to clean fuels such as forest residue or natural gas, waste contains higher amounts of N, S and Cl, which are the precursors of NO_x, SO_x, HCl and dioxins. Other inorganic compounds of great importance in the waste are heavy metals. During thermal processing these compounds becomes concentrated in one of the output streams from the process.

The content of emission precursors varies significantly in different fractions of waste. Table 1 shows a comparison between compositions of different waste fractions. As can be seen in the table; despite a negligible contribution to the energy content, certain fractions of waste such as food residue can show a very large contribution concerning the pollutant precursors.

Table 1. Comparison between the energy content and emission precursor content of different MSW fractions.

MSW fraction	Wood	Anim. Residue	Veg. Residue	Rubber & leather	Poly-ethene	PVC
Ash (% wt.)	1	5	5	8	3	
Moisture (% wt.)	15	50	70	5	0	
LHV (MJ/kg)	15	7	3	44	45	20.5
Nitrogen (mg/MJ)	638	6 019	15 876	262		
Sulphur (mg/MJ)		2 407	825	625	35	
Chlorine (mg/MJ)	5- 250	13 611	28 660	1 008		25 085

In general the first measure to reduce the risk for emission from waste thermal treatment is to control the quality of the waste to be burnt. This quality control can be achieved by the separation of waste into different fractions. The separation is however costly and labour intensive affecting the process economy negatively and results in the generation of "undesired" fractions that must be disposed of anyhow. Fractionating of waste to different categories can be done in households but there is no warranty that pollutant sources will be eliminated totally from the waste.

In thermal treatment, due to uncertainties upon the level of the contaminants in the waste the waste water and flue gas cleaning systems must be dimensioned to a maximum capacity that can be needed for the case of most contaminated waste fractions. Since these facilities stand for a considerable part of the capital and operational costs, the strengthening demands on the limits of the pollutant emissions can result in a serious drawback in deployment of the waste combustion plants in the future.

Emission of certain categories of compounds from waste combustion plants can be controlled by optimising the operational conditions. E.g. the release of heavy metals in gas phase is strongly dependent on the temperature of the flue gas. A low gas cleaning temperature results in accumulation of the heavy metals in other product streams than flue gas. For some compounds like mercury however, a total elimination can be achieved either by cooling the gas to temperatures close to room temperature (Figure 2) or by its careful separation from the fuel in the steps prior to thermal treatment. In the first case the separated mercury will contaminate the process water produced during waste treatment and measures must be taken to stabilize the captured mercury.

The existing reduction processes for mercury show a capacity of about 50%, which can be regarded as unsatisfactory for the fuels with high mercury content. There are reports available about advanced high efficient mercury capturing methods tested in the laboratory, which show a reduction capacity higher than 90%. The investment and operational costs for such processes are however high and uncertainties in verification of the performance in a real process is one of the major barriers in deployment of the technique.

The process conditions have a limited effect on the quantity and the quality of the emissions released in combustion of dirty fuels. The most reliable method to prevent the undesired emissions for these cases is to apply advanced gas or wastewater cleaning systems.

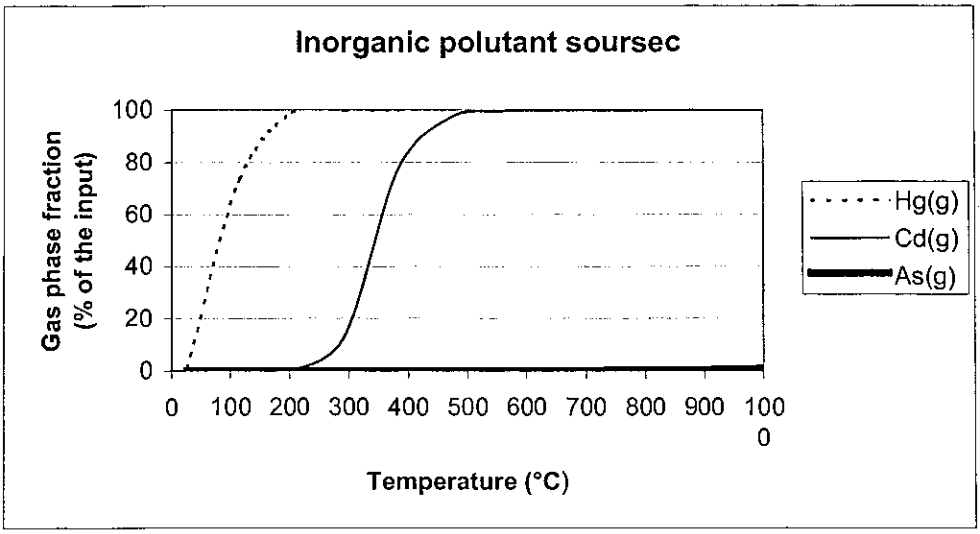

Figure 2. Gas phase concentration of critical heavy metals as a function of temperature [1].

Organic compounds

Among organic emissions from waste treatment facilities the release of polychlorinated di-benzo dioxins (PCDDs or dioxins) and polychlorinated di-benzo furans (PCDFs or furans) to atmosphere is of a major concern. Dioxins and furans are found in the fly ash, in the bottom ash and in the scrubber residues in all waste incinerators also. Their typical concentration in fly ash and scrubber residues is reported to range from parts per trillion (ppt) to parts per billion (ppb). In bottom ash, concentrations are characteristically at ppt levels. US EPA has established very stringent emission limits for dioxins and furans. Experiences from countries like Sweden and Netherlands show that there is great potential for decreasing the dioxin emissions to atmospheres (Table 2). Thorough separation of dioxin precursors such as PVC plastics from the waste is considered to be one of the major reasons behind this decrease. The most important issue concerning dioxins and furans is however the uncertainties in estimation of the global emissions. Dioxin monitoring is a very costly procedure and requires specialists with expertise skill of both in sampling and in analysis. The high costs for measurements results in that the estimations upon the global emissions are often based on short time and periodical samplings within certain conditions. Since the quality of the fuel and the process conditions can be very different in different periods the results from such estimations can be regarded questionable.

Table 2. Dioxin emissions to atmosphere in gram [2].

Country	**Incineration source**	**1990/5**	**2000**
Sweden	Municipal Waste	96.2	9.9
	Hazardous Waste	7.3	4.9
Netherlands	Municipal Waste	382	2-4
	Hazardous Waste	16	1.7

The other important question in waste thermal treatment is the amount of unburned fraction in the combustion residues. The reason to this is mostly the inhomogeneity of the fuel and the fact that different waste fractions have different chemical reaction activities (Figure 3).

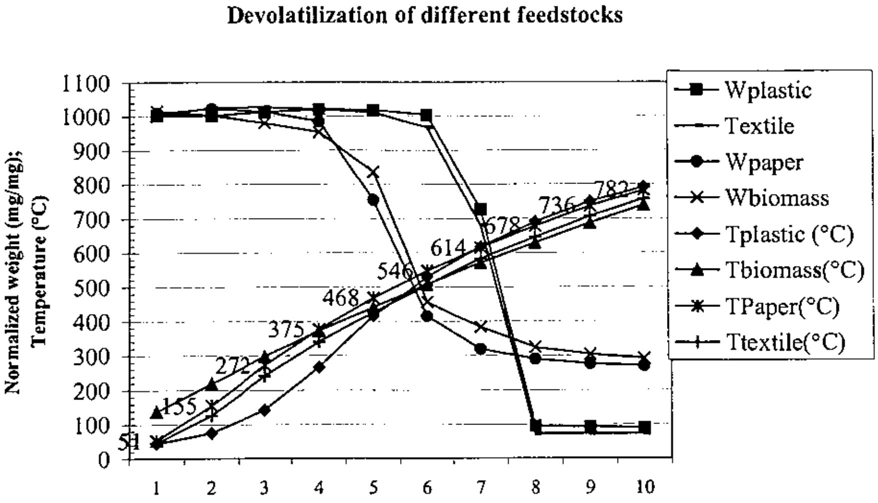

Figure 3. Comparison between devolatilization properties of biomass, plastic, paper and textile waste [3].

EU:s directive on establishing criteria and procedures for the acceptance of waste at landfills (2003/33/EG) allows a highest total organic content of 5% (wt) for combustion residues. A higher content of unburned substances in the residues from waste combustion plants will result in a different classification of these materials with a considerable increase in landfill costs as consequence. For extreme cases pre-treatment of the combustion residues can become necessary to fulfil the requirements for disposable wastes.

3.1.2 Regulations

The impact of waste incineration on the environment is regulated by the European Parliament Directive 2000/76/EC. Table 3 to 5 show the requirements set by this directive to the quality of the gas and water released from the waste thermal treatment plants.

Table 3. Air emission limit value (daily average).

Total dust	10 mg/m^3
Gaseous and vaporous organic substances, expressed as total organic carbon	10 mg/m3
Hydrogen chloride (HCl)	10 mg/m^3
Hydrogen fluoride (HF)	1 mg/m^3
Sulphur dioxide (SO2)	50 mg/m^3
Nitrogen monoxide (NO) and nitrogen dioxide (NO2) expressed as nitrogen dioxide for existing incineration plants with a nominal capacity exceeding 6 tons per hour or new incineration plants	200 mg/m^3 (*)
Nitrogen monoxide (NO) and nitrogen dioxide (NO2), expressed as nitrogen dioxide for existing incineration plants with a nominal capacity of 6 tons per hour or less	400 mg/m^3 (*)
Dioxin and furans	0,1 ng/m^3

(*) Until 1 January 2007 and without prejudice to relevant (Community) legislation the emission limit value for NOx does not apply to plants only incinerating hazardous waste.

Table 4. All average values over the sample period of a minimum of 30 minutes and a maximum of 8 hours

Cadmium and its compounds, expressed as cadmium (Cd)	Total 0,05 mg/m^3	total 0,1 mg/m^3 (*)
Thallium and its compounds, expressed as thallium (Tl)		
Mercury and its compounds, expressed as mercury (Hg)	0,05 mg/m^3	0,1 mg/m^3 (*)
Antimony and its compounds, expressed as antimony (Sb)	Total 0,5 mg/m^3	total 1 mg/m^3 (*)
Arsenic and its compounds, expressed as arsenic (As)		
Lead and its compounds, expressed as lead (Pb)		
Chromium and its compounds, expressed as chromium (Cr)		
Cobalt and its compounds, expressed as cobalt (Co)		
Copper and its compounds, expressed as copper (Cu)		
Manganese and its compounds, expressed as manganese (Mn)		
Nickel and its compounds, expressed as nickel (Ni)		
Vanadium and its compounds, expressed as vanadium (V)		

(*) Until 1 January 2007 average values for existing plants for which the permit to operate has been granted before 31 December 1996, and which incinerate hazardous waste only.

Table 5. ***Emission limit values for discharges of waste water from the cleaning of exhaust gases***

Polluting substances	Emission limit values expressed in mass concentrations for unfiltered samples	
1. Total suspended solids as defined by Directive 91/271/EEC	95 %; 30 mg/l	100%; 45 mg/l
2. Mercury and its compounds, expressed as mercury (Hg)	0,03 mg/l	
3. Cadmium and its compounds, expressed as cadmium (Cd)	0,05 mg/l	
4. Thallium and its compounds, expressed as thallium (Tl)	0,05 mg/l	
5. Arsenic and its compounds, expressed as arsenic (As)	0,15 mg/l	
6. Lead and its compounds, expressed as lead (Pb)	0,2 mg/l	
7. Chromium and its compounds, expressed as chromium (Cr)	0,5 mg/l	
8. Copper and its compounds, expressed as copper (Cu)	0,5 mg/l	
9. Nickel and its compounds, expressed as nickel (Ni)	0,5 mg/l	
10. Zinc and its compounds, expressed as zinc (Zn)	1,5 mg/l	
11. Dioxins and furans	0,3 mg/l	

Until 1 January 2008, exemptions for total suspended solids may be authorised by the competent authority for existing incineration plants provided the permit foresees that 80 % of the measured values do not exceed 30 mg/l and none of them exceed 45 mg/l.

Restrictions in the release of gas phase pollutants to the atmosphere from waste co-firing plants are defined in the same directive as well. For these processes the limit for emission is dependent on the share of the waste in the fuel. In general a co-combustion plant is defined as a plant where the purpose of firing is production of useful energy. There is in general no limitation on the proportion of waste fired in the co-firing plant. Especially for hazardous waste, if the contribution to the total energy produced is larger than 40%, the co-firing process must fulfil the same requirements as for pure waste firing processes. Table 3.

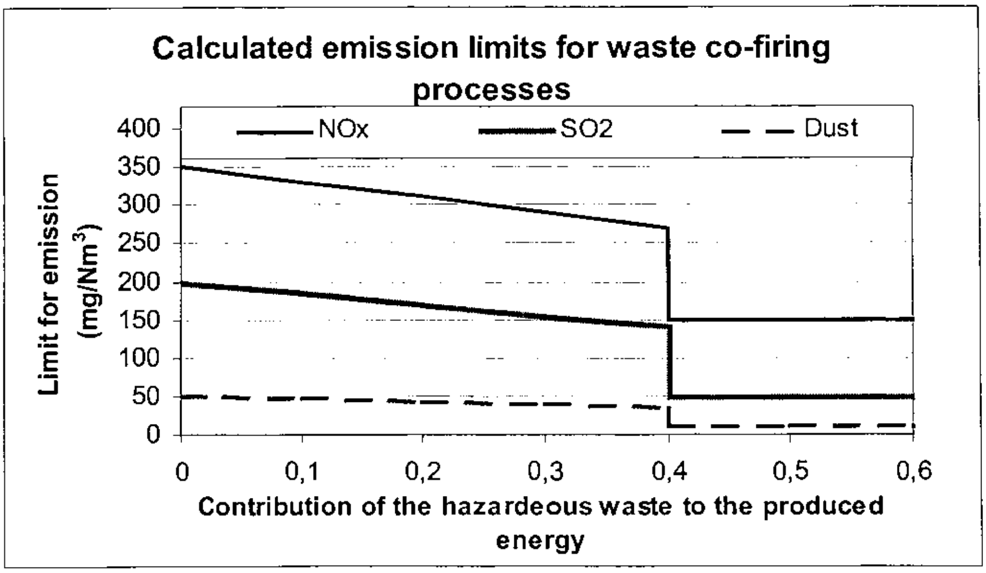

Figure 4. Emission limits for waste co-firing processes.

3.2 Plant specific aspects

3.2.1 Problems related to inorganic materials during thermal treatment of waste

Compared to renewable and other solid fuel, waste usually contains a considerable higher amount of inorganic material. A high inorganic content increases the total throughout of the ash trough the process resulting in faster erosion and wear out of tubs, vessels and filtering equipment. The main part of the inorganic content in waste can consist of inert compounds such as calcium, aluminium and silicon that are either in a stable form prior to, or becoming stabilised during, the thermal treatment. The problems caused by the non-inert part of the inorganic content in the waste can be described as:

a) Fouling and deposit formation followed by corrosion and operational failures

b) Contamination of process water

c) Contamination of bottom and fly ash

3.2.2 Slagging and fouling

Deposit formation during thermal treatment of waste occurs throughout different mechanisms but the formation of condensable products is a necessary step for initiation of depositing and fouling. Sodium, potassium and zinc are the most important components that are found in considerable concentration in the composition of unsorted waste and are able of forming compounds with low melting temperature. In fluidised bed processes sever problems of bed material agglomeration and sintering is occurred due to the formation of low temperature melting compounds containing potassium and sodium. Periodical interruptions in operation due to fouling and sintering is well known problem that decreases the reliability of the waste combustion process in energy production applications. Figure 5 shows the results from calculations, based on thermodynamic equilibrium, for condensability of the zinc, sodium and potassium salts. As can be seen in the figure, in a wide range of temperature areas there is a risk for condensation of these compounds and a consequent problem arising from their condensation.

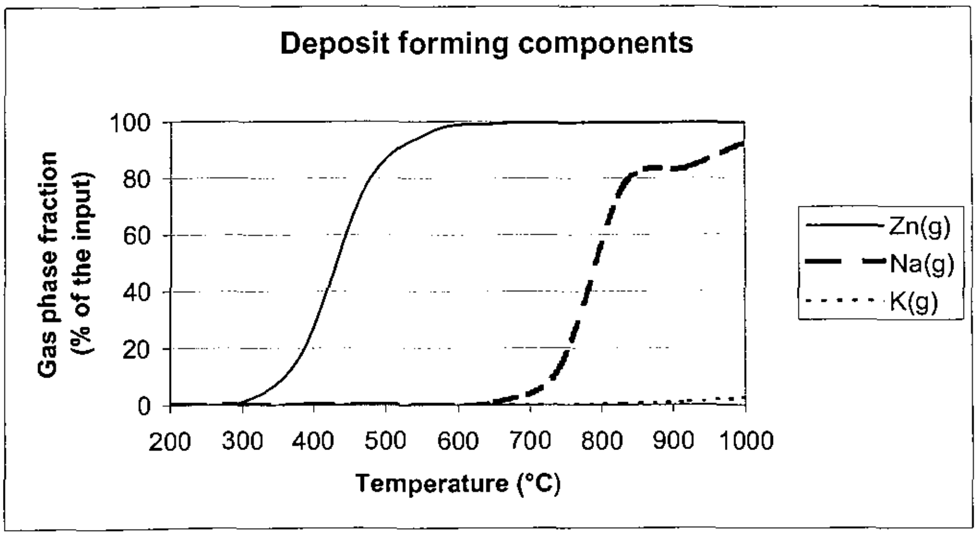

Figure 5. Condensation temperatures for Zn, Na and K salts [1].

3.2.3 Corrosion

High temperature corrosion on heat exchanger surfaces and superheater tubes is a well-known problem in incinerators and waste-to-energy plants. The problem starts when the molten salts containing chlorides or sulphates in the ashes deposit on the fireside of the tube surface. Whilst alkali salts have normally low boiling point, their presence in the ash accelerates the deposition rate. A high content of chlorine and sulphur in the deposits enhances the corrosion process as well. A total reduction of the sulphur and chlorine from the waste composition is practically impossible, hence, for minimising the corrosion rate the temperature of the heat exchanger surfaces is kept down in a lower level than that for the clean fuels. This also results in less potential for energy recovery as electric power typically to 20% compared to 30 – 40% for other fuel.

3.2.4 Treatment of ash residue

In order to minimise the environmental impacts resulting from disposal or re-utilisation of the ash from waste combustion plants, a proper pre-treatment of this by-product is a necessary measure. The applied treatment method must result either in separation, in destruction or in inertisation/stabilisation of the hazardous compounds in the ash and warranty that the quality of the treated material is in accordance with the regulatory requirements (se above). For the time being, the available processes are: physical separation, chemical extraction, thermal destruction and solidification/stabilisation. Physical separation is the less expensive method and normally is used to separate the ferric and other metals from the ashes. A complete separation of all potential hazardous compounds requires, however, more sophisticated treatment processes including several separation methods. Chemical extraction methods that are very efficient in this application are considered to be uneconomical and hence of limited use.

3.2.5 Emission monitoring methods

Continuous emission monitoring (CEM) is a necessity factor to assure regulators and the public that the thermal processing facilities are operating safely and within permitted emissions limits. For the time being there is mature and commercially available technique for measuring hydrocarbons, nitrogen oxides, sulfur oxides and hydrogen chloride. However, continuous monitoring of some analytes is much more complex than these commercially available CEMs.

3.2.6 Energy efficiency

Of several reasons the thermal conversion of waste is often associated with low overall efficiency: due to the high energy demand in gas and waste water cleaning systems and energy losses, the amount of the energy that is internally used in the plant is comparatively high in waste combustion. In a Combined Heat and Power (CHP) plant the overall efficiency is dependent on the highest applicable temperature and pressure of the steam produced. waste thermal treating plants suffer from serious problems related to corrosion on heat exchanger and superheater surfaces. The corrosion is dependent on the environment and the temperature. Increased temperature in a corrosive environment accelerates the corrosion rate. To suppress the corrosion the boiler and heat recovery systems in waste treating plants are normally operated at lower temperature than in the case with clean fuels. The low steam temperature (<420°C) and steam pressure result in an insufficient electrical efficiency for the whole process. A summary of the electrical efficiency for waste-based CHP-plants in Sweden is plotted in Figure 6. As can be seen the highest alfa value (defined as the ratio: electricity/heat) achievable in these plants is below 0.45. This can be compared to the options of CHP with clean fuels that can be as high as 0.6. As long as the produced heat can be utilised as a product the low electrical efficiency is not considered as a serious drawback. Absence of demands on heat being more relevant to Europe as a whole, however makes the question to a critical issue that affects the total economy of the process.

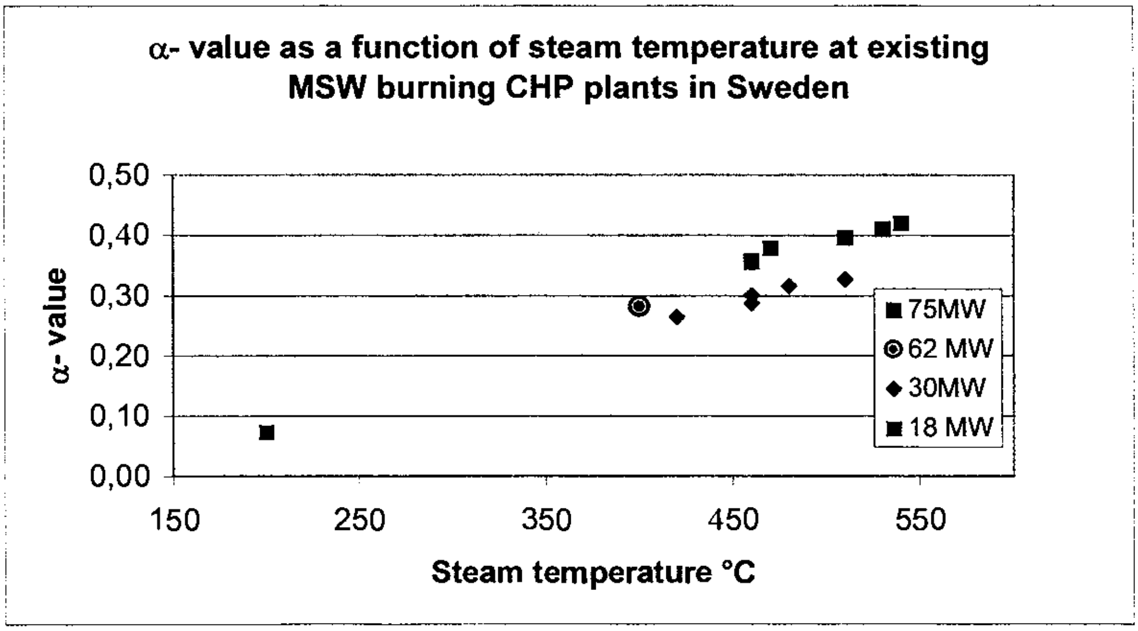

Figure 6. Electrical efficiency for waste combustion plants.

3.3 Economy

The economics of a waste treatment plant producing heat and electricity is dependant on the following parameters:

The gate fee: Since waste treatment is a capital and energy consuming process, a gate fee for treatment of the waste is necessary.

The revenues from the produced energy: The price for the produced energy is set by the market and waste treating plant are obliged to compete with the cheapest available energy in the market such as energy produced from conventional e.g. coal or nuclear sources

The investment cost: Due to the tough requirements on the gas and waste water cleaning systems the waste thermal treating plants are highly capital intensive investments.

Operational and maintenance costs: The magnitude of these costs is comparatively high for waste treatment plants. This is due to a fast worn out of the plant components and also the larger number of process units that are necessary in the plant.

Handling of the by products: By-products from the waste treatment plants are classified as waste and the disposal cost is strongly affected by their quality. For the time being, the problem with reutilising of the by-products such as fly and bottom ash is not properly solved. To reduce the disposal cost the amount of the hazardous residues in the by-products must be reduced to a minimum. Figure 7 illustrates the cost for the disposal of ashes from the waste treatment plant in accordance to Swedish regulations. As can be seen in the figure for a normal process only the cost for disposal of the produced ash is above 200 SEK/tonne waste treated. This must be compared to the existing gate fees that are normally in the range of 400 – 450 SEK/tonne waste accepted.

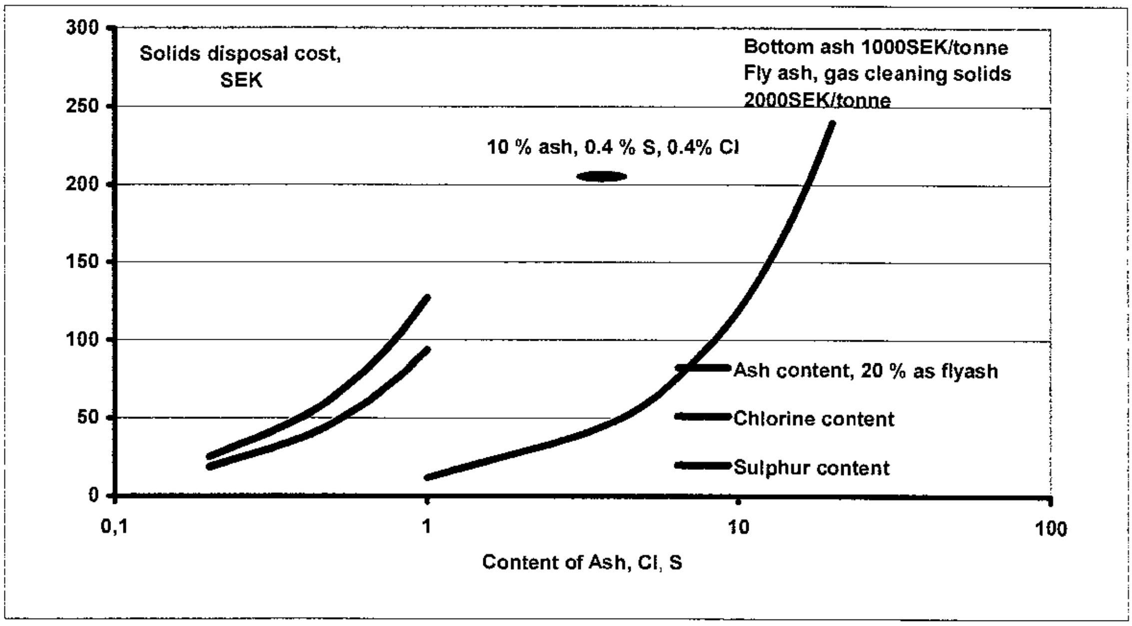

Figure 7. Cost for disposal of the by-products

Requirements on the process reliability concerning the environmental issues result in that the investment costs for waste treating plants are not going to be less in the future. Competition in the market reduces the price for the products from these plants e.g. heat and power to a minimum level. Since there is no possibility to reduce the operational and maintenance costs in these plants, the gate fee becomes the only parameter that can regulate the economy of the plant. In the cases where the produced heat can be regarded as a product with a positive market value there is a good opportunity for the survival of waste thermal treating plants even with comparatively low incomes from gate fee. Otherwise, the level of the gate fee must be adjusted to retain the economical feasibility of waste thermal treating processes. Increasing the electrical efficiency of waste combustion plants can be regarded as a solution but as can be seen in Figure 8, there is a limitation on the effect of this measure.

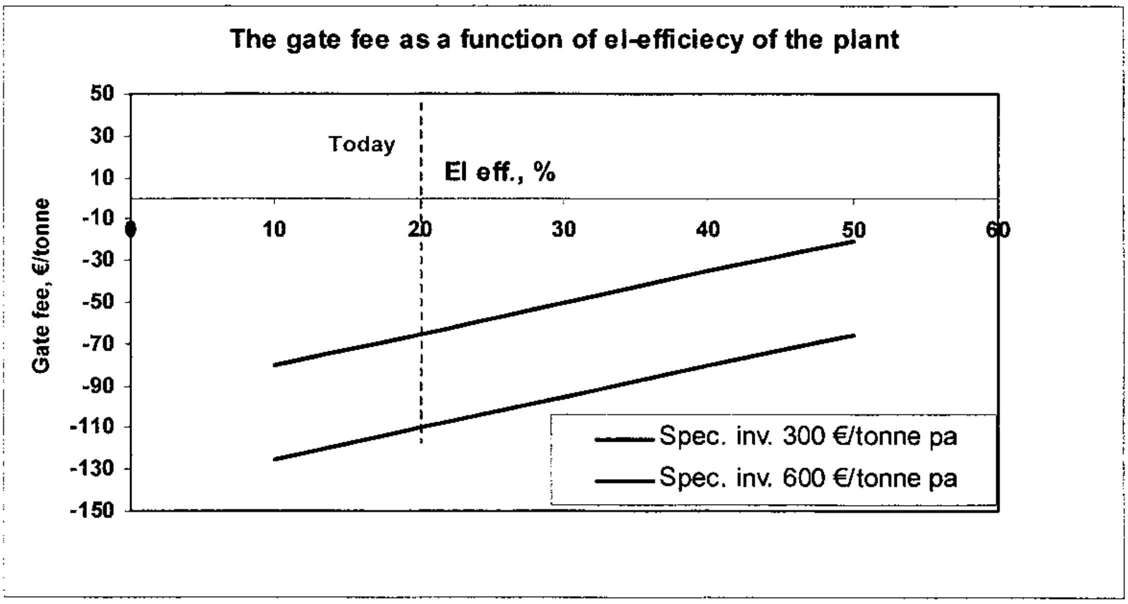

Figure 8. The gate fee required at zero-profit condition with the assumptions of: El. revenue = 60 €/MWh and O & M cost = 50 €/tonne

3.4 Conclusions

The major barriers within waste thermal treatment are non-technical, more stringent demands can technically be achievable to almost any level of the penalty of rapidly increased cost of treatment. However, alternative treatment procedures (composting, biogas) entail the risk of even higher costs of treatment, as large masses of residues requiring post-treatment are generated. Incineration of these can become a necessary part of such WtE installations.

A techno- economic barrier is presently the low efficiencies for CHP plants. In the waste minimising hierarchy (preventing, recycling, energy recovery, disposal) adopted by the EU, a breakthrough in the complex of superheater corrosion reduction could move energy recovery one full step up from recycling in this hierarchy.

4 DME PRODUCTION THROUGH GASIFICATION

In this chapter the outline and design basis of the plant concept are presented. In section 4.2 the process plant is briefly described and in section 4.3 the process is described in detail. Hereafter the mass and energy balances are described in section 4.6 and the economics of the complete plant in section 4.7.

4.1 Introduction

This part of the study considers the implementation of a waste-to-motor fuel plant for conditions representative for a medium to large city in northern Europe. Even though the plant setup is relatively unaffected by the geographical position, the logistics and dimensioning is carried out with respect to an intermediate or densely populated area. The results and conclusions derived from this presentation should therefore be applicable to any middle-sized European city, such as Stockholm, housing 1.2 million citizens. The scope is to give the reader an idea of what the waste treatment facility in such a region could look like.

The gasification plant setup is focused on the waste pre-treatment and the gasifier technique, as well as the gas cleaning processes. These processes are identified as the most important, whereas processes as DME or methanol production from synthesis gas can be regarded as well-proven technology and therefore given lower priority in the report.

The study is performed by Nykomb Synergetics AB (NSAB) and Future Energy GmbH (FE), where NSAB has been responsible for the contact between FE and Ecotraffic ERD^3 AB. NSAB has performed the overall technical and economical analysis and accounted for the final report. FE has provided the mass and energy balances, performed the dimensioning of the plant and also supplied an investment cost estimate.

4.2 Overview process description

The following description is intended to give a brief overview over the process concept of the full conversion from waste through pyrolysis and gasification technique to automotive motor fuels. Theoretically, automotive fuels may be methanol, dimethyl ether (DME), hydrogen or Fischer Tropsch diesel (FTD) etc. Here the process is configured for either DME or methanol synthesis, although the emphasis is on DME production. Previously, NSAB has been involved in a number of feasibility studies concerning methanol production from biomass fuel, using gasification technology [4,5,6]. The process scheme from waste to automotive fuel, as proposed by FE, is schematically shown in Figure 9, including the whole chain from waste receiving to syngas cleaning.

The technique chosen for the gasification process is the entrained flow gasifier, whose characteristics are further discussed in section 4.3.6. The combustible waste material obtained in the industry or in communities needs various kinds of pre-treatment in order to be suitable for feeding an entrained flow gasifier system. The pre-treatment involves a pre-drying unit followed by a pyrolysis section.

The incoming waste material is delivered to an unloading station, where the material is stored and mixed in a bunker system. The waste material considered is MSW and industrial waste, solely making up solid waste fractions. The waste fractions are neither pre-dried, nor sorted or size reduced in any way and therefore, the plant layout must contain both a pre-dryer unit as well as a shredder to reduce the size and make the fuel more homogeneous. From the bunker storage, the waste material is sent to a shredder unit and further to the pre-drying section. The dried material is now fed into the rotary kiln of the pyrolysis unit. These units generate a pyrolysis coke, a pyrolysis gas and separated from the gas also pyrolysis oil.

All three intermediate products are to be treated and temporarily stored before feeding the gasifier. The subsequent gasification of the three separate streams takes place in an oxygen-blown Noell-type entrained-flow gasifier at temperatures of 1500-1600 °C and an operating pressure of 32 bar (a). The outcome is a raw syngas, composed of hydrogen, carbon monoxide, carbon dioxide, water vapour and trace levels of hydrogen sulphide, methane, higher hydrocarbons, carbonyl sulphide, metals, chloride compounds, ammonia and hydrogen cyanide. Simultaneously, an unleachable slag is formed. The slag contains high concentrations of silica, aluminium and calcium and lower levels of a large number of other, mainly metal, species.

In a next process step the hot raw synthesis gas is cooled, primarily by quenching with water to 220 °C, ultimately down to 50 °C. The cooling is accomplished by generating steam with various pressure levels and temperatures on the cold side. A part of this heat recovery system (HRS) is made up of a water gas-shift reactor, where the exothermic reaction provides heat to the incoming syngas to the reactor. A part of the gas stream is by-passed the shift unit, to achieve the desired stoichiometry of hydrogen and carbon monoxide for the following synthesis.

The synthesis gas from the heat recovery section still contains sulphur components in form of hydrogen sulphide and carbonyl sulphide as well as other undesired compounds such as carbon dioxide, traces of higher hydrocarbons including benzene, and possibly other traces that can be harmful for the synthesis step.

A proven technology suited to meet the high quality demand for DME synthesis gas is the Rectisol® process. The Rectisol plant separates hydrogen sulphide, carbonyl sulphide from the syngas and generates a highly purified cleaned gas, using a cooled solvent. It is possible to achieve an off gas containing less than 1 vppm of sulphur and carbon dioxide in the ppm range as well. Low sulphur concentration is important in order not to deactivate the DME catalyst. The catalyst activity is not reduced by the carbon dioxide, but the carbon dioxide content should be minimised due to its dilution and increase of the total gas flow. Lowering the carbon dioxide concentration is, however, energy demanding and therefore an optimisation should be carried out. Any ammonia, hydrogen cyanide existent and the carbon dioxide content will also be removed. Since the concentrated solvent is hygroscopic as well, this leaves a cleaned gas of just hydrogen and carbon monoxide.

The cleaned outlet gas is then compressed to about 60 bar (a) prior to the DME synthesis loop. The gas cleaning unit will produce a hydrogen sulphide-rich gas which is treated and used in a Claus plant to produce elemental sulphur. The separated carbon dioxide is used as purging gas e.g. within the gasifier island.

Both the gasification and the gas treatment are carried out under pressurised conditions at a pressure above 30 bar (a), since a lower pressure results in an exergy loss of the recoverable heat evolved in the gasifier reactor. The high pressure also simplifies the final compression prior to the synthesis step. Methanol and DME synthesis is thermodynamically favoured at increased pressure and low temperatures. Traditionally, methanol synthesis was carried out at around 300 bar (a), modern catalysts have reduced the necessary operating pressure to 50-100 bar (a) and 200-300 °C [7, 8] This interval also reflects the optimal conditions from an economic point of view.

In the DME synthesis the syngas reacts to a DME/methanol/syngas mixture by means of catalysts in the DME reactor. The cooling of the methanol reactor generates low pressure steam, which is used directly for the further DME treatment. The raw DME contains water and fusel oil that are removed as a waste water stream and a combustible stream respectively. Raw DME and water are separated from the gas mixture by cooling and condensing, whereas the syngas is recycled to the DME reactor. After a final distillation the purified DME stream appears as a water-free product. In parallel to the production of DME a direct manufacture of methanol is possible, which is a very similar process to the DME synthesis loop by using a special catalyst. By-product streams from the DME synthesis are the combustible purge gas, which is recycled to the gasifier, and the flash gas streams, which are flared together with other vent streams.

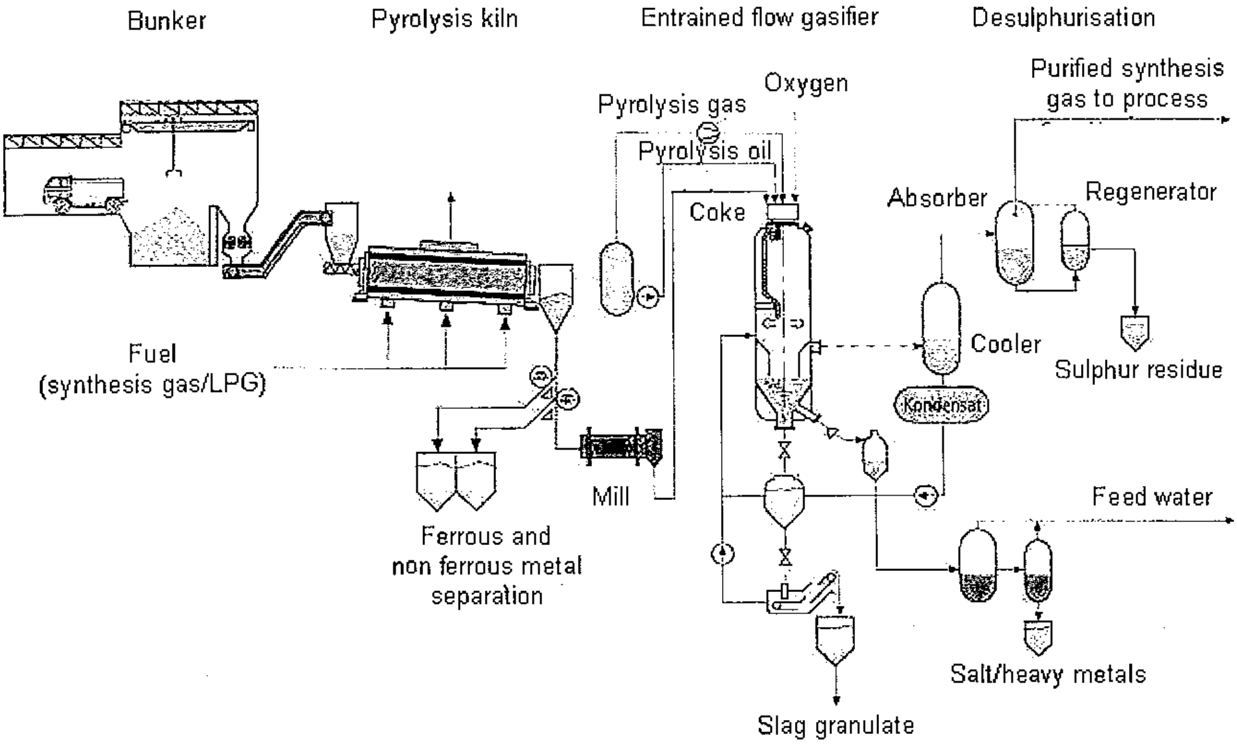

Figure 9. Process scheme, involving key features such as waste receiving, pyrolysis, gasification and gas cleaning and relevant material streams.

In detail, the complete system described above, and also seen from Figure 9, is comprised of the following subsystems:

1. Waste handling and preparation

- Waste unloading and storage
- Waste shredder
- Waste drying.

2. Thermochemical conversion

- Pyrolysis
- Feed preparation and supply to the gasifier
  - Media supply systems to the gasifier
  - Pyrolysis coke supply system
  - Pyrolysis gas supply system
  - Pyrolysis oil & slurry supply system
- Gasifier system
  - Burner and burner cooling circuit
  - Reactor with quencher
  - Slag discharge.

3. Gas conditioning and cleaning

- Heat recovery system
  - Steam generator
  - Raw gas cooler
- Gas cleaning and conditioning
  - Water gas-shift reactor and pre-heater
  - Rectisol plant
  - Refrigerator system
  - Regeneration system
  - Claus plant.

4. Fuel synthesis

- DME production
- DME separation and purification
- DME storage.

5. Auxiliary systems

- Purge and vent system

- Flare system
- Steam and condensate system
- Cooling water system
- Emergency system
- Waste water cleaning unit
- Slag discharge
- Air separation unit.

The different process parts can be schematically shown, in analogy with the block diagram as seen in Figure 9 (where the shift and methanol/DME units are not shown). The features of the plant will be more closely described in the following section, where each part is handled in the same order as above, i.e. divided into functionality.

4.3 Process configuration

4.3.1 Waste handling and preparation

A representative German waste composition, mass flow and heating values are presented in Table 6. Here, the composition is given for the waste *as received* and after the pre-drying process step to 10%$_{wt}$ water content, respectively. As previously mentioned, the waste is composed of both MSW and industrial waste, and it reflects the composition for northern Germany without any sorting or size-reductions. As can be seen, the ash and alkali contents are significant, as well as the sulphur content that is comparable to that of many coal fuels. This waste composition is, however, only an example of a European waste fraction and used as a reference for the plant setup. A similar approach to a representative Swedish waste fraction would reveal a different composition with lower sulphur and ash content.

The waste is delivered by truck and quantitatively registered and examined for identity. Although this report address solid waste only, with the composition given in Table 6, it is possible to handle liquid waste as well if desired. The solid waste is loaded into a bunker where it is stored temporarily, whereas any liquid waste is collected in a tank storage. Waste is delivered to the plant five days a week. The size of the bunker storage has to be dimensioned with respect to the five days a week deliveries, to allow for thorough mixing of waste and for contingency situations. Any solids larger than 1 *mm* contained in the liquid waste, are removed in a drum screening unit and transferred to the solid waste bunker. The solid material is manually moved by crane to the shredder unit, which is composed of two redundant rotary scissors. Before being fed to the pre-dryer, the waste is cut up into approximately 40 mm sized parts by rotary scissors.

The water content, which may be significantly higher than shown in Table 6, requires that the waste is dried before fed to the pyrolysis and gasifier trains, this also reduces the size of down-stream apparatus since the total mass flow decreases. The installation of pre-dryers makes it possible to process waste material containing with maximum moisture content of 50%. The pre-drying is carried out in dryer drums, heated indirectly using LP-steam. The steam demand is controlled by the temperature in the overhead vent gas, which is purged

Table 6. Elementary composition of waste as received and pre-dried to 10%$_{wt}$ respectively. Base case 400,000 tpa. Within parenthesis, the water free composition is given.

	Waste material, as received	Waste material, pre-dried
Total mass flow [tph]	50	44.4
mass flow [t DS/h]	40	40
HHV [MJ/kg]	12.8	
LHV [MJ/kg]	10.9	12.6
Composition [%$_{wt}$]		
C	20 (25)	22.5
H	6 (7.5)	6.75
N	1.8 (2.3)	**2.03**
S	0.7 (0.9)	0.79
O	10 (12.5)	11.3
Cl	1.5 (1.9)	1.7
Ash	40 (50)	45
Water	20 (0)	10

with nitrogen in order to minimise the risk of explosion. The vapour vent from the dryer is cooled and dried through condensing the water vapour, before being reheated and recirculated to the dryer. The condensed water is used as wash water in scrubbers and finally sent to the waste water treatment. A small part of the circulating gas is exhaust. There are five separate drying trains, each providing 25% capacity, where the maximum size is limited by its physical dimensions and the suppliers of equipment.

4.3.2 Thermochemical conversion

4.3.2.1 Pyrolysis

The principles of the pyrolysis and gasification processes are combined in order to utilise the advantages of each process. The pre-dried waste is transferred to the pyrolysis rotary kiln, by apron-type and drag chain conveyors. To prevent the infiltration of oxygen into the rotary kiln and to prevent the pyrolysis gas from escaping, the lock process is accompanied by a specific inerting process with nitrogen. Liquid feedstocks, however, would be directly fed into the rotary kiln via an injector lance.

As the waste material is heated, the remaining water is evaporated; thereafter carbonisation is taking place at 200-500 °C parallel to gas and liquid production. At still higher temperatures, higher hydrocarbons are thermally cracked into carbon, methane and hydrogen, according to reaction 1.

$$C_nH_m \ \delta \ xCH_4 + (m/2-2x)H_2 + (n-x)C(s) \qquad (1)$$

Steam reforming reactions also occur and the solid carbon is gasified into carbon monoxide and hydrogen via the water gas reaction, as shown by reactions (2 and 3.

$$CH_4 + H_2O \ \lambda \ CO + 3H_2 \qquad (2)$$

$$C(s) + H_2O(g) \ \lambda \ H_2 + CO \qquad (3)$$

In total, the process unit consists of five rotary kilns, following the five trains of pre-dryers, heated indirectly by a large number of gas fired burners. The burners are distributed into six individually burner zones, which can be adjusted according to local energy demand, that ensures the exact setting of a specific axial temperature profile. The burners are initially fired with LPG (syngas after stabile operation of the gasifier system) and the exhaust gas is discharged via the stack.

The discharge system is directly connected to the rotary kiln. This system makes it possible to discharge the pyrolysis gas and the pyrolysis coke separately. The pyrolysis coke is discharged via a discharge chute according to the filling level. Coke is deposited at up to a height of 1.5 m in the discharge chute, which provides a virtually gas-tight division between the pyrolysis gas in the outlet and the following coke treatment stage. In order to avoid gas from escaping, the entire coke treatment stage is operated with carbon dioxide at a pressure of at least 1 bar above the pressure inside the reactor space.

The generated gas is separated from liquid tars by cooling, initially a quencher and subsequently a cooler. Any oil and dust content is thereby separated giving a liquid slurry, parallel to the cleaned gas. Any acidic gas components are removed from the gas by means of an alkaline scrubbing stage. The slurry is further treated by means of two decanters, one for each cooling section. The high-solid fraction in the first decanter is transferred back to the solid waste bunker whereas the oil phases from both decanters are stored before feeding the gasifier. The solid residues are separated into a coarse and a fine fraction by means of a vibrating screen. The fine coke is loaded into silo transport vehicles for recovery, whereas the coarse-grain fraction is cooled directly by a submerged wet slag extractor, transported to separator to remove first the ferrous particles, and then the non-ferrous ones. Both sizes of coke are stored in silos before feeding the final grinding unit. The milling unit consists of a screening unit and a ball mill. The milled fine coke is sent to a buffer silo by a pneumatic conveyor, using a carrier gas (nitrogen in the start up phase, and recycled carbon dioxide during normal operation). By means of a conveyer system, the pulverised pyrolysis coke is passed to a dense flow feeding system consisting of a sequence of an atmospheric fuel bunker, three lock hoppers and a feeder vessel.

Pyrolysis coke is charged from a storage bin to pulverised fuel feeding. The pulverised fuel is partially fluidised by means of the carrier gas in the vortex shaft of the feeder vessel, in which the fuel conveying lines are immersed. The fuel is pneumatically transported in a dense flow to the gasifier nozzle. The fuel mass flow is determined by correlation measurement comparing conveyance velocity and the mixed flow (fuel and carrier gas) density. The fuel mass flow rate is established through control of the pressure drop between the feeder vessel and the gasifier reaction chamber. Buffer tanks compensate for varying carrier gas requirements. The entire process of pulverised fuel feeding is integrated into the automation system as sequence control system. Thus, all parameters that are relevant to the system are constantly monitored. A sequence-independent interlocking system guarantees the maintenance of the pressure regime.

Before feeding the gasifier, each stream is pressurised to comply with the operating conditions in the gasifier. The liquid fraction, a slurry of oil, water and dust is intensively agitated to emulsify the mixture and prevent separation into water and oil. To improve the characteristics the slurry is heated with LP-steam before pumped with piston pumps to 45 bar (a). The slurry should be of constant quality to be finely atomised by means of the nozzle. Prior to main burner start-up, the slurry is recirculated in a closed loop. Purging of slurry lances is carried out with nitrogen during the start-up phase. Finally, the pyrolysis gas pressure is increased using a speed-regulated compressor, compressing the gas to 35 bar (a) before feeding it to the main burner of the gasifier system. The compressor is redundantly installed. This procedure results in three streams, which flows are regulated and optimised before being fed to the gasifier. This is carried out by means of buffer storages, for each of the feed streams, which also ensures stable operation of the gasifier.

These three streams are fed to the main combination burner; above this, a pilot burner is used to generate the necessary heat. In the start-up phase and during the heating-up phase LPG is used as fuel for the pilot burner. As soon as the production of syngas is established, the generated syngas will instead be used as fuel gas, operating as hot standby. The oxygen is provided to the gasifier from the ASU at a pressure of 40 bar (a) and a temperature of 120 °C. The oxygen feed rate to each burner is regulated by a control valve by ratio control with the actual fuel feed rate. Downstream the last shut-off valve before the burner, a nitrogen purge line leads into the oxygen line, which shall ensure a definite stream in reactor direction at burner shut-down. The oxygen supply system is part of the gasifier safety system.

4.3.2.2 Gasification plant

The entrained gasifier, quench and burner system by Noell used in this study are shown in *Figure 10*. The reactants (fuel and gasification media) are fed into the reaction chamber in parallel flow through the main and pilot burner at the gasifier top. The latter are converted in a heterogeneous flame reaction in entrained flow at a pressure of approximately 32 bar (a) and temperatures of about 1500 °C. The partial oxidation reaction converts the organic components of the feed materials primarily into hydrogen and carbon monoxide, with secondary formation of carbon dioxide, water vapour and low levels of hydrogen sulphide, methane, higher hydrocarbons, carbonyl sulphide, metals, chloride compounds, ammonia and hydrogen cyanide. The non-volatile and inert components in the feed are forming a slag or salts.

The specified high-ash feedstock will be gasified in a patented "cooling screen" design gasifier. The cooling screen design is highly suitable for high-ash containing feedstocks. This design lowers the risk of slag attack on the refractory lining and offers long and low maintenance-cost operation. For safe capture of slag and solids a full-quench system is proposed.

Gasifier control at the Future Energy gasifier system is automatic. The initial set-point for the gasification oxygen requirement is controlled by the mass flow rate of the fuels. The oxygen-to-fuel ratio is trimmed to adjust for changes in load, fuel characteristics (such as inert fraction and composition, slag melting temperatures etc.), pressure differential across the exit throat of the gasifier and the carbon dioxide content of the raw gas. The reactor is started on natural gas and oxygen and brought up to the necessary operating pressure and temperature.

The gasifier system, including the heat recovery section, is composed of three separate reactors, each designed for 50% capacity. This redundancy increases the availability of the complete plant as well as the flexibility for running on part loads.

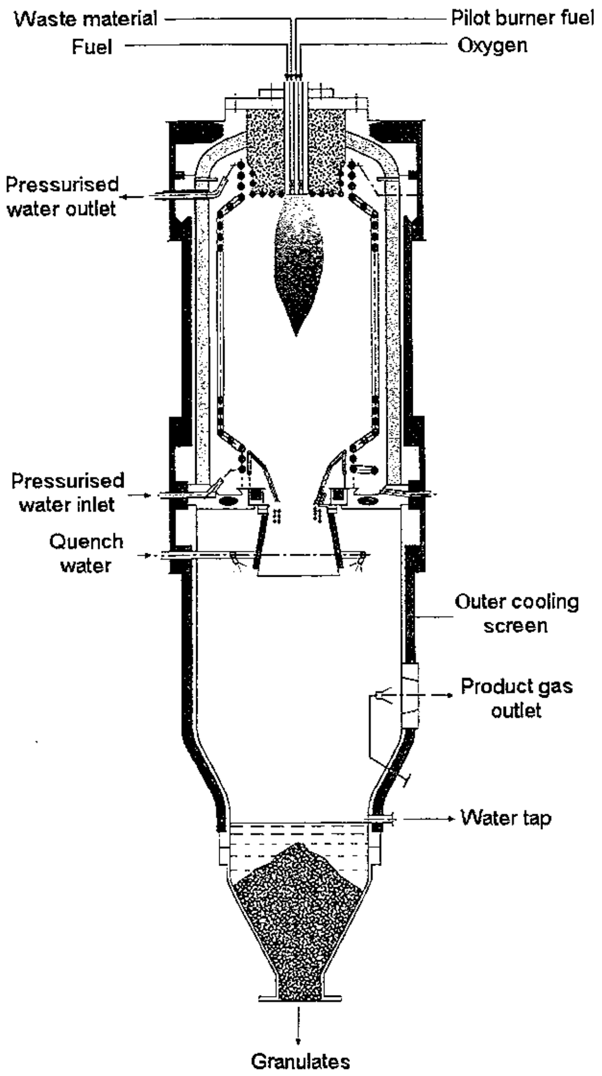

Figure 10. The Noell entrained bed gasifier, designed for waste feedstock.

The gasifier system can be broken down into the following main parts:

- Reaction chamber (reactor)
- Quencher with circulation system
- Burner
- Reactor outlet
- Burner cooling system
- Burner support unit.

The reactor designated for waste gasification comprises an outside pressure wall and an inside cooling screen (inner diameter about 1.7 m) cooled by pressurised water to protect the outside wall against chemical and thermal attacks. The cooling screen consists mainly of a spiral pipe coil studded and covered with a ceramic ramming mass. The reactor head is covered by the burner support unit, which bears the combination burner.

Heat from the reaction chamber is rejected to the cooling screen steam generator, the burner cooling circuit (BCC) and to the burner support unit through a closed-loop cooling system. Liquid slag and solids from the gas in the reactor flow down the inner wall, which is protected by solidified slag, through the cooled reactor outlet and passing the direct coupled quench vessel.

The burner installation comprises a pilot burner with ignition device and flame monitoring system and a main burner, useable for different kind of feedstock (solids, slurry, gas). During the start-up phase, i.e. until carbon dioxide is available from the gas cleaning unit, nitrogen is used for purging. Following the ignition of the main burner, the pilot burner is switched from LPG to syngas. Media supply systems comprise all instrumentation and control installation necessary to regulate the media feed rates.

Once the pilot burner for the ignition of the fuel is in temperature maintenance operation, the gas content in the system pressurised, the gasifier can be brought on line within minutes. From the hot standby condition it can be brought to full load within 10 minutes. About 0.5 to 1 hours are necessary to bring the gasifier from "cold condition" to full load. To achieve high plant availability it is common practice to keep the stand-by gasifier in "warm condition", i.e. the gasifier being run with pilot burner.

Burner components that are subjected to high thermal loads are intensely cooled by a separate cooling water circuit, which includes a buffer vessel, an air cooler and redundant BCC pumps. The pressure of this cooling circuit follows the reactor pressure in such a manner that the burner cooling water pressure exceeds the reactor pressure by about 1 bar. This prevents the migration of syngas into the cooling circuit in the event of a leak in the cooling coils or in the cooling shroud of the burner. The cooling water used is recycled, cooled by an air cooler.

The hot raw synthesis gas and the liquid slag leave the gasifier reaction chamber and flow in parallel vertically downward and discharge directly into a quench section. The raw gas is instantaneously cooled down to approximately 220 °C by direct injection of water. Generated slag granulates in the water bath in the bottom of the quench system.

After passing the quench section, the raw gas is completely saturated with water vapour. This water content is condensed in the following cooling steps and it will be used again as quench water. The liquid water part of the quench process, i.e. the remaining quench water, is flashed together with suspended solids (slag, fine ash, coke, soot and salts) and finally sent to the waste water pre-treatment. Main parts of this cleaned water are recycled to the quencher as quench water whereas a small flow is discharged as waste water in order to maintain the salt concentration in the cycle water.

Preceding the quench section the remaining ash and soot particulates are removed from the raw gas in a venturi scrubber. The scrubber is run on gas condensate from a downstream process and part of this scrubber water is directed to the waste water treatment unit.

4.3.3 Gas conditioning and cleaning

The cleaning and conditioning of the derived raw gas is perhaps the most delicate part of the process, together with the gasifier, where the composition of the gas is shifted to match the desired stoichiometry in the synthesis section. Prior to the conditioning of the raw gas, the heat is recovered in a multi-stage system.

4.3.3.1 Heat recovery system

The hot raw gas exiting the quencher outlet is cooled in a multi-stage HRS. The first stage is a MP-steam generator, followed by a water gas-shift unit with pre-heater and shift-reactor. Downstream the pre-heater the gas has a temperature of about 280 °C, which facilitates steam generation at 40 bar (a) in a HP-steam generator. The gas is further cooled in a second MP-steam generator followed by a LP-steam generator. Part of this LP-steam is used for pre-heating of slurry and oxygen. The sixth and last section is a cooling section using cooling water. The outlet temperature of the raw gas leaving the HRS is approximately 50 °C, before entering the Rectisol plant.

The condensate generated during the cooling operation is collected in a gas condensate vessel that is operated at raw gas pressure. The main part of the condensate is used as quench water and is recycled to the quench. A small part of this water, containing ammonia and other trace compounds, is passed to the waste water treatment plant.

4.3.3.2 Water gas-shift reactor

Downstream the first MP-steam generation step, a water gas-shift reactor is installed to convert parts of the carbon monoxide content in the raw syngas into desired hydrogen and carbon dioxide. The overall process is delivered by Linde, using a "dirty-shift" catalyst, where the active phase is Co/Mo. The dirty-shift catalyst requires a certain amount of hydrogen sulphide in the gas to remain in its active conformation, i.e. sulphated. The sulphur content in the gas is well above the critical limit of 700 ppm stated by the manufacturer. To handle any trace compounds that could deactivate the catalyst, the catalyst is installed in three sections. This improves the catalyst life for the second and third sections. Depending on the feedstock and the resulting concentrations of pollutants in the gas, an inactive guard bed could be placed upstream the catalyst bed.

The exothermic water gas-shift reaction starts at an initial temperature of about 280 °C and increases to about 430 °C. The generated heat from the shift reaction is used to heat up the syngas upstream the shift reactor to the inlet temperature of 280 °C. A by-pass to the shift reactor is used to adjust the demanded hydrogen to carbon monoxide ratio, before entering the synthesis unit. The carbon dioxide content in the processed gas stream is subsequently removed in the Rectisol plant.

4.3.3.3 Rectisol plant

The Rectisol process is an acid gas removal system using an organic solvent at temperatures below 0 °C. In general, methanol is used for hydrogen sulphide/carbonyl sulphide in parallel to carbon dioxide removal. By means of the Rectisol process it is possible to produce a purified synthesis gas with less than 0.1 vppm total sulphur and a carbon dioxide content in the ppm range. The degree of carbon dioxide reduction should be further investigated and optimised in a more detailed study. In the given one-stage Rectisol design hydrogen sulphide/carbonyl sulphide and carbon dioxide are simultaneously removed in a single wash column.

The main advantage compared to other processes is the use of cheap and in-process available methanol as solvent, the very flexible process configuration and the rather low utility consumption figures. In addition, the sulphur compounds (trail gas) and the carbon dioxide can be removed in separate fractions.

The Rectisol process is a commercially tested and verified method, used world wide for the purification of hydrogen, ammonia- and methanol syngas, pure carbon monoxide or oxogases. Since the gas from the entrained gasifier is tar free, the Rectisol is the only required gas cleaning utility.

The raw gas that enters the Rectisol plant is cooled down in a heat exchanger system while heating the cleaned syngas and the generated carbon dioxide gas, before exiting the Rectisol plant. The physically acting absorption unit removes hydrogen sulphide/carbonyl sulphide and carbon dioxide from the crude syngas by cold lean and semi-lean methanol, cooled to temperatures below -10 °C. Trace compounds introduced in the process together with the feed gas, such as hydrogen cyanide and ammonia will also be removed. Preferable solvent is methanol.

The methanol from the bottom of this section is loaded with carbon dioxide and hydrogen sulphide/carbonyl sulphide. The heat of solution is covered partly by heating of the methanol and partly by external refrigeration (temperature level -42 °C). The purified gas stream from the top of the wash column is heated by the incoming gas stream and given to the syngas compressor before entering the methanol/DME plant.

The loaded methanol stream from the main scrubber is expanded in the flash column to an intermediate pressure in order to recover an impure carbon dioxide gas stream. The flashed carbon dioxide is heated, and in addition to being given to the carbon dioxide compressor for recycle, it is sent out for external use.

The loaded methanol from the flash column is expanded further, close to ambient pressure, for supplementary carbon dioxide flashing. Thereafter the methanol stream is split; one part is pumped back to the main absorber as semi-lean solvent, whereas the other part is stripped with low pressure nitrogen in order to recover the last heat of solution and thereby decrease the consumption of external refrigeration in the absorption process. The overhead gas (mainly carbon dioxide and nitrogen) is warmed up in the feed gas cooler.

The cold stripped methanol is heated and fed into the regeneration column, where all yet dissolved acid gases are stripped off by means of methanol vapour, generated in a steam heated reboiler. The lean methanol from the bottom is cooled and pumped back to the top of the main scrubber and to the top of the carbon dioxide scrubber. Methanol vapour is condensed from the acid gas fraction before leaving the column overhead.

The methanol/water mixture from the bottom of the stripping column is separated in the methanol/water distillation column into methanol and water. The column again is heated by steam, as reflux lean methanol is used. The methanol from the top supports the warm regeneration.

The acid gases from the flash column, the regeneration column and the benzene stripper column are collected and passed through a water wash column for removal of methanol before given to the sour gas treatment. The wash water is water from the methanol/water separation and demineralised water. The loaded water is routed back to the decanter for diluting the methanol and for methanol recovery. A part of the water from the methanol/water distillation is given out of the process as waste water in order to bring out impurities and balance the water of the Rectisol unit.

4.3.3.4 Sour gas treatment

From the regeneration step of the Rectisol, a hydrogen sulphide-rich sour gas comes out. The pre-cooled gas, finally washed with demineralised water, is fed to a Claus plant to generate pure sulphur for commercial use. For the Claus plant the Oxyclaus process is chosen. As the hydrogen sulphide-rich gas from the Rectisol unit enters the Oxyclaus plant, it is passed through a knock-out drum to remove any entrained liquids. From the knock-out drum the gas is routed to the Oxyclaus burner, which consists of a central burner called burner muffle, where LPG is burnt with air in heating purpose. Around the burner muffle, a number of hydrogen sulphide burners are located. Each of these burners consists of a central oxygen lance for oxygen supply and concentric mounted tubes for hydrogen sulphide and air supply. All burners eject their hot flue gases into the Claus combustion chamber. In the combustion chamber, the hydrogen sulphide in the feed gas is converted to elemental sulphur by partial oxidation with oxygen and air. The air is supplied by an air blower.

The size of the Claus combustion chamber is suitably dimensioned to reach nearly the thermodynamic equilibrium in the flue gas from the hydrogen sulphide-burners. The chemical reactions taking place in the Claus combustion chamber transform approximately 50% of the hydrogen sulphide into sulphur vapour.

The chemical reactions occurring during the process are described by reactions 4-7 below, where reaction 4 is the net reaction of a number of hydrogen sulphide reactions in the Claus process, exemplified by reactions 5-8. The predominant reactions 4,5 and 8 are strongly exothermic and the heat is used to generate MP-steam, parallel to precipitating the sulphur vapour as elemental sulphur. As the process gas is cooled down, the sulphur in the form of S_2 is converted to higher atomic sulphur, i.e. for decreasing temperature the molar weight of the sulphur species increases.

$$2H_2S + O_2 \lambda 2H_2O + S_2(g) \qquad (4)$$

$$H_2S + 3/2O_2 \tau H_2O(g) + SO_2 \qquad (5)$$

$$H_2S + CO_2 \tau COS + H_2O(g) \qquad (6)$$

$$2H_2S + CO_2 \tau CS_2 + 2H_2O(g) \qquad (7)$$

In the first Claus reactor hydrogen sulphide and sulphur dioxide are further catalysed to elementary sulphur according to reaction 8 in the presence of a catalyst.

$$2H_2S + SO_2 \lambda 2H_2O(g) + 3/2S_2(g) \qquad (8)$$

Other sulphur compounds of the process gas are initially hydrolysed according to reactions 18-19 below.

$$COS + H_2O(g) \lambda CO_2 + H_2S \qquad (9)$$

$$CS_2 + H_2O(g) \lambda COS + H_2S \qquad (10)$$

Upon leaving the first reactor, the process gas is cooled down in a sulphur condenser by producing LP-steam. As the process gas is cooled down, the sulphur once again is converted into higher atomic sulphur.

Prior to entering the second reactor, the process gas is reheated using HP-steam to reach the proper reaction temperature. The reactor operates with a highly active aluminium oxide catalyst which further converts the remaining sulphur compounds to elementary sulphur.

Downstream the second reactor the process gas is cooled in a sulphur condenser to precipitate most of the sulphur vapour left in the gas. In the last sulphur condenser the gas is cooled by cooling water. Preceding the last sulphur condenser the process gas passes a sulphur separator, a special separator with agglomeration of particles to compress the fine mist droplets. Downstream the separator the Claus tail gas is routed to the flare for combustion.

The converted liquid sulphur drains via double-shell traced pipes into sulphur collecting tank. The sulphur collecting tank is equipped with two submerged sulphur pumps which are used to degas the sulphur (by circulating and spraying) and to transfer the sulphur to the sulphur storage or to sulphur loading station.

4.3.4 Fuel synthesis

4.3.4.1 DME production

Based on a commercial methanol technology, the LPMEOH™ liquid phase process by Air Products and Chemicals Inc, the methanol reactor can be converted to produce DME in one step by including a dehydration function in the catalyst. This increases the productivity of the reactor since the methanol formed is removed, which further shifts the equilibrium position in the methanol formation reaction. The equilibrium shift results in higher conversions per pass and thus, more DME formed. This process, LPDME™, is also commercialised by Air Products and Chemicals Inc. Haldor Topsøe A/S has separately developed a DME catalyst, which converts synthesis gas into DME. This catalyst has, except the dual function for converting synthesis gas into methanol and further to DME, also activity for equilibrating the water gas-shift reaction. The process choice for the current waste-to-motor fuel plant is the liquid phase reactor by Air Products and Chemicals Inc.

The synthesis of DME from the cleaned syngas involves compressing the syngas from the syngas cleaning unit, and pre-heating it before entering the liquid phase DME reactor system. The compressor is equipped with a by-pass including a gas cooler, utilising cooling water. The pressure downstream the compressor is controlled by a control valve at the discharge of the compressor. A control valve, at the recycle of the compressor, controls the flow rate through the compressor by controlling upstream gasifier system pressure. This gas-recycle system, including cooler and return to the suction side, is provided to avoid surge conditions through the compressor during periods of low forward flow and during the start-up phase. On occasions when the DME plant is unable to receive the syngas, the flare system is designed to meet the capacity of produced syngas.

The reaction from synthesis gas to DME is a sequential reaction, involving methanol as an intermediate product. The first part of the reaction, i.e. synthesis gas to methanol is quite exothermic and it is thermodynamically limited at a fairly low temperature. Therefore, the first part of the reaction takes place in a cooled reactor, where the reaction heat is continuously removed by generation of HP-steam, and the equilibrium may be approached at optimum conditions.

The second part of the reaction from methanol to DME is much less exothermic, and the equilibrium is limited at a different temperature. Therefore, this part of the reaction takes place in a separate adiabatic fixed-bed reactor.

In the DME synthesis section, the first step involves reacting hydrogen, carbon monoxide and carbon dioxide into methanol according to reactions 11-12, both exothermic.

$$CO + 2H_2 \lambda CH_3OH \qquad (11)$$

$$CO_2 + 3H_2 \lambda CH_3OH + H_2O \qquad (12)$$

The stoichiometry for these reactions implies a volumetric relation between the reactants, commonly written as equation 13 below:

$$\frac{H_2 - CO_2}{CO + CO_2} \approx 2 \qquad (13)$$

Table 7. The gas composition entering the DME synthesis step.

Compound	%$_v$
H_2	68
CO	28
N_2	3.2
H_2O	0.53
CO_2	0.42

The purified and highly hydrogen enriched gas, that enters the DME synthesis reactor has the composition shown in Table 7. It could be seen that, after passing through the shift reactor and the sour gas cleaning, the number of compounds in the synthesis gas has been reduced. The relation stated in equation 13, is around 2.3 and the carbon dioxide content could probably be increased from the low level in Table 7 to further optimise the process.

The second reaction step including the formed methanol as reactant is the dehydration of methanol to from the di-methyl ether, shown in reaction 14.

$$2CH_3OH \lambda CH_3\text{-}O\text{-}CH_3 + H_2O \qquad (14)$$

In addition, some side reactions take place to a very limited extent, for instance formation of higher alcohols and the water gas-shift reaction shown in reactions 15-16.

$$2CO + 4H_2 \lambda CH_3CH_2OH + H_2O \qquad (15)$$

$$CO + H_2O \lambda CO_2 + H_2 \qquad (16)$$

Consequently, the two-stage reactor concept permits both steps of the sequential reaction from syngas to DME to take place at optimum conditions, while at the same time the synthesis section becomes more similar to a conventional methanol synthesis loop. With respect to technology verification at industrial scale, the only major difference between the DME synthesis and the methanol synthesis is the second stage adiabatic reactor, loaded with the proprietary dual-function catalyst.

The generated DME gas is then cooled in the economiser, followed by a cooling water cooler before separating the DME/methanol/water mixture from the unreacted syngas and inert gas. The separated gas is partly recycled to the feed gas while a small rest is washed with methanol and sent as purge gas to the gasifier system.

4.3.4.2 DME separation and purification

Given that the LPDME™ process does not generate chemical grade DME product during the synthesis, no provision for DME storage or extensive distillation is included. If flexibility is desired to make AA Chemical grade methanol or Chemical grade DME, such could be added at additional cost. Compared to methanol synthesis, the recovery of the

DME is more complex as DME is gaseous at normal conditions and unconverted methanol must be recovered for recycling.

The specific layout of the separation and purification section ultimately depends on the specific demands for product purity. Naturally, lower demands on product purity result in lower investment and energy consumption. In fact, substantial savings are achieved by producing fuel grade DME, i.e. DME containing minor amounts of methanol (7-8%) and water (appr. 3%), compared to a chemical grade product. The specific heating value is only slightly lowered compared to pure DME. From a reference point of view, the direct DME purification section may be considered as a combination of a methanol distillation section and the purification section of a conventional DME plant based on methanol dehydration. In this case, water is also produced as a by-product and vents are to be recycled to be used as fuel in the gasification unit.

4.3.4.3 DME storage

Because fuel grade DME has physical characteristics similar to LPG, fuel grade DME can leverage from the vast experience, mature technologies and proven equipment developed and used to handle LPG. Consequently, fuel grade DME can utilise LPG loading and off-loading, storage and shipping equipment and technology with only minor modifications. DME, like LPG, can be stored onshore in either a pressurised, semi-pressurised, or refrigerated condition.

A crude DME vessel, designed for 16 hours of DME production volume, is used to store materials that will be sent to the DME distillation section for purification. It acts as a buffer between the synthesis and distillation sections to maximise on-stream time. All off-spec DME product and any contaminated water or methanol collected from the DME unit are sent to these tanks for processing in the DME distillation section.

Product DME from distillation flows to the DME day vessels, which are designed for 16 hours of DME production, just as the crude vessel. These vessels are used to allow the time required to analyse its contents to ensure product quality before pumping to the large product DME tank, designed for 4 days of DME production. All vessels are kept under a pressurised nitrogen blanket to minimise venting and also to control pressure. Furthermore, each vent is routed to a collector pipe and sent to the flare.

Product DME is fed from the storage tank to the truck/rail car loading station. Prior to loading the fuel, the receiving vehicles are purged with nitrogen and vented through the vent collector to the flare.

4.3.5 Auxiliary systems

The utility system of the complete gas to motor fuel system consists of some key features, including vent and flare system, steam and condensate system, cooling water system, emergency system and an air separation unit. These systems are needed to sustain the main systems of the plant, but they also provide potential links to external plants. Closely related to these systems, is the waste water cleaning unit and the slag discharge system.

4.3.5.1 Vent and flare system

The produced syngas is normally consumed in the methanol/DME plant or used as fuel in the pyrolyser and pilot burner in the gasifier. However, when these plant parts are not operating, or when syngas cannot be forwarded to further treatment because of unspecified quality (during start operation or shut down), the syngas is combusted and exhausted to atmosphere via a flare. The flare system includes a knock-out drum for separating any liquids from the stream, from which a bottoms pump forwards the collected liquid to the waste water treatment for disposal. Because syngas is a clean burning fuel, the ground flare does not require any steam or air assist, although ignition is insured by a continuous fuel gas pilot. The fuel gas is possible to replace by purge and vent gas coming out of the methanol/DME distillation. The flare is capable of combusting maximum plant syngas capacity. A small fuel gas/vent gas purge is maintained through the flare header to the drum and through the flare to prevent the ingress of oxygen back into the gas system.

Tail gases from the Claus plant and purge gas (nitrogen) from the pyrolysis, tank area and from buffer vessels are to be collected in a header line and sent to flare for combustion and for safe discharge to atmosphere.

4.3.5.2 Steam and condensate system

Boiler feed water (BFW) is the base for steam generation, divided into three different qualities: LP-steam at 4 bar (a), MP-steam at 10 bar (a), and HP-steam at 40 bar (a). These streams are utilising redundant BFW-pumps for the respective pressure level. Depending on its temperature and pressure domain, every stream has a certain usage in the waste-to-motor fuel plant.

The steam and condensate systems are important items in parts of the complete waste-to-motor fuel plant, such as: the gasification plant, the gas treatment unit, the Claus plant and the methanol/DME plant. Steam is required for different purposes, involving heating, process and cleaning medium. Formed condensates are to be collected, cooled and applied as demineralised water in the sour gas wash water column. Remaining parts are possible to send as boiler feed water to the boiler system.

Condensate is to be applied in the following areas:

• Heat Recovery	During start and heating up
• Feed system	Continuous
• Claus plant	Continuous
• Rectisol regeneration	Continuous
• Methanol/DME distillation	Continuous
• Utility stations	Clearing and washing.

During normal operation, a surplus of condensate is generated and a fraction of the water has to be exported to the boiler system. Some issues are site-specific and must be investigated further, for instance the use of MP-steam condensate for LP-steam generation.

The LP-steam generated in the heat recovery and through the reactor cooling is used partly for heating purposes in the waste drying, partly for the reboiler at the columns in the Rectisol regeneration unit as well as in the methanol/DME distillation. If desired, a system for generation of LLP-steam (2 bar (a)) in the heat recovery and in the Claus plant could be added.

4.3.5.3 *Cooling water system*

Heat return from all cooling processes is transferred via cooling water to ambient. The cooling tower will give a 5 °C approach to summer wet bulb temperature of about 15 °C, for a cooling water supply temperature of 20 °C. Tower duty represents the heat duty of all consumers of the complete plant at full load. Naturally, where available, heat sinks in lakes and rivers should be utilised. The available cooling water supply temperature from large lakes is maximum 10-15 °C, depending on the depth. The lower temperature, compared to cooling towers, reduces the necessary size of heat transfer units and thereby the costs associated with heat exchangers. Clarified river water is used as make-up water to the tower basin when cooling towers are used.

Each plant owns its own pump group operating with one running and one spare pump at design capacity. Before sending to the consumers the cooling water is filtered and checked by pH-value and the conductivity. Biocide is stored in a vessel to prevent biological growth in the water system and is to be pumped to the basin.

4.3.5.4 *Emergency system*

The emergency power supply system shall be used in case of a power failure to supply critical equipment, such as cooling screen circuit, burner cooling circuit, process control, flare system or nitrogen purging. The emergency power supply system consists of two units: an emergency generating set (Gen-set) and an emergency power distribution system (EPD).

The emergency generating set includes an automatically controlled diesel driven generator set. In case of a power failure the diesel engine starts automatically and, after having accelerated to normal speed, automatically cuts in the generator voltage, the moment the latter has stabilised.

4.3.5.5 *Waste water treatment*

The waste water that is produced during pyrolysis (moisture from the input and product water during the pyrolysis process) is cleaned in a conventional plant, in compliance with the requirements specified by the plan approval. The biological waste water cleaning plant consists of the following areas:

- Nitrite separation (reduction of ammonia)
- Oxidation (cyanide, hydrogen sulphide decomposition)
- Precipitation/flocculation (removal of heavy metals)
- Tower-type biological systems (CSB, phenol decomposition, denitrification)
- Filtration with subsequent activated carbon filter.

Only the cleaned waste water which complies with the guidelines for discharge to surface water is allowed to discharge continuously to the local waste water network. Another part of waste water is generated in the gasification system and during the heat recovery. This waste water originates from the following sources:

- Waste water from the slag discharge
- Remaining quench water

- Wash water from the venturi circuit
- Waste water from the DME plant and from the Claus plant.

The treatment plant has to reduce a number of components, for instance solids (fine slag/soot), heavy metals, cyanide, ammonia, phosphate, carbonate, fluoride, sulphides and salts.

To fulfil these demands, the waste water treatment plant consists of the following units:

- Slag discharge
- Water cooling and steam generation for the waste water vaporisation
- Separation of fine slag
- Precipitation/flocculation (removal of salts/soot/heavy metals).

The main part of the pre-treated waste water is recycled to the gasification system. The remaining part is further treated by various methods, such as oxidation for cyanide and hydrogen sulphide decomposition, precipitation/flocculation/neutralization for removal of additional cyanide/sulphide and waste water vaporisation.

After cooling, the different liquid effluents, i.e. from the quench system, slag discharge unit and the scrubbing water from the venturi scrubber, all contain fractions of fine particulate matter, soot, salts and volatile heavy metal sulphides removed from their respective gas stream. The fine particulate matter is filtered, and any heavy metal compounds are chemically precipitated, coagulated and filtered. The waste water pH is adjusted to precipitate metal hydroxides. Fine slag and precipitate are removed in a clarifier, thickened and dewatered using a fabric filter to separate the precipitate from the waste water. The washed and dried filter cake is containerised for appropriate off-site disposal.

Waste water for discharge is further treated by cyanide oxidation, by means of hydrogen peroxide and the pH is adjusted by addition of sodium hydroxide. The last step in this procedure is the waste water vaporisation, where the heat of the waste water cooling is used. The generated concentrate is finally dried to a moisture content of about 15% before being deposited.

4.3.5.6 Slag discharge

Generated slag that is produced in the gasifier reactor granulates in a water bath in the bottom of the quench system. The slag, i.e. slag, fine ash, coke, soot and salts, discharged from the quencher sump falls into a water-filled pressurised lock hopper. The slag displaces the water and an upper lock is closed. After cooling a lower lock is opened, and the slag and any water remaining in the hopper are discharged into a slag receiving tank.

The major portion of the slag settles in the slag-receiving tank from where it is discharged by means of screws, and may then be put to further utilisation. Water carried out of the slag discharge system are collected in a conveyor overflow and pumped to the waste water treatment plant.

4.3.5.7 *Air separation unit*

The oxygen required in the gasification process is delivered by a cryogenic air separation unit (ASU). Gaseous oxygen and nitrogen are provided with a pressure of 40 and 56 bar (a) respectively. The nitrogen delivered is an important part of the safety system and is also used to replace carbon dioxide when the gas cleaning process is not operating. In detail, the main parts of the ASU consist of:

- Air compressor with filter
- Air cooler and air scrubber
- Air cleaning and drying
- Nitrogen compressor
- Oxygen compressor
- Refrigerator unit.

Nitrogen is supplied from the ASU as HP-nitrogen at 56 bar (a) for the gasifier and gasifier supply systems as well as LP-nitrogen for start up processes and for purging. When carbon dioxide is available from the gas cleaning unit and stable operating conditions have been established, the process is switched over from HP-nitrogen to carbon dioxide, since the nitrogen content in the syngas should be minimised.

The nitrogen system for purging the oxygen lines is also part of the gasifier safety system. To prevent malfunction, the oxygen supply system must be technically segregated from the nitrogen supply system for purging pipelines and vessels bearing combustible gases. To ensure safe plant shut-down if nitrogen supply is interrupted, nitrogen is stored in buffer tanks before supplied to the gasifier.

4.3.6 Discussion

The availability of the complete waste-to-motor fuel plant is ensured using built-in redundancy. The plant is configured with a number of parallel trains, designed with sufficient over-capacity so that at least one process unit in delicate parts of the process, e.g. a gasifier or a pyrolyser, can be under maintenance (i.e. for *n* trains, *n-1* would suffice the design spec.). The current setup is also due to physical limitations of the size of certain reactors. This is, apart from the larger capacity in the gasifier reactor, one explanation of why the number of trains converges from five to three, since the mass flow of solid fuel decreases from the pyrolysis zone to the gasifiers. In total, the expected availability of the plant is around 8,000 hours per year. The availability of the plant is dependent on the fuel characteristics as well as the plant design, regarding environmentally and safety concepts.

The complex layout of the complete waste-to-motor fuel plant could be deepened further by including a biomass fired boiler. This would make the plant self-sustained on electrical power, which otherwise has to be purchased from the national grid. The boiler would then heat exchange the MP-steam from the waste-to-motor fuel plant against the boiler feed water. Feeding steam at 40 bar (a) and 540 °C to the turbine, generating the required 26 MW_e (see Table 11), would then imply that the transferred net energy from the boiler should amount to around 9 MW_{th}, if the steam were to be condensed at 20 °C.

The implementation of a biomass plant is only one possible solution. Making the total waste-to-energy plant self-sustained on electricity, however, gives a common basis for comparison with other biofuel plants (see references in section 4.1). Another possible configuration might include the production of district heating by heat exchanging the MP-steam against a district heating grid. The general relation between heat and power prices probably makes this the most economical option. Therefore, the following sections will consider the district heating option, where electricity is purchased from the grid.

The current plant layout is, however, not claimed to be the most optimal, and it is always a matter of choice for the referred application to design the process. This, of course, is reflected in the investment cost as well. Depending on the site conditions, the choices vary for the utilisation of surplus heat, whereof the district heating option has already been mentioned. It could be possible to also deliver the MP-steam to nearby process plants, having electrical power in return or even using the steam in a condensing turbine to generate additional power. The latter alternative results in an extra investment cost, which however, could be economically feasible. Since these options are more of niche alternatives, they are not further investigated.

4.3.6.1 Feedstock characteristics

The waste fuel characteristics put demands on every part of the process, and also determine the plant layout. It is therefore important to get as well specified fuel as possible, to avoid large fluctuations in fuel quality. One significant parameter is the water content which, in spite of the drying process, affects the dimensioning and layout of for instance the steam and condensate systems. The water content of the delivered waste may vary with season and depending on its origin etc. It is therefore necessary to mix several fractions in the bunker to achieve a relatively homogeneous waste material, before feeding it to the drying and pyrolysis sections. At this position, it is important that the fuel feeding system is non-compacting in order to get an even feed of fuel. Furthermore, large objects have to be removed prior to the shredding unit, and metal contains should be removed by using magnets and eddy current separators for aluminium materials.

Another parameter of the fuel characteristics is the ash content. The ash content shown in Table 6, is the highest occurring limit value. Waste material is, however, often around 20% in ash content. For the operation of the gasifier, however, a waste fuel with high ash contents could even be advantageous since the slagging characteristics improve. To ensure a stable operation, the relatively high ash content calls for a high discharge capacity. This is one feature which is easily dealt with using an entrained flow gasifier, additional advantages and disadvantages of this gasifier technology are given below.

Advantages:

- Feedstock ash content between 1 and 45%
- Liquid, solid (grinded) or gaseous feedstock possible to gasify simultaneously
- No impact of aggressive slag on the inner contour of the reactor, caused by self-protecting surface
- Wide range of possible feedstock and feedstock mixture
- Vitrified slag as by-product – non-leachable material
- Tar free syngas
- High lifetime and availability of reactor by special cooling screen design

- Very short start and shut-down period of the gasifier
- Low risk of blocking the reactor outlet
- Compact design
- Small footprint
- High capacity.

Disadvantages:

- Feedstock preparation for gasifier feeding (pyrolysis, solid grinding, dense flow feeding)
- Slow changes in feedstock composition – intimidate buffer necessary
- Heat loss by special cooling screen design
- Large exergy loss by quenching
- Special safety consideration necessary
- Pilot burner.

4.3.6.2 Safety and environmental concept

The safety philosophy of the pressurised gasification process by Future Energy starts out from undesired primary events inferred from the fire and explosion hazard analysis of the process and their danger potential. Said primary events can be classified by their causes into three groups:

- Penetration of free, unconverted oxygen from the reaction chamber into the downstream raw gas system involving the danger of explosive oxygen-fuel mixture formation
- Exceeding the design pressure of the reactor and downstream plant
- Exceeding the design temperature of the reactor/quencher.

Therefore, explosion and fire risk precautions including technological and safe-practice measures must avert said dangerous conditions with a high degree of reliability. Control and instrumentation field equipment necessary to meet said requirements has been considered and included into the layout. It is characterised by the following features:

- Decoupling of control and monitoring functions
- Redundant or multi-redundant design of measuring systems, (e.g. flow rate measurement for oxygen and fuel)
- Application of diversity systems to ensure special operation mode.

Said control signals are processed by special control systems (for example protective interlocking systems, shut-down control mechanisms to establish safe plant condition). Control systems mentioned are either integral part of the higher-order supervisory control system, or exist as separate control devices. Regarding the control system in general, the facility control systems shall be tied through local PLC's to a facility central control system. It is assumed that a central control system will serve as the operator interface to monitor and/or control the processes, alarm generation, report generation and data archiving.

Apart from the hazards related to gases produced in the process, there are numerous liquid streams resulting from the plant. For instance, in the Rectisol process, the removed water in the syngas stream is withdrawn as a waste water stream. Since there are trace compounds from the gasification process purged with this stream, the waste water is treated in a biological water treatment unit.

Environmental impacts from air emissions could consist of in odour and VOC, potential smog forming compounds. Thus, any evaporation losses of DME to the atmosphere should be minimised and tanker filling will therefore be performed with equipment for pressurised bottom filling. This will provide a user-friendly operation, which reduces manpower needs and simultaneously reduces the environmental effects. The transportation of LPG is also associated with potential risks. The storage of large amounts of LPG has to be considered in the fire and explosion hazard analysis, but is the transports that are associated with the largest risk. Transportation of large amounts of LPG, either on road or railway, should be planned with respect to preferred routes for hazardous materials. Furthermore, the *number* of transports should be kept as low as possible due to the safety aspects.

4.4 Outlook of the manufacturing process

Companies like Air Products and Chemicals Inc and Haldor Topsøe A/S (HT) have developed an integrated process for the direct production of DME from synthesis gas, which has been demonstrated in pilot plants. This process can produce fuel grade DME using a converter catalyst with a function to take advantage of equilibrium conditions that favour the formation of DME over methanol. Because of the attractiveness of this process for large scale fuel manufacture, BP Amoco and HT have entered into an alliance for the commercial development of DME by this one-step manufacturing route. The new DME technology is ready for commercialisation, but it may be emphasised that this new technology actually is a modified, methanol technology which has been practised for many years.

Due to the extensive catalyst testing and the simple adiabatic reactor configuration, the technology risk in the DME synthesis is minimal. Recent advances now permit the construction of large scale fuel grade DME plants which leads to further reduction in manufacturing cost. Based on their extensive experience in syngas production, methanol synthesis, and DME-related pilot plant work, HT and BP Amoco have identified proven technologies for the construction of greenfield DME plants with capacities in the range of 8,000-10,000 tons per day, based on natural gas.

4.5 Local requirements

4.5.1 Space requirements

Among the requirements on the site location is naturally the physical space. The overall space requirement for the complete plant (including streets, parking places, distance areas, storage areas) is an area of 78,000 m^2 (approximately 350 x 220 m). The area used for buildings and storages is 32,400 m^2, giving a space factor of about 2.4 compared to the total area required.

4.5.2 Personnel requirements

Table 8. Manpower requirements for a complete waste-to-motor fuel plant, with an annual waste capacity of 400,000 tons.

Category	Number
Supervisor	1
Secretary	1
Economist	1
Maintenance Technicians	4
Operators:	
Waste take over	5 x 4
Waste pre-treatment/ASU	2 x 4
Gasifier/Rectisol	1 x 4
DME/Methanol unit	1 x 4
Waste water treatment	1 x 4
Total	47

The expected manpower required for the continuous operation of the plant is shown in Table 8. This is the required personnel for the continuous operation of the plant, presumed to be in a four shift working mode. To estimate the personnel requirements for a plant, with only a few or no references, is of course difficult. Further automatisation in the operation, of for instance the waste take-over section, can be expected to reduce the manpower required. Centralised control and surveillance systems for different units should trim down the number of employees needed for each unit. It is however, hard to reduce the personnel requirements very much, without having to outsource activities. It should be remembered that a gasification plant differs from, for instance a conventional power plant, in terms of complexity and therefore personnel requirements. A plant of this kind should rather be compared to a chemical process industry than a power plant.

In Table 8, the staff requirements are segregated with respect to the number of shifts. A number of professionals are only needed in the day-shifts, such as the supervisor, secretary, economist and the maintenance technicians. The four maintenance technicians are separated into one electrician, two mechanics and one laboratory staff. The laboratory position is a one shift activity, examining samples collected by the night-shifts by the respective operators as well. This includes samples taken from the operation of the power plant. Some, less sensitive processes, could be operated by a smaller staff. This is shown by lumping the gasifier and the Rectisol unit and the waste pre-treatment and the ASU plant respectively, into one operator each. The five operators handling the cranes in the waste receiving are not possible to reduce, since the cranes must be manually operated for the five individual lines.

4.5.3 Logistics

The size of the current plant results in a large number of transports to and from the plant area. These transports of fuel and products to and from the plant are crucial, since the fuel supply to the plant must be continuous because of the technically advanced processes involved. Waste fuel is available all year around and provided five days a week. Most of the waste is transported to the plant by local waste management companies, but it is also possible that a portion of the waste fuel is delivered from reloading stations in nearby municipalities. In case of future over-capacity of waste incineration, long-term contracts with waste managers should be concluded. Transportation of waste over longer distances has, once the waste has been collected, a relatively small impact on the total economics, energy consumption and environmental impact [9]. This plant is, however, presumed to be located in the direct vicinity of a middle-sized European city and relatively long distances are not relevant.

The various material streams related to the operation of the waste-to-motor fuel plant, are transported by lorry on road. Land transport by train is also a viable alternative, if possible with respect to the location. The majority of all transports regards the waste delivery, which to avoid reloading vehicles, is most easily transported by lorries. The loading capacity for road vehicles differs for the various materials, depending on their density, and the different types of vehicles relevant to each stream. The loading capacity for lorries is assumed to be 40 tons for bulk material except for waste material. The loading capacity for waste is 7 tons for local lorries and 30 tons for lorries arriving from reloading capacities. The weighted average value, assuming 20% of all waste transported from reloading stations, is 12 tons.

Table 9. Average number of lorry transports, in case all transports are made by lorry 7 days a week.

Material stream	Lorries/day
Waste	100
Slag	12
DME	3
LPG	< 1
Sulphur	< 1
Total	**115**

In Table 9 the transports by lorry are summarised for the various streams, based on these load capacities. From this it is seen that the waste transport makes up the majority of all transports, although the formed slag is also a significant post in the logistic scheme. The numbers presented are calculated as average values. Taken into consideration that waste is only delivered five days a week, the waste transports increase to 140 lorries per day.

4.5.4 Additional requirements

As indicated in the previous sections, cooling is essential for the operation of the plant. In northern Europe cooling towers are seldom used, because of the easy access to cooling water in coastal areas as well as rivers and lakes. In this study, a cooling tower has been included, which allows operation in other than coastal areas. Water is also often used for feed water, since large industrial units rarely are connected to the district water supply. The make-up water is fed to the water treatment plant before being used in the processes.

There is also need of LPG, for instance in the safety and flare system and the Claus unit. Where available, LPG should be substituted with natural gas which is relatively common in Europe. The natural gas grid is, however, not considered to cover the general region of interest in this study, even though the plans for further expansion in Europe according to the guidelines on trans-European energy networks perhaps will change this. The difference in heating values, between natural gas and propane is only slight and the mass balance is expected to be unchanged in large, no matter what fuel is chosen.

The required supply of LPG was calculated to approximately 209 Nm^3/h, which corresponds to 149 kg/h. On the plant site, LPG is stored in pressurised, vertical tanks to which the gas is transported either by tank lorries or train, depending on the local conditions. These lorry tankers have a loading capacity of 25 tons, which result in an average transport of less than one lorry a day, as shown in Table 9. Using transportation by train, the loading capacity is 45 tons, but this calls for auxiliary equipment for un-loading the LPG from the train. The pressure under which the LPG is stored depends on the ambient temperature, but is usually 2-9 bar (a). Based on the annual consumption of 1,300 tons, the required tank volume is around 300 m^3. Whether this volume should be comprised in a single tank, or two smaller, has to be decided considering leasing contracts and investment costs, required maintenance/inspections and matching delivery capacity with the tank capacities etc.

Other waste streams, such as the sulphur and slag products should be found a market for. Finding purchasers for the relatively small amount of sulphur produced should be possible on a chemical market for elemental sulphur, for instance to the paper industry. The contracted price is however, likely to be lower than the market price because of the smaller volume, perhaps lower quality and discontinuous deliveries. The formed slag would be safe to put on landfill, but its attritional and inert characteristics make it useful; for instance, slag from the waste gasification plant in Karlsruhe, Germany, has been used as blasting material. Blasting sand has usage outside the lacquer industry and may be used in drilling operations as well. The treatment of the slag to fulfil the requirements on blasting sand could mean an additional investment. The slag is more likely to be used as road filling or construction material, which also eliminates the cost for depositing the slag formed. As a first and conservative alternative in this study, the slag is deposited, which implicates costs for landfill deposits. Over longer time-period contracts should be established for other allocation of the slag stream.

4.6 Mass and energy balances

The total mass and energy balances of the plant have been calculated. This section, in large, comprises the work made by Future Energy, extended with an exergy analysis. It should be emphasised that the current scenario, is the "worst case" using a waste fuel with ash and heating value in their upper and lower regions respectively, as shown in Table 6.

The calculation is based on a one load case using waste with a relatively low heating value, resulting in the largest size of equipment/plant by a relatively low energy/product generation. This worst case could show the point of lowest efficiency of the plant. Based on the results, an overall mass balance, including all units, is generated to show final products, by-products and wastes as well as the demand of utilities and feedstock by using interconnections among the units.

4.6.1 Assumptions for calculation

Parameters, prices, and costs used to calculate the cost of fuel grade methanol produced in the plant are given in Table 10. All amounts appearing in the context of this report are recalculated from the different currencies using the exchange rates given in the lower part of Table 10. The currency used in running text is EUR for consistency, whereas the basis for calculation often is expressed in other currencies.

The parameters are intended to be realistically set even though some values, such as the operational hours for heat, may be applicable to Northern Europe only. The ambient temperature is exclusively used in the exergy analysis and its value is rather conservatively chosen. Another technical assumption made, is the quality of the produced DME. The

Table 10. Project assumptions during the study

Project assumptions		
Financial year	Q3 2003	
Inflation	2.0	%
Interest rate on debt	7.0	%
Project lifetime	20	years
Operational hours	8,000	hours/year
Operational hours, heat	5,000	hours/year
Ambient temperature	10	°C
Fuel and product costs and prices, incl. tax		
- Waste fuel gate fee	14	EUR/MWh
- District heating	32	EUR/MWh
- Electricity	33	EUR/MWh
- Slag deposit	44	EUR/tonne
- Sulphur	25	EUR/tonne

Exchange rates: 7.74 SEK/USD; 9.12 SEK/EUR (Stockholmsbörsen AB, 3 June 2003)

product is classified as fuel grade and therefore contains small quantities of water and methanol. This fact has been neglected when calculating the mass and energy balances, i.e. energy balances are based on the heating value for pure DME.

The construction period is expected to be two years in total, ranging from foundation to complete waste-to-motor fuel plant. To this time period comes the commissioning phase. The total time should therefore be close to 2.5 years before the plant is in commercial operation.

4.6.2 Results of the mass and energy balances by unit

In Table 11, governing mass and energy balances of the complete waste-to-motor fuel plant are shown. From Table 11, information about the main product streams, the consumption materials and the process effluents could be withdrawn. Basis for generating these mass and energy balances are separately developed computer models for gasification and gas cooling with water gas-shift reaction respectively. For evaluation of balances for the pyrolysis, the Rectisol process, the DME plant, the ASU and the Claus plant respectively, material from potential suppliers was used and adapted to the conditions of the given study.

Performance characteristics for the gasifier system, including the quench, have been taken from special firm models by Future Energy, calculated by assuming chemical equilibrium at the exit of the gasifier, and adapted to the gasification of waste materials. The gas composition leaving the gasifier was taken as the starting point in the thermodynamic modelling (using CHEMCAD™) of the following processes of gas treatment. The production of different sorts of steam for use in the complete system was also included in the modelling.

Downstream process steps (methanol/DME synthesis, methanol/DME distillation, ASU, Claus plant) were modelled based on performance estimates obtained from vendors. To simplify the analysis, pressure losses were neglected, except where the loss is substantial, i.e. through the high-pressure methanol synthesis unit. The compression preceding the DME synthesis was assumed to be completed in a single stage, with a polytropic efficiency of about 85%. Some of the information used in the calculations, mainly concerning the DME synthesis step and the ASU unit, has been derived from in-house knowledge of NSAB, and adjusted to the current application.

Table 11. Plant overall mass and energy balances, divided on the individual process units.

	unit	ASU	Shredder Dryer	Pyrolysis	Feeding	Gasifier Quench/SD WWT	Heat recovery CO shift	Gas Treatment [REC]	DME Plant	Cooling Tower/Utility Flare	Claus Plant	Bio-WWT	Tank Station	Total
Products														
DME	m^3/h								**10.6**					**10.6**
DME	tpd								**170.3**					**170.3**
CO2	Nm^3/h			-1449	-3100			18455						13906
Nitrogen	Nm^3/h	85952	-5208	-200	-7631	-80	0	-16002	0	-200	-229		-250	55951
MP Steam / 10 bar	tph						86,18				22,82			109,00
HP Steam / 40 bar	tph						0,89				-1,05			-0,17
Sulphur	kg/h										333			333
Consumptions														
Catalyst	t/a						-20		-11					-31
LPG	Nm^3/h									-150	-59			-209
LPG (Start)	Nm^3/h			-8540		-160					-50			-8750
Nitrogen (Start)	Nm^3/h			-1159	-1440	-1475					-500			-4574
River Water	m^3/h									-180				-180
LP Steam / 4,1 bar	tph		-31,02	-0,75	-1,29	7,93	7,86	-1,27	-2,83		4,21			-17,15
Output														
Slag	kg/h					30285								30285
Vents	Nm^3/h		14583	7625	24286	556			2102			301		49453
Waste water	m^3/h		4,72			55,0	2		0,3		4,0			66
Waste water Solids	kg/h					471								471
Internal														
Air	Nm^3/h	-158860												-158860
BFW	m^3/h					-8,1	-96,8		-7		-32,90			-145
Condensate	m^3/h		31,02	0,37	1,29	1,29		1,3	9,4		1,06			45,70
Cooling Water	m^3/h	946	1019	1207	250	783	380	31	494		100			5209
Demin Water	m^3/h							-41						-41
Nitrogen LP	Nm^3/h		-5208	-200	-5821					-100			-250	-11580
Nitrogen HP	Nm^3/h				-2010	-80		-16002		-100	-229			-18421
Oxygen	Nm^3/h	23976				-20500					-3394	-81		**0**
Sludge	m^3/h			-0,54								0,54		0
Syngas	Nm^3/h			-13338		-250		25468						11880
Power Comsumption	kW	9000	1892	5010	914	709	50	410	5100	1834	1155	72	27	26173

Table 12. Mass and energy balances of the complete waste-to-motor fuel plant

Stream	Mass flow [tph]	Energy [MW_{th}]
Input		
Waste material (LHV, 20% moisture)	50	151.4
Electric power	-	26.2
LPG	0.1	1.8
Total:	-	**179.4**
Output		
DME (LHV)	7.1	55.8
District heating	545	25.3
Sulphur	0.33	-
Slag	20	5.0
Losses	-	93.3
Total:	-	**179.4**
DME yield	14.2% (mass)	31.1% (energy)

4.6.3 Yields and efficiencies

The calculation of the mass and energy balances is performed for the case where electric power is purchased to cover the intern needs. The background for the calculations is given by Table 11, where the steam production can be seen, as well as the power consumption in the complete waste-to-motor fuel plant. According to Table 11, the configuration chosen results in purchase of 26 MW electric power and a DME production of 170.3 tpd from the 151 MW contained in the waste input.

These results can be summarised in a Sankey diagram, Figure 11, graphically showing the in- and output energy streams, regarding the complete waste-to-motor fuel plant. The data used to generate this figure can be seen in Table 12, where apart from the energy terms, also the mass balance is shown. Here, mass and energy flows of input streams, i.e. waste, electric power and LPG, are presented as well as the product streams of DME and district heating. From this table, it is concluded that approximately 1% of input energy is LPG, 15% electric power and the rest as waste fuel.

Although the slag granulates transfer much of their thermal energy content to the water reservoir in the gasifier bottom, there is still a certain amount of sensible heat that cannot be withdrawn, as well as unburned carbon. There is also heat associated with the inert fraction leaving the pyrolysis ovens. An approximation on the amount of energy in slag and inerts is the 5 MW stated in Table 12, which makes about 3% of the total energy output [10]. Because of the uncertainty of this value, it is not included in the exergy analysis.

The plant configuration also allows for district heating, amounting to some 25.3 MW or 14% of the total output. The mass flow stated is within parenthesis, since the flow is dependant on the temperature differences (here assumed to be 40 °C). This relatively low value reflects the fact that no major efforts have been made to withdraw all generated waste heat as district heating. A more extensive study should address the optimisation of each process unit, and thereby maximise the district heating yield. As energy is a conservative property, the difference between the sum of the different output stream and the input streams represent losses in the system. Losses, in most cases are unrecoverable heat, either as low-grade hot water or heat released via flares in the safety system.

The desired products, DME and district heating, amount to 81 MW or 45% of the output. That is, the total energy efficiency of the waste-to-motor fuel plant is 45%. The DME yield is 31% on an energy basis and 14% on mass basis of the waste input. This implicates that the rest, is made up of losses (the energy contained in slag and inerts is also losses, since they are not recovered).

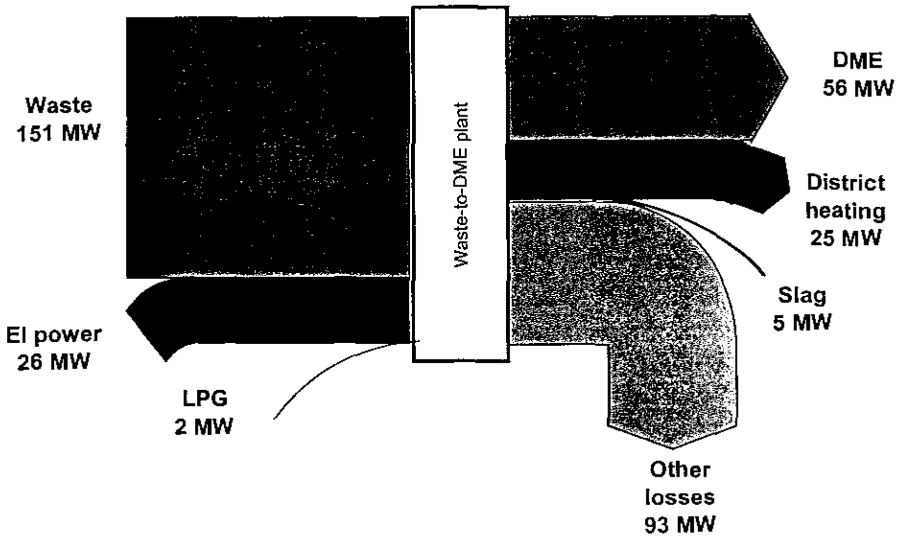

*Figure 11. **Sankey diagram showing the qualitative relative sizes of the in and output energy streams to the waste-to-motor fuel plant. Arrows are not to scale; exact figures are shown in Table 12.***

4.6.4 Exergy analysis

To further shed some light on the advantages of the gasification technology compared to conventional incineration an exergy, or availability, analysis is made. Exergy is a property that could be used as a complement, or instead of, the energy concept. Regarding energy only, there is a penalty in producing a higher-value product since the process is more complex and the total losses increase. Differently put, it is easier to achieve high energy efficiencies in an incineration plant producing district heating only compared to the current gasification plant where a high-quality product is synthesised. Exergy is a property that discriminates between these two product streams, considering not only the energy contained; exergy puts values on different kind of energy types depending on their nature, or their *potential of use*. This indicates that electricity has higher exergy than thermal heat (electricity and work is pure exergy) and steam has higher exergy than hot water (more contained energy per mass unit). This also indicates that exergy, unlike energy, is not conserved during a process.

After the brief introduction to exergy given above, the analysis of the total waste-to-motor fuel plant is given. That is, putting the boundaries around the complete plant area. In Table 13 the exergy balance is provided, notice here the fact, that exergy is not conserved, i.e. exergy is consumed during the conversion from residue fuel to DME. Since the heat losses are not well specified and are emitted at low temperatures, these are excluded in the balance. All large posts, as the different fuel and product streams are implemented and shown in Table 13. The figures in Table 13 may also be described in a Grassman diagram, as shown in Figure 12. This is the counterpart to the Sankey diagram for the gasification option shown in Figure 11. The exergy flows associated with fuels are often approximated with the respective HHV, which often is close to the "true value".

By comparison, the corresponding plot for a modern waste incinerator is provided in the lower part of the diagram in Figure 12. The incineration plant used for comparisons is the planned plant in Uppsala (Block 5), Sweden, to be commissioned in May 2005 [11]. This plant supplies heat production from waste with 22 tph or 70 MW of district heating and steam delivered. These figures are derived from a waste with slightly higher heating values and so the 70 MW is down-graded to approximately 67 MW according to the relatively difference.

The large exergy loss in the incineration plant is taking place in the boiler, which would have to operate at an infinitely high temperature to retain the exergy content of the fuel. The large drop shown for the gasification plant as well, i.e. the lower plot in Figure 12, is more difficult to locate in the process. It is interesting to notice that, in spite of the relatively poor energy efficiency of the gasification plant, the exergy efficiency of 34% exceeds the one for the incineration alternative, which is 23%. This is due to the down-rating of heat compared to DME, as the exergy contained in input streams is similar between the incineration and the gasification alternatives. The "lost exergy" is either found in purge streams as heat or in irreversibilities in the process units.

Table 13. Mass and exergy balances of the governing streams of the waste-to-motor fuel plant (gas), compared to a conventional incineration plant (inc).

Stream	**Mass flow [tph]**		**Exergy [MW]**	
	gas	***inc***	***gas***	***inc***
Input				
Waste material (HHV)	50	50	178	178
Electric power	-	-	26.2	5.3
LPG	0.1	-	2.1	-
Total:	-	-	**206**	**183**
Output				
DME (HHV)	7.1	-	61.6	-
District heating	545	2,905	7.9	41.8
Total:			**69.5**	**41.8**
Exergy efficiency			34%	23%

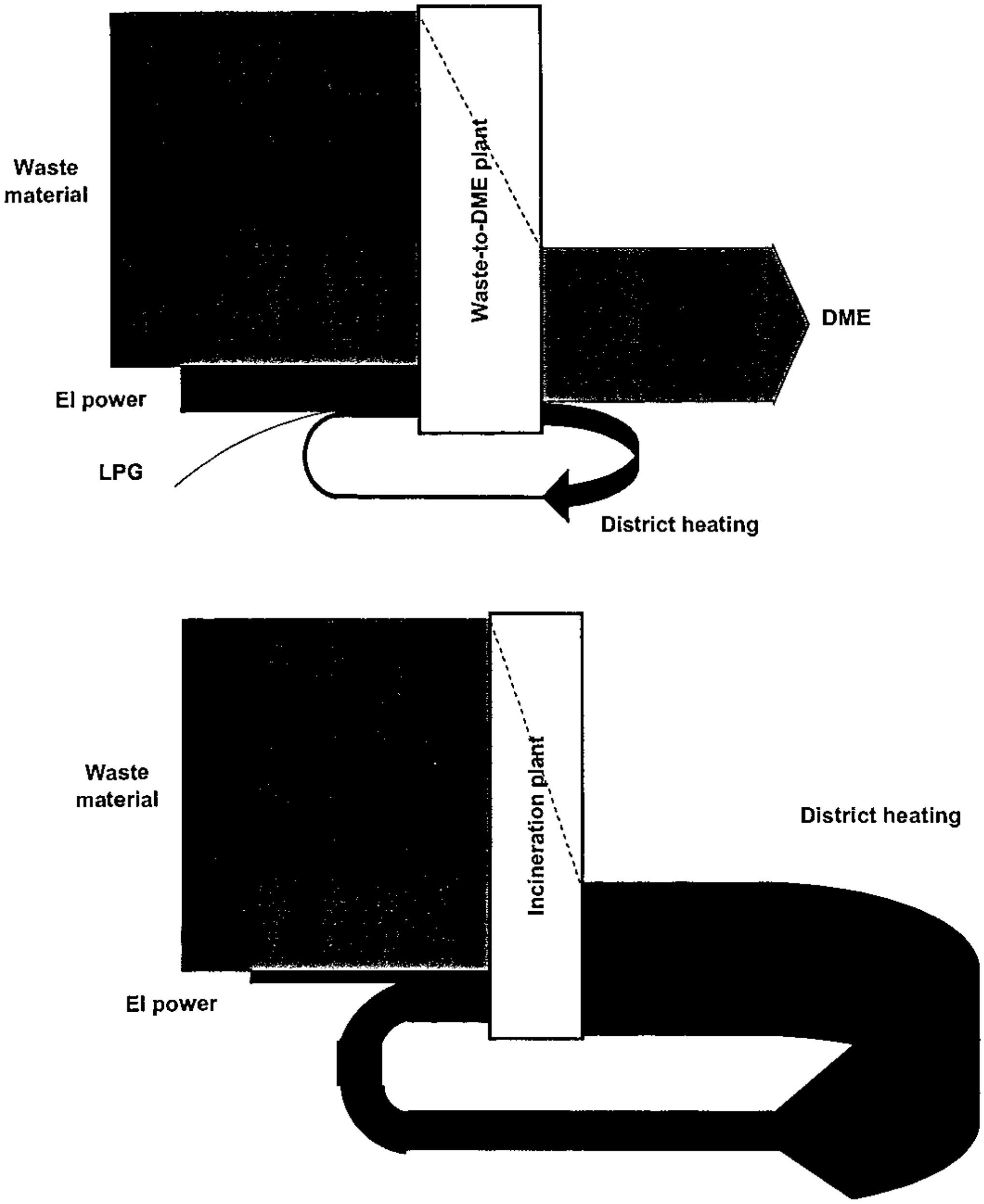

Figure 12. Grassman diagrams, describing exergy flows, for waste gasification and waste incineration respectively. The size of each stream is not to scale; figures are available in. Table 13.

4.6.5 Optimisation

In view of the results in Table 11, the optimisation should be carried out with emphasise on the pyrolysis unit, which together with the shredder unit, consumes large amounts of energy and syngas. The energy consumption in the ASU is fixed and related to the compressions in several stages and the ASU is therefore not subject to any optimisation. The DME yield could be increased if the internal syngas consumption would be lowered, creating a larger available feedstock to the DME reactor. This could be achieved by using LPG or natural gas, NG, where available, instead of the syngas in the heating of the pyrolysis kilns. Replacing all syngas with NG could double the DME yield, although lowering the total plant efficiency. That is, replacing syngas with NG is not energetically favourable. This scenario also moves towards the current DME plants, using NG as feedstock and thus reducing the environmental benefits of the current plant setup.

The total DME efficiency could also be increased by using nitrogen, instead of carbon dioxide, as fluidising medium in the transportation of coke from the pyrolysis. This would result in more carbon dioxide available for synthesis and therefore higher carbon efficiency. This increased carbon efficiency would, however, result in more nitrogen in the syngas, which affect the downstream DME reactor negatively. This would also affect the power consumption of the ASU negatively because of a larger throughput of air. The absolute benefits of this configuration must be further investigated.

As previously discussed, the district heating output could be increased by assessing each process unit more thoroughly. A total plant efficiency of 45% must be considered low, whereas the DME yield is more feasible. To improve the efficiency as well as the economics, the largest potential lies in reducing the losses from the current level of 93 MW.

4.7 Economics

The economics of a complex process plant such as the current is hard to establish on a fair basis. As a complete plant, the operational costs and revenues are relatively easy to establish, but this does not constitute a fair comparison to conventional incineration plants. The main purpose of thermochemical conversion of waste is to minimise the waste stream to be deposited and also to provide district heating (and in some cases electrical power). These purposes are fulfilled with the gasification plant as well, but there are also additional product streams generated. This fact is most justly described by calculating the alternative costs for installing a gasification plant *instead* of an incineration plant and dividing that additional cost with the produced amount of DME. Theoretically, this sounds straightforward, but it might be troublesome to correctly estimate what part of the total cost that is the alternative. This discussion is continued in the subsequent sections, where both the complete plant costs and the alternative, or incremental, costs are examined.

4.7.1 Investment cost estimate

The investment cost for the complete plant is given as a turnkey sum, including engineering work, procurement, civil, approval and permission, license and commissioning of all parts, including staff training, of the plant. Besides, all process related plants, buildings, bins, all auxiliary systems, loading station, streets, landscape gardening measures, drainage and ditch systems (without biological clarification system), fencing and office, and social buildings are included. Construction, interest during construction, commissioning and unspecified costs are stated separately in Table 14. The investment costs are based on comparable investment estimates of the units, resulting in a cost estimate within ±30%. Units not included in this lump sum are for instance: wheel loader, forklift truck, spare and wear parts, costs for experts during approval, office consumption material, tools and cleaning facility, computer/network system/software/telephone system. Compared to the included units, the latter are minor parts of the total investment cost.

Without discriminating between the different plant units, the cost of the complete waste-to-motor fuel plant amounts to EUR 346 million, seen in Table 14. It may be concluded that some parts of the plant involves larger uncertainties than other, less commercially proven technologies. Since there are no commercial waste-to-motor fuel plants of this kind, a learning effect reducing the operational as well as the investment cost could be anticipated. This would lower the investment cost as the number of erected plants increases. Every waste-to-motor fuel plant will, however, be more or less unique on every new site, depending on the specific requests of the customer. Thus, the benefits from the learning effect are somewhat reduced to mainly comprise engineering knowledge, still, it will always be beneficial to establish a broadened in-house knowledge. Many of the included process units are, however, well-known techniques, usually expensive units, and hard to further reduce the cost for, unless the process is modified in order to optimise their size.

Table 14. Investment costs, broken down into functional parts for the complete waste-to-motor fuel plant. Additional assumptions are stated below.

Investment costs	MEUR
Equipment and assembly (a)	**280**
Construction costs (b)	29.4
Interest during construction period ©	19.6
Start-up and commissioning costs (d)	3.0
Unspecified costs (e)	14.3
Total investment cost	**346**

a) Equipment and assembly (EA) covers all relevant process units of the plant, control system, waste water cleaning and engineering etc.

b) Construction cost includes construction and foundation work, calculated as 10.5% of EA.

c) Interest during construction has been estimated with principal payments during 1.5 years at an interest rate of 7%

d) Start-up and commissioning has been estimated as EUR 3 million

e) Unspecified costs are taken as 5% of equipment and assembly

The learning effect on the cost development for a complicated plant, similar to this kind of plant, could be illustrated by Figure 13, showing the specific cost development for different phases of development. The status of the current project is probably intermediate the first commercial service and available for commercial order position in the figure. According to this data, the cost is not likely to decrease very much from the current level of development; rather the cost is increasing towards the first commercial plant. From this first commercial plant to the *n*:th, however, the relative cost reduction is significant.

The relatively high investment cost reflects the complexity of the plant. There is, for instance, several process units divided on five lines. This is an expensive configuration, as well as the separate units are expensive. The total cost for the shredders and pyrolyser, divided on five lines and the feed preparation and the gasifier, which are divided into three lines is

EUR 140 million, or 40% of the total cost for the waste-to-motor fuel plant. The control and electric systems are also contributing significantly to the plant cost, as well as the ASU, the DME and the Rectisol units. Smaller costs, below EUR 6 million, are the Claus plant and the heat recovery system.

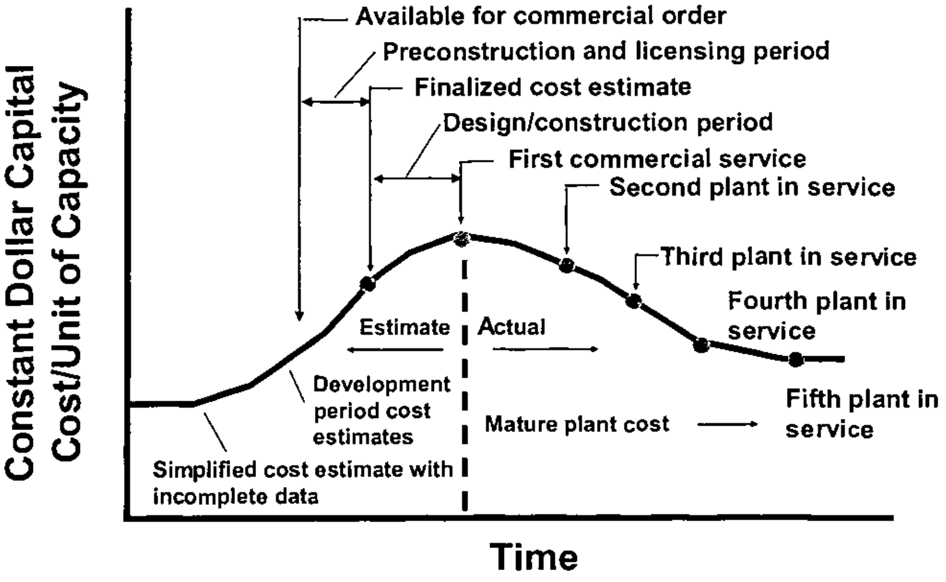

Figure 13. Generic capital cost trend for early commercial units of new power plant technology, based on technical assessment guide by EPRI.

4.7.2 Operation cost estimate

Based on the investment cost and the economical assumptions made in Table 10, production costs can be broken down into some large components shown in the left part of Table 15. From this table it can be seen that the dominant post is the capital cost. In the same order of magnitude are the revenues from the waste, whereas slag is deposited for a lower cost of EUR 7 million. The gate fee used in this calculation is only EUR 44/tonne, which is a low and conservative estimate even for MSW. In a real installation, the MSW may be mixed with commercial and industrial wastes as well, which are objects to higher gate fees. It should be recalled that the strength in gasification technology is to handle troublesome waste that is hard to process in conventional incineration plants. Such wastes, for instance liquid fractions, could well command gate fees exceeding EUR 100/tonne.

The sales of elementary sulphur are practically negligible, amounting to less than a million euro a year. The staff cost is also minor in comparison, contributing to the operating cost with only EUR 2.3 million annually. The salaries are included in the operation and maintenance cost, housing the catalyst cost as well. It could also be reasoned that some costs are left-out, for instance real estate for building site. This cost is however site-specific and rather included in the unspecified cost of the investment than in the operational cost.

Table 15. ***Production cost divided into cost components, shown in MEUR. Left column shows total plant cost and right column shows incremental costs compared to reference incineration plant***

	MEUR/y *(tot)*	**MEUR/y** *(incr)*
Revenues		
Gate fee (a)	17.5	0
DME (b)	35.3	35.3
District heating ©	4.0	-17.5
Sulphur revenue (d)	0.068	0.068
Total revenues:	**56.9**	**17.9**
Costs		
Capital (e)	32.7	17.0
Operation and maintenance (f)	13.5	4.8
Electrical power consumption (g)	6.9	5.5
Slag (h)	7.0	0
Total costs:	**60.1**	**27.3**
Gross profit	-3.2	-9.3
Daily DME production [tpd]	170.3	170.3
Production cost DME [EURc/kWh]	8.7	10
Production cost DME [EUR/tonne]	679	787
Production cost per diesel equivalent [EUR/l] (i)	0.82	0.95

a) A conservative estimation on the revenue from gate fee is 400 SEK/tonne, or 0.13 SEK/for every kWh received. Gate fee is unaltered for the incineration alternative.

b) The DME price is referred to the diesel price of 3.80 SEK/l diesel, i.e. 6.90 SEK/ diesel eq litre (0.72 SEK/kWh). When calculating the production cost, the revenues from DME is not included.

c) District heating revenues are calculated for 5,000 h/a using 0.29 SEK/kWh. Less heat in the gasification plant results in an alternative *cost*, compared to the incineration plant.

d) The elementary sulphur produced amounts to 2664 tpa, with a market price of over $30/tonne. Here $30 is used, as a conservative approximation. (Alberta sulphur terminals Ltd, www.sulphurstorage.com, last visited 2003-06-18). No sulphur revenues for incineration.

e) The capital cost is based on 7% interest and 20 years project lifetime, thus an annuity of around 9%. Investment is reduced with reference incineration plant cost (SEK 1,640 million) in right column.

f) The operational and maintenance cost includes mainly staff and chemicals. The assumed salary is 25,000 SEK/month plus social costs of 50%. DME catalyst cost is 100,000 EUR/year. Maintenance and chemicals are calculated as 3% and 1% of EA respectively. LPG is included in the chemical post, amounting to SEK 3.8 million/year (149 kg/h) or SEK 3.20/kg LPG (AB Shellgas 2003-08-15).

g) Purchase price is 0.30 SEK/kWh electricity. Incineration plant power consumption is scaled from 3 MW power consumption for processing of 225,000 tons/yr.

h) The slag could be regarded as revenue, possibly sold as blasting sand or building material etc. A conservative estimation is done on putting the slag on landfill, with an associated cost of 400 SEK/tonne. No difference in cost compared to incineration alternative.

i) The total production of DME per year in litres is calculated with a production of 170 tpd and a yearly availability of 8,000 hours and a DME density of 668 kg/m^3 at 20°C, 1 bar (liquid). The cost is calculated relative to the energy content in one litre diesel fuel.

It should be emphasised that the uncertainties in most of the figures in Table 15, ultimately depends on the site conditions and what agreements that may be contracted. If slag may be approved as building material, to be used in roads for instance, this may constitute revenues instead of the cost shown. Furthermore, the process may be configured for additional power production.

As discussed in the beginning of this section, the total cost, as well as the operating costs, associated with the implementation of this waste-to-motor fuel plant could be handled differently. The main argument for using this approach is that when a municipality is discussing to erect an incineration plant, it is the incremental cost for choosing the gasification plant instead that is relevant. That is, the same functions are delivered with the gasification plant as with the incineration plant; the total amount of waste to be deposited is reduced and heat could be produced. Above these features, automotive fuel is delivered. The cost per unit DME or methanol produced should therefore not be calculated with respect to the complete plant cost, but to the *additional* cost for the gasifier choice.

Since the district heat production in this specific configuration is smaller than for the incineration alternative, there is a negative sign on the district heating revenue in Table 15. In other words, this makes an alternative cost. The amount of waste is reduced, however, and thus the, perhaps, main purpose is fulfilled. The reference incineration unit used is the same as used in section 4.6, in the exergy analysis. The estimated cost for this plant is EUR 110 million. To compare this with the gasification plant, the waste capacities are scaled with a conservative exponent of 0.6, resulting in a total investment cost of EUR 180 million. The incremental capital cost for the gasification plant is the difference in capital costs between the waste-to-motor fuel plant investment cost of EUR 346 million and the EUR 180 million for the reference incineration plant.

The comparison to this plant, as well as the absolute costs and revenues associated with the waste-to-motor fuel plant, is shown in Table 15. It is noticed that the total incremental cost for building a gasification plant, instead of an incineration plant, exceeds the absolute cost. This is related to the large revenues from the waste, which naturally is the same for both the incineration and gasification alternatives, and the revenues from district heating sales that is less for the gasification alternative. The somewhat lower capital cost and the negative electricity cost, when considering the incremental cost only, does not compensate for the incineration plant revenues from district heating and the higher operation cost.

When comparing the revenues between the absolute and the incremental part, a price has been put on the DME. This price has been calculated from the current price on diesel fuel. The price on the DME therefore equals the diesel price on energy terms, which is taken as EUR 0.76/litre diesel equivalent. The use of the DME price is limited to the comparison with the incineration plant and when calculating the production cost for DME, this revenue is obviously excluded. As seen from the last rows in Table 15, the production cost marginally exceeds this diesel equivalent price. Considering the "worst case" scenario and most of the costs taken on their conservative boundary, this small difference is not frightening. See for instance the sensitivity study addressing the influence from a relatively small increase in tipping fee in Figure 14. A gradually increasing fuel price for conventional, fossil, fuels in the near future will decrease the difference further and make the waste-to-motor fuel concept indeed viable.

4.7.3 Production cost sensitivity

The cost for producing DME is dependent on various input parameters in the calculation. This effect from important parameters on the DME cost is easily visualised in a sensitivity analysis, altering the parameters within reasonable intervals. This is done varying one variable at a time, and the variables chosen are: availability in hours per year, price on the waste material and the total investment cost, shown in Figure 14 to Figure 16. Each parameter is allowed to vary approximately 75 to 130% relative to the base case, where the base case is shown as vertical lines in the plots. On the primary y-axis the production cost per litre DME is shown, whereas the secondary y-axis shows the cost of one diesel-equivalent litre. That is, compensating for the lower energy content per kg in the DME as well as for the lower density, according to Table 22.

In varying the gate fee for receiving waste, the break even price is identified with respect to the DME production cost. The waste revenue is also the second largest income, which results in a sharp climb of the graph in Figure 14 From this figure, the price on waste corresponding to the break-even cost of DME could be seen as approximately EUR 1.7 c/kWh of waste. The availability has a rather limited effect on the DME cost in the examined interval, shown by the slowly descending graph in Figure 15. This indicates that the fixed costs are less important compared to the operating costs. The dominating fixed cost is the capital cost, which is varied in Figure 16. The steep slope indicates a proportional relationship between the DME cost and the investment cost. The large sensitivity towards the investment cost implicates that this cost should be determined as exactly as possible, and preferably minimised. The break-even cost for DME is reached just below EUR 320 million, all other parameters fixed.

As the ash content used in this study is rather high, it would be interesting to also calculate the DME production cost when the ash content is reduced. In Figure 17 the ash content is reduced from the $40\%_{wt}$ used as the reference case, down to $20\%_{wt}$ representing, perhaps more common MSW compositions in Sweden. The change in ash content, is mainly affecting the deposit cost for the formed slag, but it is of course also affecting the heating value of the waste fuel. That is, keeping the amount of delivered waste fixed, the heat input is increased. Considering the additional heat input ending up proportionally in the DME output, neglecting changes in district heating output etc., it could be seen in Figure 17 that the DME cost is very dependant on the ash content. Notice, however, that the scale is somewhat different compared to Figure 15to Figure 16. Figure 17 shows the importance of the waste composition and similar plots could be generated for various moisture and carbon fractions etc.

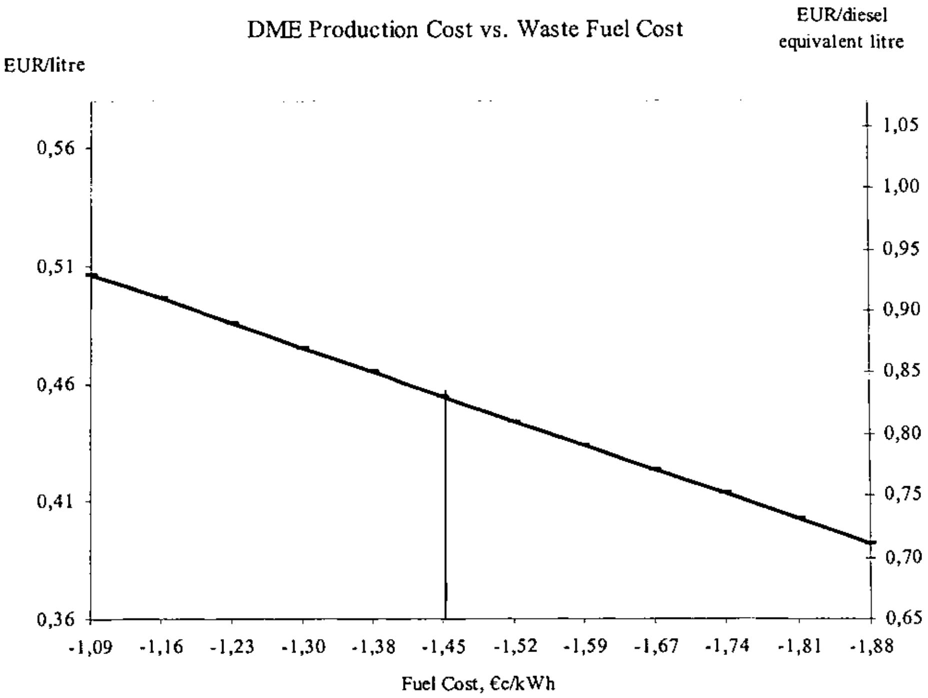

Figure 14. DME production cost in EUR/litre and EUR/litre diesel equivalent, versus the gate fee expressed in EURc/kWh waste fuel.

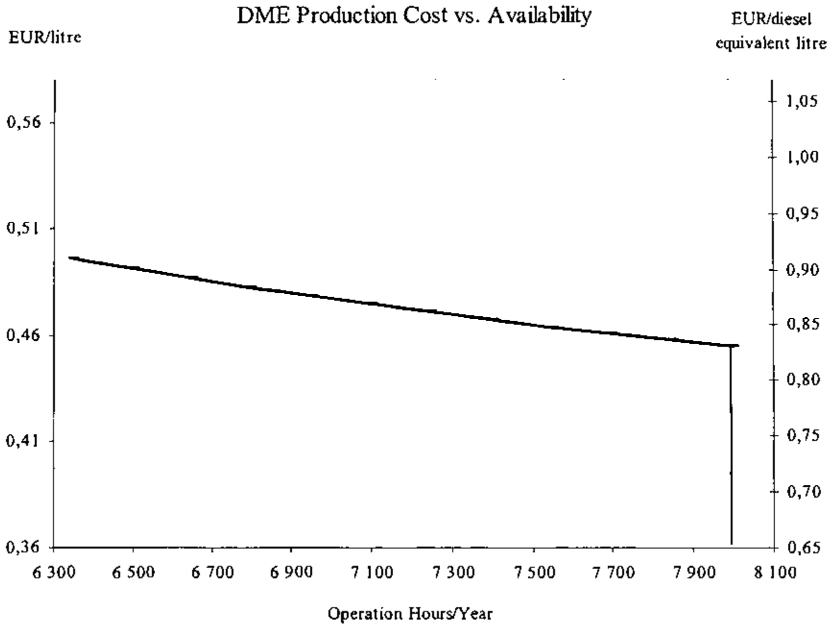

Figure 15. DME production cost in EUR/litre and EUR/litre diesel equivalent versus the plant availability.

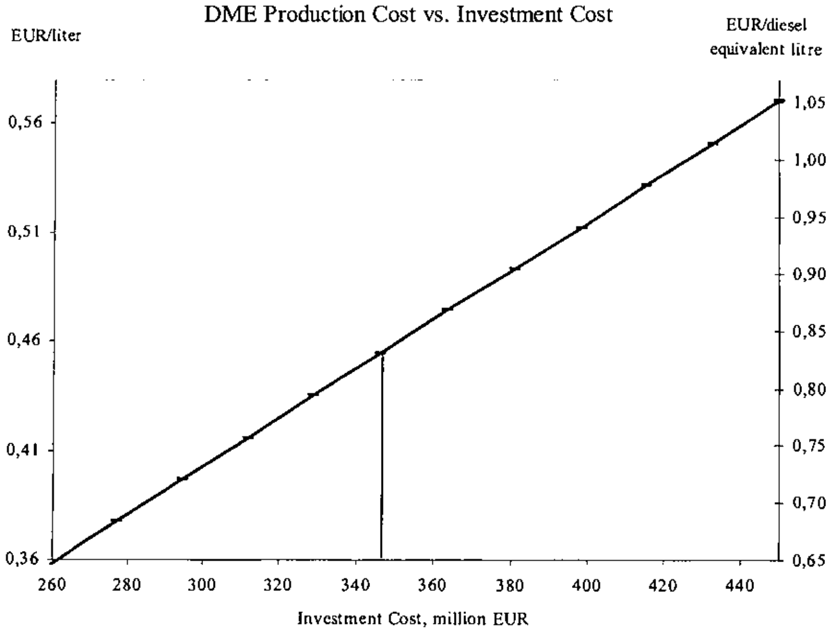

Figure 16. DME production cost in EUR/litre and EUR/litre diesel equivalent versus investment cost.

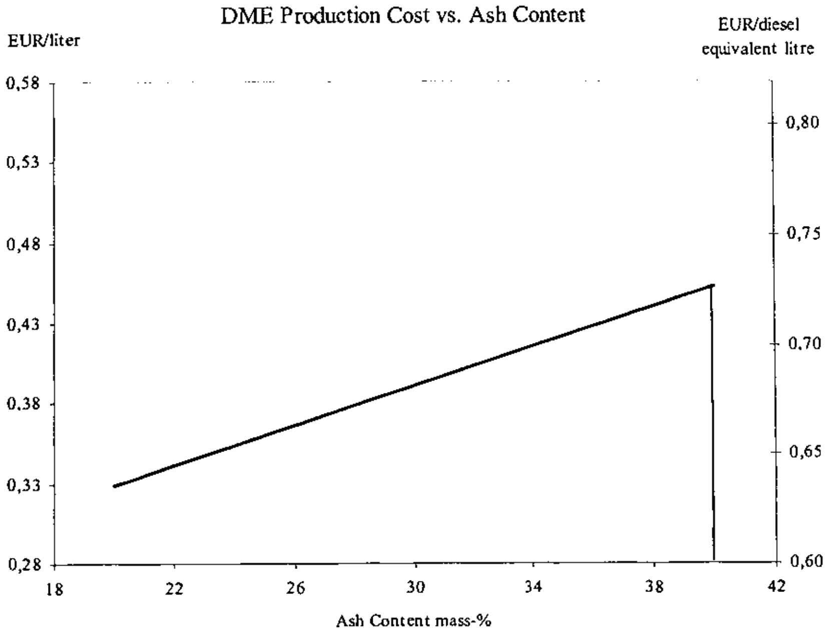

Figure 17. DME production cost in EUR/litre and EUR/litre diesel equivalent versus ash content, expressed in mass-% (as received).

4.7.4 Feasibility

Although the economical analysis generates a somewhat high cost for the produced DME, EUR 680/tonne DME, a cost that is roughly 50% higher compared to the production cost for DME derived from natural gas (EUR 438/tonne DME [12]), the implementation of the discussed plant may still be legitimate. There are for instance, several parameters that can be varied in order to optimise the economics of this plant. Combining this plant with a power plant and exchange process steam for electric power would be a feasible solution, reducing the net purchase of electric power. Since the capital cost makes the dominant part of the total operating cost, efforts should be made to reduce the total investment either by choosing an alternative process or reducing the number of lines.

Contacts have been taken with additional vendors of both alternative gasification processes and pre-treatment units for the waste material. Without further presenting the information received, the data implies that the complete waste-to-motor fuel plant could be optimised when examining the apparatus in each unit operation separately. There seems to be potential for lowering the investment cost with more than 25%, conservatively estimated. The optimisation and evaluation of different process alternatives should be the scope of a future study. The derived fuel prices from the current study are, however, not extreme when considering previous studies on fuel production via biomass gasification. Further optimisation in investment cost, process configuration and trimming operating parameters should therefore have the potential to generate a competitive fuel, possibly even compared to fossil counterparts. This assumption is based on tax-exemptions for "green fuels".

Countries using gasification extensively as waste reduction method, e.g. Japan and Germany, often see the method as a cleaner way of waste reduction compared to conventional incineration. The main purpose is, hence, often to decrease the amount of waste to be put on deposit and not to derive products such as automotive fuels. These products would rather be considered as valuable by-products. The main objective is reflected in the gate fee, which is set to a market value without referring to the energy content. Waste is thereby not considered as fuel in the same sense as biofuel or coal etc. It could be noted that the price (for the provider to pay!) used on waste currently is in the same order as biofuel (EUR 1.1 c/kWh). Increasing the gate fee to, say, EUR 90/tonne (EUR 3.0 c/kWh) would result in a DME cost of EUR 24 c/litre, according to the current calculations. This aspect is also reflected in the previous production cost sensitivity analysis and illustrated by Figure 14, although the boundary is not that broad. It should be kept in mind that, in European countries e.g. Holland, Germany, Norway and Denmark, the average gate fee in all cases exceeds EUR 79/tonne (corresponding to EUR 2.6 c/kWh). Germany and Norway both have taxes on incineration as well, which reduces this gross revenue. Still, in a European perspective the gate fee used in the reference case is far lower than the average value.

The current study has focused on the production of DME. This implies that the derived results, in large, are equally true for methanol production instead. The major differences lie in DME reactor, and the dehydrating function of the catalyst. Excluding this second reactor, the investment is slightly reduced as well as the operating cost related to maintenance. The configuration in the distillation step would also be altered, but the investment cost is likely to be unchanged. The storage tanks do not have to be pressurised, which would also lower the investment cost. An improved yield in the synthesis step will lower the specific cost for methanol.

It is obvious that gasification of waste to produce an automotive fuel is a very feasible process, generating a production cost relatively close to the one using fossil feedstock in much larger plants. The great benefit of waste gasification is the revenues associated with the fuelstock as well as the derived product. This revenue-in revenue-out concept makes a larger investment cost more legitimate.

4.7.5 Conclusions

In view of the process description part in chapter 4 some important conclusions are made. The production of automotive fuels via gasification of waste is a technically feasible process, generating a DME yield of 31% on an energy basis. The single process layout investigated, given a certain waste composition with high inert content, results in a production cost for DME of EUR 0.82/litre petrol equivalent, using the assumptions stated in Table 10. A future study should investigate the potential for alternative processes, which could be more energy efficient. The investment cost is higher compared to conventional incineration plants, as well as the personnel requirements are higher. The waste-to-motor fuel plant thereby fulfils, in principle, the same targets as the incineration plant, to a higher cost. This is compensated by an additional, higher quality product stream. This also results in a higher exergy efficiency for the gasification configuration than for the incineration alternative, calculated as 34 and 23% respectively. The gasification alternative has a lower energy efficiency than the incineration plant, but the flexibility is higher, as well as the utilisation of waste as feedstock for an automotive fuel is exergetically favourable.

5 QUESTIONNAIRE SURVEY ON BARRIERS

The objective of this phase is to carry out a survey of the barriers for the utilisation of biomass from waste. These barriers comprise of a variety of different areas, such as technology, economy, legislation and environmental impact. The Stakeholder Group has had an essential role in the accomplishment of this work.

Questionnaires were sent to members of the reference group and other important persons in the field of waste management. Respondents were asked to characterise the barriers in question as either “Very important”, “Important”, “Not important” or “Don’t know”. In additions there was a possibility for the respondents to enter comments connected to each individual barrier. After each of the three main barrier groups the respondents were also given the possibility to suggest other barriers connected to each main group.

The results are shown below, indicating for each of the barriers how many of the respondents gave the respective characterisation. All the comments are also shown.

5.1 Barriers connected to input material (waste):

1.1. Waste incineration/gasification may be in conflict with goals of waste reduction, increased product reuse and material recycling.

3 Very important
3 Important
4 Not important
0 Don’t know

Comments:

- Recycling will always be the first alternative. What is left will be gasified or incinerated.
- There is a conflict between energy recovery and material recycling. This conflict has been very apparent in Sweden. There may also be a conflict with waste reduction. The household waste in Sweden has increased about 20 % during the last ten years. The governmental policies have stimulated increased material recycling and increased incineration, but not the waste reduction.
- In a system where energy from waste stands for a reasonable share of the energy demand the waste as fuel could be replaced by wood fuels (chips, pellets) which can normally be used in waste incinerators.
- Since reasonable decisions about a balance between the alternatives can be taken on grounds of fact, there is no in-built conflict other than a political one.

1.2. Waste incineration/gasification may be in conflict with goals of more biological waste treatment.

1 Very important
4 Important
4 Not important
1 Don’t know

Comments:

- The Swedish EPA has proposed goals for biological treatment of biodegradable household waste.
- Biological treatment uses only a part of the waste. If the waste includes heavy metals, dioxins or other hazardous components it is a bigger problem for biological treatment than for incineration.
- Since reasonable decisions about a balance between the alternatives can be taken on grounds of fact, there is no in-built conflict other than a political one.

1.3. Waste incineration/gasification can cause much transport of waste, which consumes much energy and is the cause of large emissions.

0 Very important
3 Important
6 Not important
0 Don't know

Comments:

- Therefore, maybe a small scale gasification of wastes at the production plant is an alternative.
- But it is very important that many people erroneously believe that this is important. Attitudes and wrong beliefs are the greatest barriers.
- Should be verified
- LCA of waste management has shown that transports are of minor importance, compared to the other sub-processes.
- Referring to a study by IVL Sweden waste can be transported quite a long distance without affecting the total energy-efficiency. According to the regulations emissions from road transports will not be a problem in the future.
- This is not a special problem for waste combustion in comparison with other alternatives.

1.4. The EU definition of input material as waste, and not as resource, may imply restrictions for incineration/gasification.

3 Very important
2 Important
4 Not important
1 Don't know

Comments:

- But it is important that people still believe that incineration is the same as destruction.
- There is a need for "declassifying" of waste - when is a residue or a processed residue classified as waste and when as product or raw material or fuel.
- The waste classification complicates the administration as well as the handling of the waste.
- Since the EU defines waste as waste and not as a resource in the first place, this does not seem to be any problem.

1.5. Poor quality of input material (waste) is a barrier for making gasification economically feasible.

3 Very important
6 Important
1 Not important
0 Don't know

Comments:

- But there are techniques, which can be used to gasify low quality wastes.
- I think gasification is more sensitive than incineration.
- The variation in quality is the biggest problem. Especially if syngas for fuel production is to be produced.
- Partly this depends on exactly what sources and applications that we consider.

1.6. Increases in number of incineration plants might out-compete gasification regarding available waste material.

2 Very important
5 Important
3 Not important
0 Don't know

Comments:

- Today incineration and gasification often are seen as competing methods. If the gasification technology becomes successful, incineration and gasification may have different markets.
- Since incineration is less demanding than gasification as regards homogeneity, these methods do not necessarily compete for the same wastes.

1.7. The requirement of very homogenous input material (waste) can be a limitation of the gasification technology.

4 Very important
5 Important
1 Not important
0 Don't know

Comments:

- We should try to develop technologies which can also work with heterogeneous wastes
- Some techniques have lower requirements on fuel quality
- I think gasification is more sensitive to the input than incineration.
- To some extent it is a limitation but since we get more out of gasification, it may be more advantageous for some special wastes, not least for production wastes that cannot be recycled in the industry.

1.8. Are there other barriers connected to input material (waste) that you consider important? Give a short description of these.

- Various materials will require different types of gasifiers but also the fuel gas cleaning systems. Thus cost of installation is also dependent on type of wastes gasified.
- The goal for material recycling is a problem. Today there is a lot of recycling which can neither be motivated by energy saving, nor by material saving or general environmental reasons. In north Europe it is even doubtful to recycle paper when the alternative is to burn it for district heating.
- Cost of purifying the syngas from catalyst-poisoning elements coming from the waste.
- We do not see any!

5.2 Barriers connected to the gasification/incineration process (plant conversion system):

2.1. Incineration of waste is producing air emissions and is spreading pollutions through the disposal of ash.

1 Very important
4 Important
5 Not important
0 Don't know

Comments:

- Dependent on technique, solutions are available
- The problem is that people do not believe in what modern flue-gas (can achieve?)
- LCA of incineration has shown that incineration is a rather "clean" method.
- It is a long-term problem, of making the land-fillings into potential risk areas.
- Every alternative has its own environmental disadvantages, and a fair comparison cannot be done by just pointing out disadvantages of one of the alternatives. Air emissions and emissions from ash disposal are smaller problems today than they have been. The resource issue seems to be more of a problem than the one of emissions.

2.2. Gasification of waste is producing air emissions and is spreading pollutions through the disposal of ash.

1 Very important
2 Important
6 Not important
0 Don't know

Comments:

- Therefore, we should focus techniques which are free of such problems
- LCA of gasification has shown that gasification is a rather "clean" method.
- Gasification does not generate dioxins.
- Every alternative has its own environmental disadvantages, and a fair comparison cannot be done by just pointing out disadvantages of one of the alternatives. Air emissions and

emissions from ash disposal are smaller problems today than they have been. The resource issue seems to be more of a problem than the one of emissions.

2.3. The new EU incineration directive might constitute a barrier to waste incineration through stringent emission restrictions.

1 Very important
4 Important
5 Not important
0 Don't know

Comments:

- Modern incinerators fulfil these demands
- In Sweden there is an expanding incineration capacity, despite the incineration directive. The directive may be a barrier to bad, unqualified waste incineration.
- It may be a problem that already existing incineration plants for other fuels, which are suitable for waste as well but not allowed for it, do not want permits for waste incineration, because they would then be treated like waste incineration plants all over, facing more stringent emissions restrictions than necessary for all other fuels.

2.4. The new EU incineration directive might constitute a barrier to waste gasification through stringent emission restrictions.

1 Very important
2 Important
6 Not important
0 Don't know

Comments:

- Does not interfere
- Large scale can carry the cost
- If gasification shall have a future, it must be better than incineration.
- Considering the extremely dioxin-free and NOx-free process of low-oxygen gasification under high pressure, this is less of a problem for gasification than for incineration.

2.5. Gasification is a high-risk technology for investors due to its complicity, requiring large scale production in order to be commercially feasible.

6 Very important
3 Important
1 Not important
0 Don't know

Comments:

- But the real problem is what to do with the gas. If you just burn it you could as well just select incineration.

- History has shown that there are a lot of gasification projects that has failed, while incineration is a successful technology!
- It is most important for fuel production since the fuel have to be price-competitive with gasoline and diesel oil.
- Gasification can be feasibly performed in small plants (an on-going project at KTH shows this).

2.6. Gasification is not a politically favoured technology as of today.

3 Very important
2 Important
2 Not important
3 Don't know

Comments:

- Gasification has to show both good qualifications and that it is a sustainable technology, before it can be favoured.
- If gasification could be shown to contribute by making use of some waste fractions that otherwise would give less return, there should be no political obstacle. The real problem is that politicians know too little about all alternatives including gasification, and not least how to combine them optimally.

2.7. The fact that the gasification technology is not well known, with no demonstration plants, while incineration technology is well known, might constitute a barrier to gasification.

7 Very important
1 Important
2 Not important
0 Don't know

Comments:

- Existing demonstration plants have not made enough progress, so there is not many commercial installations.
- Concrete technology demonstration is a key issue in this respect.

2.8. Are there other barriers connected to the gasification/incineration process that you consider important? Give a short description of these.

- Properties of wastes influence design of gasifier. Therefore, we must develop gasification process for some specific group of wastes
- Gas cleaning processes are not demonstrated widely with gasification. Lack of market and suppliers, trained operators and other skilled personnel.
- Prejudice based on the bad environmental performance of old incineration plants.

5.3 Barriers connected to the products (fuel, power, heat)

3.1. The regulations for transportation of dangerous goods may be barriers for the increased use of fuels from gasification (DME and hydrogen - explosion hazard, methanol toxic and water soluble - spillage hazard).

2 Very important
1 Important
6 Not important
1 Don't know

Comments:

- Depending on the fuel
- Needs to be addressed
- The products should be of minor importance. Probably waste will substitute other raw material, so the amount of fuel is independent of how much waste that is gasified.
- Technical solutions are available so it is not a problem. The cost for distribution of hydrogen is a very important barrier.
- This should not be more difficult to handle than for a lot of other chemical products out on the roads.

3.2. The EU taxation act, which allows tax-exemption for pilot tests only, is an important barrier for increased use of biofuels.

4 Very important
3 Important
2 Not important
1 Don't know

Comments:

- But the description is not correct
- This is because 1) the environmental cost of fossil fuels tends not to be fully reflected by today's pricing/taxation on the market and 2) relative cost advantages tend to be an unavoidable prerequisite for the initial build-up of new systems, competing with well established old solutions.

3.3. The cost of products from gasification is too high for competitiveness with products obtained by other routes.

3 Very important
5 Important
1 Not important
1 Don't know

Comments:

- Without respect to taxes and a full LCA
- Gasification of biomass to motor fuels is costly compared to fuels from natural gas.
- It may even be very important but is not within our best expertise to comment!

3.4. Electricity and heat from gasification can be produced cheaper by incineration.

5 Very important
2 Important
1 Not important
2 Don't know

Comments:

- It is site dependent, not generally.
- Established methods usually have a cost advantage!

3.5. The necessary technology is not yet developed for use of biofuels from gasification (methanol – corrosivity and cold-start problems, fuel cell vehicles – far from commercial stage).

3 Very important
3 Important
4 Not important
0 Don't know

Comments:

- Considering low blend, more important for higher blends
- Problems are over-exaggerated by opponents. If there is a will to change, it is very possible.
- More experience is needed.
- The technology for using methanol is developed and the auto industry is well aware of what is required. Methanol can and have been used in Otto and diesel engines and could be introduced as low blend in petrol immediately. Piston engines for DME and hydrogen are in a development phase.
- There still seems to be some R& D needed in these respects.

3.6. Are there other barriers connected to the incineration and gasification products that you consider important? Give a short description of these.

- Gasification products depends on properties therefore the products cleaning system must be adjusted to its properties and type of the equipment which will utilise the gas (gas engine, fuel cell or gas turbine, chemical process)
- Today there is no market demand for methanol, DME or hydrogen. That is the major barrier for syngas fuels. FTD (Fischer Tropsch Diesel) could easily be blended in conventional diesel oil but the production is not as energy effective as for methanol, DME and hydrogen. To be competitive as motor-fuel there have to be long term tax exemptions.

5.4 Discussion

5.4.1 Barriers of low importance:

From the characterisation of the barriers it is possible to select out one group of barriers which mainly were considered by the respondents to be of low importance. They are barriers which more respondents answered "Not important" then "Very important/Important".

1.3. Waste incineration/gasification can cause much transport of waste, which consumes much energy and is the cause of large emissions.

2.2. Gasification of waste is producing air emissions and is spreading pollutions through the disposal of ash.

2.4. The new EU incineration directive might constitute a barrier to waste gasification through stringent emission restrictions.

3.1. The regulations for transportation of dangerous goods may be barriers for the increased use of fuels from gasification (DME and hydrogen - explosion hazard, methanol toxic and water soluble - spillage hazard).

5.4.2 Barriers of medium importance:

Another group can be considered barriers of medium importance. Roughly the same number of respondents characterised these barriers as "Not important" or "Very important/Important".

1.2. Waste incineration/gasification may be in conflict with goals of more biological waste treatment.

2.1. Incineration of waste is producing air emissions and is spreading pollutions through the disposal of ash.

2.3. The new EU incineration directive might constitute a barrier to waste incineration through stringent emission restrictions.

5.4.3 Barriers of high importance:

The largest group is the barriers that can be considered of high importance. Most of the respondents characterised these barriers as either "Very important" or "Important". These barriers, ranked according to the number of "Very important/Important" answers (shown in parenthesis) are:

1.5. (9) Poor quality of input material (waste) is a barrier for making gasification economically feasible.

1.7. (9) The requirement of very homogenous input material (waste) can be a limitation of the gasification technology.

2.5. (9) Gasification is a high-risk technology for investors due to its complicity, requiring large scale production in order to be commercially feasible.

2.7. (8) The fact that the gasification technology is not well known, with no demonstration plants, while incineration technology is well known, might constitute a barrier to gasification.

3.3. (8) The cost of products from gasification is too high for competitiveness with products obtained by other routes.

1.6. (7) Increases in number of incineration plants might out-compete gasification regarding available waste material.

3.2. (7) The EU taxation act, which allows tax-exemption for pilot tests only, is an important barrier for increased use of biofuels.

3.4. (7) Electricity and heat from gasification can be produced cheaper by incineration.

1.1. (6) Waste incineration/gasification may be in conflict with goals of waste reduction, increased product reuse and material recycling.

3.5. (6) The necessary technology is not yet developed for use of biofuels from gasification (methanol – corrosivity and cold-start problems, fuel cell vehicles – far from commercial stage).

1.4. (5) The EU definition of input material as waste, and not as resource, may imply restrictions for incineration/gasification.

5.4.4 Important barriers connected to various sub-systems:

By using the matrix for barriers shown in Table 16 is possible to characterise these barriers further. Many of the barriers of high importance are connected to Sub-system 1 - **the input material** (collected waste fractions). They include:

1.1. Waste incineration/gasification may be in conflict with goals of waste reduction, increased product reuse and material recycling.

1.4. The EU definition of input material as waste, and not as resource, may imply restrictions for incineration/gasification.

1.5. Poor quality of input material (waste) is a barrier for making gasification economically feasible.

1.6. Increases in number of incineration plants might out-compete gasification regarding available waste material.

1.7. The requirement of very homogenous input material (waste) can be a limitation of the gasification technology.

In comparison, relatively fewer barriers of high importance are connected to Sub-system 2 - **the gasification/ incineration process** (plant conversion system). The following two are of this category:

2.5. Gasification is a high-risk technology for investors due to its complicity, requiring large scale production in order to be commercially feasible.

2.7. The fact that the gasification technology is not well known, with no demonstration plants, while incineration technology is well known, might constitute a barrier to gasification.

Many barriers of high importance are however connected to sub-system 3 - **the products** (fuel, power, heat). They include:

3.2. The EU taxation act, which allows tax-exemption for pilot tests only, is an important barrier for increased use of biofuels.

3.3. The cost of products from gasification is too high for competitiveness with products obtained by other routes.

3.4. Electricity and heat from gasification can be produced cheaper by incineration.

3.5. The necessary technology is not yet developed for use of biofuels from gasification (methanol – corrosivity and cold-start problems, fuel cell vehicles – far from commercial stage).

5.4.5 Important barriers of various types:

Within the category of **environmental barriers** (Attitudes of environmental organisations) only one barrier was characterised as being of high importance. That was the following barrier:

1.1. Waste incineration/gasification may be in conflict with goals of waste reduction, increased product reuse and material recycling.

Of **regulative/legislative** barriers only two were considered of high importance:

1.4. The EU definition of input material as waste, and not as resource, may imply restrictions for incineration/gasification.

3.2. The EU taxation act, which allows tax-exemption for pilot tests only, is an important barrier for increased use of biofuels.

A total of four **economical** barriers of high importance were identified. They were:

1.5. Poor quality of input material (waste) is a barrier for making gasification economically feasible.

2.5. Gasification is a high-risk technology for investors due to its complicity, requiring large scale production in order to be commercially feasible.

3.3. The cost of products from gasification is too high for competitiveness with products obtained by other routes.

3.4. Electricity and heat from gasification can be produced cheaper by incineration.

One **political** barrier of high importance was characterised as being of high importance. That was the following barrier:

1.6. Increases in number of incineration plants might out-compete gasification regarding available waste material.

Three **technological** barriers of high importance were identified. They were:

1.7. The requirement of very homogenous input material (waste) can be a limitation of the gasification technology.

2.7. The fact that the gasification technology is not well known, with no demonstration plants, while incineration technology is well known, might constitute a barrier to gasification.

3.5. The necessary technology is not yet developed for use of biofuels from gasification (methanol – corrosivity and cold-start problems, fuel cell vehicles – far from commercial stage).

5.5 Conclusions

The survey of barriers to incineration/gasification of waste revealed that, among the stakeholders in the project, there are many different views on the importance of the various barriers. This is reflected through the answers to the questions, where in total, almost all answer alternatives were chosen by the respondents altogether.

However, there were also some trends in the stakeholder groups, which could be seen by the ranging of the answers, according to how many respondents choose one particular answer. From this ranging it was possible to differentiate between those barriers that were considered unimportant and those that were considered of higher importance. Few stakeholders were of the opinion that the potential increase in transport of waste from increased incineration/gasification would constitute an important barrier. Neither were the regulations for transportation of dangerous goods considered important. The same could be said about the potential of gasification for producing air emissions and pollution. The new EU incineration directive, through stringent emission restrictions, was not considered a main barrier to waste gasification.

A wide range of issues presented for the Stakeholder Group were considered as constituting very important barriers for the increased use of gasification/incineration of waste. These covered all three sub-systems 1) input material, 2) gasification/ incineration process and 3) products. The important barriers are also of different kinds, either in the form of 1) environmental, 2) regulative/legislative, or 3) economical barriers.

It is thus possible to conclude that the barriers to incineration/gasification of waste are not limited to one or a few key barriers. It is on the contrary a large set of barriers that must be overcome for increased utilisation of waste by incineration/gasification. Neither is it possible to conclude that the most central barriers are connected to one single part of the overall system for incineration/gasification of waste. There are important barriers present in many areas, connected to the various sub-systems.

Table 16. Important barriers connected to various sub-systems

Type of barrier	Sub-system 1: Input material (collected waste fractions)	Sub-system 2: Gasification / Incineration process (plant conversion system)	Sub-system 3: The products (fuel, power, heat)
Environmental (Attitudes of environmental organisations)	Resource barriers: Waste gasification/incineration is not compatible with: → **Waste reduction** → Product reuse → Material recycling → Making products more durable → Biological waste treatment Long transports of waste consume much energy and cause large emissions.	Emission barriers: Increased emissions to air of POPs (persistent organic pollutants, incl. dioxins and brominated dioxins), asthma/lung disease- causing compounds, and high numbers of unknown substances. Increased spreading of heavy metals, POPs and unknown substances through more disposal of ash (mainly going to general waste disposal sites).	
Regulative/ Legislative	EU definition of input material as waste, not as resource. This implies many restrictions, e.g. to transport of input material, which is thus treated as hazardous material.	New EU incineration directive will imply stringent emission restrictions.	DME explosion hazard, MeOH is toxic and water-soluble: spillage hazard. Must comply with transportation of dangerous goods regulations. Hydrogen regulations are not yet in place. EU taxation act – only exemption for pilot tests.
Economical	Low quality of waste gives low economy.	Complicated technology gives expensive facilities. High investment cost of facilities, require large scale production to be commercially feasible. High risk for investors.	Cost of products is too high to be competitive with products obtained by other techniques. Fossil fuels are cheaper. Power and heat from incineration is cheaper than from gasification.
Political	Incineration politically favoured with strong increases planned in Sweden, resulting in limited waste available for gasification.	No municipal plans for gasification in Sweden.	
Technological	The gasification technology requires very homogenous input material (waste).	Gasification technology is not well known. Incineration technology is well known. No gasification demonstration plant exists.	Technology is not developed for improving MeOH cold-starting. Fuel cell engines are still not in commercial stage. MeOH is corrosive.

6 MARKET OPPORTUNITIES AND PRODUCTION POTENTIAL

6.1 Approach to analysis of market opportunities and production potentials

In this chapter we will analyse the opportunities for producing energy from waste. The new directive for phasing-in of biofuels implies that the EU-member states shall replace 2 % of the mineral-based fuels by biofuels in 2005, increasing to 5.75 % in 2010. This results in a strong demand for biofuels in Europe the next years to come. The amount of biofuels needed in Europe can be estimated to about 6 mill. tons in 2005 increasing to 17 mill. tons in 2010. A main barrier for realising these production amounts of fuels from waste is the uncertainty regarding the consideration of waste as a renewable energy source. The biofuels-directive is not clear on the issue about waste qualifying as a source for biofuels production.

The analysis aims at determining the amount of waste that could be utilised as raw material, and their potential for producing fuel, electricity and heat production in Norway, Sweden, Germany and Europe. Using the conversion rate ranges for the use of state-of the art technology, it is possible to estimate the production potentials for these forms of renewable energy from waste material. Three different cases for the utilisation of waste energy are applied:

Case 1: Heat production only

Case 2: Production of electricity plus heat

Case 3: Production of motor fuel plus heat

The fuel calculations are performed for methanol only. However, similar results would be obtained if DME were chosen as the fuel of preference.

6.2 Norway

6.2.1 Waste amounts

The waste statistics for Norway for the years 1998, 2000 and 2001 are shown in Table 17.

Table 17. Waste statistics for Norway for the years 1998, 2000 and 2001 (1000 tons)

	Total	**Sorted**	**Landfill**	**Incineration**	**Other**
1998	1,365	453	592	320	
2000	1,452	581	467	406	
2001	1,507	668	382	445	11

It is first of all the amounts of waste going to landfill, which must be considered utilised in fuel production. The composition of the waste is however crucial for determining how much fuel can be produced. The composition of the total waste in Norway is as shown in Table 18.

Table 18. The composition of total household waste of 1.45 mill. tons in Norway (2000)

Type of waste	%
Paper/Cardboard	33.0
Food	27.9
Plastics	8.2
Metal	4.6
Glass	3.6
Hazardous waste	0.1
Other	22.6

Source: Statistics Norway (2001)

There are no statistics for the total composition of the land-filled waste in Table 17. However, some information regarding wood waste and organic waste going to landfills is available. Of a total of 1.15 mill. tons wood waste in 1998, 25 % were deposited on landfills. This amounted to 0.29 mill. tons, which could potentially have been utilised for fuel production. Of the total wet organic waste in 1998, 75 % were deposited on landfills. This amounted to 0.19 mill. tons, which also could potentially have been utilised for fuel production.

However, since 1998 there has been a trend, which is shown in Table 17, of less household waste going to landfills, and more to incineration and recycling. In 2001 a total of 25 % of all waste from household was deposited on landfills, or about 0.37 mill. tons.

It is then possible to estimate the amounts of waste that could be used as raw material for fuel production, as shown in Table 19.

Table 19. Estimate of amounts of waste that could be used as raw material for energy production

Type of waste	**Amount (1000 tons)**
Wood[5]	260
Wet-Organic (incl. paper/cardboard contaminated with food)[6]	150
Other (incl. plastics contaminated with food)[7]	70
Total	480

6.2.2 Case 1: Heat production only

The energy amount that could be utilised in district heating connected to the combustion of waste in state-of the art plants is in the range of 90-95 % (Nykomb, 2003). Using the energy content of 151.4 MW per 50 tons waste as applied in Table 12, section 4.6, of this report, or 3.0 MWh/tons, this implies that a total of about 1.3 TWh available heat could be produced from the total waste in Norway shown in Table 19.

6.2.3 Case 2: Production of electricity plus heat

The electricity production potential in connection with gasification of waste can be determined by applying conversion rates based on a study of a 90 MWh cogeneration plant [13]. In this study, an electricity amount equivalent to 28 % of the energy in the waste could be generated using a gas furnace gasifier. However, with the use of a gas turbine gasifier, an electricity amount equivalent to 36 % of the energy in the waste could be generated. This is somewhat higher than the state-of-the-art process developed by Thermoselect, with waste energy conversion rates of 25-30 % to electricity and 60-65 % to heat [14]. We have chosen to use these conversion rates in the determination of production potentials for electricity and heat in combination. The amount of electricity that could be produced from the waste amount in Norway in Table 19, would be about 0.40 TWh. The annual electricity consumption in Norway was 113 TWh in 2001 [15]. This implies that electricity produced from waste in combination with heat has the potential to contribute about 0.35 % of the total electricity consumption in Norway.

The heat production that could be produced from the waste in Norway, in combination with electricity would be about 0.91 TWh annually.

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[5] Based on the assumption of a continuation of the trend that more wood will be incinerated or sorted out for recycling/reuse, and less be deposited on landfills.

[6] Based on the assumption of a continuation of the trend that more wet-organic waste will be composted, and less be deposited on landfills

[7] Based on the assumption of a continuation of the trend that more plastics are sorted out and incinerated or recycled/reprocessed.

6.2.4 Case 3: Production of fuel plus heat

An energy conversion rate of 22 % for turning the energy in waste into methanol in a gasification plants has been applied by Nykomb Synergetics [16]. However, Lindblom & Berglin [17] claims that a waste biomass to methanol conversion rate of 50-55 % is possible based on state of the art technology. At the facility in Schwarze Pumpe in north eastern Germany, it is annually produced 100,000 -120,000 tons methanol from an input of 450,000 tons waste. This gives a conversion rate of approximately 0.24 tons methanol per tons waste. However, this facility is not completely representative of pure waste conversion technologies, as there is a component consisting of brown coal in the input material at this facility. In Table 12, section 4.6 of this report a mass based yield of DME of 14.2 % is used. This corresponds to 20.4 % methanol. The amount of methanol that could be produced from the waste amounts in Table 19, would thus be about 0.098 mill. tons. In comparison, the total fuel use (gasoline plus diesel) for transport in Norway in the year 2000 amounted to 2.8 mill. tons [18]. Taking into consideration that the specific energy content[8] of methanol equals approximately half of the specific energy content of gasoline and diesel, fuel from waste thus has a maximum potential for replacing not more than 1.7 % of the total fuel use for transport in Norway.

The energy amount that could be utilised in district heating connected to the conversion of waste into fuel through a state-of the art gasification plant has been determined in Table 12, section 4.6 of this report. For such a facility, an energy amount of 25.3 MWh in the form of district heat can be generated from a waste input of 50 tons per day with energy content of 151.4 MWh. This implies that 16.7 % of the daily input waste energy, or 0.51 MWh/tonne waste can be used in the form of district heating. Applied to the annual available waste amount of 0.48 mill, tons in Norway, this could have the potential to produce 0.24 TWh heat annually.

6.3 Sweden

6.3.1 Waste amounts

Since RVF (www.rvf.se) started collecting statistics on waste in 1994, the amounts going to landfills have been reduced by approx. 30 %. The part being made up by household waste has been reduced even more, from 1.38 mill. tons in 1994 to 0.88 mill. tons in 2001, in other words a reduction by 36 %. Within the same years, the number of landfill sites that receives more than 50 tons municipal waste per year has been reduced from about 300 to closer 230 sites.

The estimated amount of combustible waste being landfilled in Sweden today is 2.6 mill. tons [19]. This includes household waste and industrial waste. One can assume that a waste amount corresponding to 80 % of this could be utilised in fuel, electricity and heat production in 2003.

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[8] Specific energy content is here understood as energy content per volume unit of the fuel

6.3.2 Case 1: Heat production only

Using the same conversion factors as for Norway above, a total of about 5.8 TWh available heat could be produced from the 2.06 mill. tons available waste in Sweden.

6.3.3 Case 2: Production of electricity plus heat

When using the conversion rates as for Norway above in the determination of production potentials for electricity and heat in combination, the amount of electricity that could annually be produced from the 2.06 mill. tons available waste in Sweden, would amount to about 1.7 TWh. The annual electricity consumption in Sweden was 129 TWh in 2000 [20]. This implies that electricity produced from waste in combination with heat has the potential to contribute about 1.3 % of the total electricity consumption in Sweden.

The heat production that could be produced from the waste in Sweden, in combination with electricity, would be about 3.89 TWh annually.

6.3.4 Case 3: Production of fuel plus heat

When using the conversion rates as for Norway above in the determination of production potentials for fuels and heat in combination, the amount of methanol that could be produced from the 2.06 mill. tons available waste in Sweden, would be about 0.42 mill. tons. In comparison, the total fuel use (gasoline plus diesel) for transport in Sweden was 6.31 mill. tons in 2000 [20]. Again taking into consideration the differences in energy content between methanol and gasoline/diesel, fuel from waste thus has a maximum potential for replacing 3.3 % of the total fuel use in Sweden.

The energy amount that could be utilised in district heating connected to the conversion of waste into fuel through state-of the art gasification plants in Sweden would be about 1.05 TWh heat annually.

6.4 Germany

6.4.1 Waste amounts

In Germany, a total of 27.8 mill. tons waste was deposited at landfills in 1993. One can assume that a waste amount corresponding to 70 % of this could be utilised in fuel, electricity and heat production in 2003.

6.4.2 Case 1: Heat production only

Using the same conversion factors as applied above, a total of a total of about 54.6 TWh available heat could be produced from the 19.5 mill. tons available waste in Germany.

6.4.3 Case 2: Production of electricity plus heat

When using the conversion rates as applied above in the determination of production potentials for electricity and heat in combination, the amount of electricity which could annually be produced from the 19.5 mill. tons available waste in Germany, would amount to about 16.2 TWh. The annual electricity production in Germany was 555.4 Mtoe in 1999 [21]. This corresponds to about 6,465 TWh, and implies that electricity produced from waste in combination with heat has the potential to contribute about 0.25 % of the total electricity production in Germany.

The heat production that could be produced from the waste in Germany, in combination with electricity, would be about 36.9 TWh annually.

6.4.4 Case 3: Production of fuel plus heat

When using the conversion rates as applied above in the determination of production potentials for fuels and heat in combination, the amount of methanol that could be produced from the 19.5 mill. tons available waste in Germany, would be about 3.98 mill. tons. In comparison, the total fuel use (gasoline plus diesel) for road-based transport in Germany in the year 1999 amounted to 57.54 Mtoe (EC, 2002). This corresponds to about 55.3 mill. tons[9]. Again taking into consideration the differences in energy content between methanol and gasoline/diesel, fuel from waste thus has a maximum potential for replacing 3.6 % of the total fuel use in Germany.

The energy amount that could be utilised in district heating connected to the conversion of waste into fuel through state-of the art gasification plants in Germany would be about 9.94 TWh heat annually.

6.5 Europe

6.5.1 Waste amounts

In Europe, approx. 156 mill. tons waste per year is deposited at landfills, based on reporting by each country, mainly 1999-data, but also from some countries back to 1993 (Eurostat). One can assume that a waste amount corresponding to 75 % of this could be utilised in fuel, electricity and heat production in 2003.

6.5.2 Case 1: Heat production only

Using the same conversion factors as applied above, a total of a total of about 328.5 TWh available heat could be produced from the 117 mill. tons available waste in Europe.

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[9] A factor of 11 640 GWh/Mtoe is applied. An energy content of 12.1 kWh/kg is assumed as the average of the total fuel consumed.

6.5.3 Case 2: Production of electricity plus heat

When using the conversion rates as applied above in the determination of production potentials for electricity and heat in combination, the amount of electricity which could annually be produced from the 117 mill. tons available waste in Europe, would amount to about 97.7 TWh. The total annual electricity production in Europe was 2,531 TWh in 1999 [21]. This implies that electricity produced from waste in combination with heat has the potential to contribute about 3.86 % of the total electricity production in Europe.

The heat production that could be produced from the waste in Europe, in combination with electricity is about 222 TWh annually.

6.5.4 Case 3: Production of fuel plus heat

When using the conversion rates as applied above in the determination of production potentials for fuels and heat in combination, the amount of methanol that could be produced from the 117 mill. tons available waste in Europe, would be about 23.9 mill. tons. In comparison, the total fuel consumption (gasoline plus diesel) for transport in Europe was 279 Mtoe in 1999 [22]. This corresponds to about 268 mill. tons fuel[10]. Again taking into consideration the differences in energy content between methanol and gasoline/diesel, fuel from waste thus has a maximum potential for replacing 4.5 % of the total fuel use in Europe. This fuel-production from waste materials alone is well above the biofuels directive-target of achieving a 2 % phase-in by 2005, and not that far from the 2010 -target of 5.75 % replacement.

The energy amount that could be utilised in district heating connected to the conversion of waste into fuel through state-of the art gasification plants in Europe is about 59.8 TWh heat annually.

6.6 Summary

The summary of the result from the analysis of potentials for energy from waste in Norway, Sweden, Germany and Europe is shown in Table 20.

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[10] A factor of 11 640 GWh/Mtoe is applied. An energy content of 12.1 kWh/kg is assumed as the average of the total fuel consumed.

Table 20 ***Potential of not utilised energy from waste in Norway, Sweden, Germany and Europe. Summary of results.***

	Norway	**Sweden**	**Germany**	**Europe**
Available waste (million tons)	0.5	2.1	19.5	117.3
MeOH production potential (million tons)	0.1	0.4	4.0	23.9
MeOH replacement potential (%)	1.7	3.3	3.6	4.5
Electricity production potential (TWh)	0.4	1.7	16.2	97.7
Electricity replacement potential[11] *(%)*	0.4	1.3	0.3	3.9
Heat alone (TWh)	1.3	5.8	54.6	328.5
Heat in combination with electricity (TWh)	0.9	3.9	36.9	222.0
Heat in combination with fuel (TWh)	0.2	1.0	9.9	59.8

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[11] The calculations of electricity replacement potential for Norway and Sweden are based on total electricity consumption, while the cooesponding figures for Germany and Europe are based on total electricity production.

7 NETWORK

The objective of the work presented in this chapter is to propose the utilisation of a network in order to achieve an increased market share of bioenergy from waste in the future. The work has been carried out by interviews, questionnaires and workshop discussions.

7.1 Interest groups and networks today

The utilisation of waste to produce energy involves many actors of different kinds. There are several interest groups with waste as a common basis but with different purposes. The most important organisations active in Europe in this field are listed below. In this connection it doesn't seem to be a lack of interest organisations. FEAD and ASSURE are organisations representing a wide range of members. A significant difference between the two are that FEAD's members are those who take care of the waste while ASSURE's members are mainly involved in the creation of products that one day will be classified as waste but FEAD is also a member.

FEAD - European Federation on Waste Management and Environmental Services.

FEAD have members from most EU Member States and four accession countries and Norway representing companies with activities in all forms of waste management. These companies employ over 300,000 people who operate around 3,000 controlled landfills, 1,350 recycling and sorting centres, 1,000 composting sites and 350 incinerators and play an important role in the determination of the best environmental option for waste management problems.

FEAD's role in Brussels is to gather expertise and up-to-date information from its members on the many subject areas covered, to compare experiences and to advise decision-makers of the overall situation in Europe. Lessons learnt in practice should lead us to better, more effective legislation, and therefore superior environmental and economic performance.

FEAD works with a broad network of other similar organisations in Brussels ensuring that opinions are not formed in isolation, and obtain wide-spread approval for a given policy position or direction.

ASSURE - The Association for the Sustainable Use and Recovery of Resources in Europe

ASSURE is a partnership for action, which aims to play an important role in transforming Sustainable Resource Management from a concept into a practical process and to work for a better EU legislative framework through better dialogue between all relevant actors and the EU institutions. ASSURE have a broad membership basis and expertise able to present a holistic non-sectoral view of the interlinked phases which represent the full life cycle of materials, from cradle to grave.

ASSURRE's approach is to:

- Raise the level of informed debate as regards the key issues of sustainable resource management and feed expertise into the EU institutions
- Uphold the vital link between EU policy formulation and implementation and ensure that experiences on the ground are fed back into the decision-making system.
- Commission Best Practice case studies and share lessons learned
- Track key issues and developments in technology and policy

CEWEP - Confederation of European Waste-to-Energy Plants.

CEWEP is a lobby organisation for European waste incinerators seated in Brussels. The basic environmental law is made by the EU and member states have to implement these regulations made in Brussels into national law.

CEWEP is a European representation:

- to represent and coordinate the interests of W-t-E Plants and to bundle up their forces;
- to give competent address to the decision-makers in the EU;
- to explain to public and political sector the high technical standard of W-t-E Plants and their environmental advantages; this must also be communicated to the environmental organisations;
- to take part in the Commission's decision processes and provide qualified statements before the official legislation process begins;
- to influence and create the EU-environmental legislation;
- to build up continual communication to the decision-makers in the EU and to make them aware of the concerns of W-t-E Plants;
- to reach a good reputation of waste incinerators, accepted as producers of green energy, replacing fossil fuels;
- to obtain a level-playing-field with regard to other waste treatment facilities, especially the industrial plants co-incinerating waste;
- last, but not least to exchange experiences between the European waste incinerators, to learn from each other and to develop new ideas for the daily practice.

ISWA - The International Solid Waste Association.

ISWA is a global professional network in the field of waste management with the mission to promote sustainable waste management world-wide. The organisations declared goal is to help implement eco-efficient and sustainable waste management systems on a global scale. Especially developing countries and economies in transition need support in this field.

Mission:

- Protect human health, natural resources and the environment
- Provide information

- Promote research and development, education and training
- Influence policies by providing advice
- Serve the membership

ETC/WMF - The European Topic Centre on Waste and Material Flows

(ETC/WMF), established in 1997, is one of five Topic Centres under the European Environment Agency. The mission of the Topic Centre is to provide reliable and comparable data and information on waste and material flows in Europe to decision-makers and the public.

The Topic Centre is a consortium of eight specialist partner organisations from environmental authorities and research communities in Europe. The consortium is led jointly by the Danish Environmental Protection Agency and the Environmental Protection Agency of the City of Copenhagen. The Topic Centre is part of the European Information and Observation Network (EIONET).

7.2 Aspects and actors

On a workshop arranged by Ecotraffic on May 23, 2003 the projects Reference group penetrated issues regarding constitution of a network. The main questions were which actors are important to create conditions for increased use of waste for energy production and what would be the most important tasks for this network. The work defined important actors and problematic issues in different parts of the lifecycle chain from product construction of the article of consumption to energy production. The chain were divided into six main parts, each including aspects and actors affecting the possibilities for later energy utilisation for products that will end up as waste at the end of the chain, Table 21.

Part 1. Product design:

The design of a product decides how it should be treated as waste. Aspects that affect the waste handling are e.g. material choice, complexity in structure, use of composites, possibility of easy dismantling, material labelling etc. The product designer decides the final shaping but does it in a way to satisfy the byer. This means that current trends will affect the design. Legislation will affect the design as well and as an example the producer responsibility regarding recycling of packaging have resulted in development of packaging that reduces the recycling costs.

Part 2. Purchasing:

At the moment of purchase the price and function of course is essential but reasonably the way to dispose of the product ought to affect the purchasing. Especially for enterprises that can see the direct costs for different kinds of waste. Clear product labelling and declarations would help buyers to chose easy incinerated and green products.

Table 21. Affecting aspects and important actors for energy recovery at the end of a product's lifecycle.

Part	Affecting aspects	Actors
1. Product design	Material choice Composites Hard to dismantle Producer responsibility	Packing developers Product designers Legislators
2. Purchasing	Price Environmental labelling	Purchasers Private persons
3. Disposal	EU waste definition Available waste separation system	Employees Private persons Municipalities/Waste responsible
4. Collecting and transport	Waste separation system Transport time and number of fractions	Municipalities/Waste responsible Waste management companies
5. Waste treatment	Price, including taxes Waste quality Available facilities	Municipalities/Waste responsible Legislators
6. Energy demand	Price, including taxes Type of energy	Governments Energy consumers

Part 3. Disposal

The actual waste handling system decides how the product is going to be disposed of. A waste separation system with a "combustible" fraction would significantly raise the quality of the waste as a fuel. More common is a system where the unsorted rest is incinerated which of course leads to a bad fuel quality. The EU waste definition is affecting the handling of the waste but what if some fractions could be classified as fuel or biofuel and be exempted from the waste definition and the municipalities responsibility? As a fuel it could be traded on a free market to probably lower costs.

The waste definition can only be changed by the EU administration. Effective waste handling systems are affected of the current legislation and the municipalities or waste responsibles ambitions. The quality of the separated waste fractions is also depending on the knowledge of employees or private persons on how to sort and the importance of correct sorting.

Part 4. Collecting and transport

Transport distances have only a small affect on the costs [9]. More important are the time needed for collecting (tons/hour) and the number of fractions to be transported. In this aspect an outsorting of a high quality fuel would be costly. The transport extent is a consequence of the waste separation system and is influenced by municipalities or those responsible for the waste. Waste management companies have a role in developing more effective methods and equipment.

Part 5. Waste treatment

The way the waste is treated depends on price including taxes (gate fees), waste quality and available treatment facilities. Since the waste responsibility falls on the municipality or local authority waste treatment solutions, and so the treatment costs, vary from one place to another. The treatment costs are sort of say fixed in short to medium terms. Introducing a fuel fraction could raise the heating value in the fuel but existing incinerators may have limits in design for the fuel's heating value. In a long term there must be regulations promoting energy from waste. Cost harmonising for thermal treatment in comparison to landfilling is necessary. The actors affecting the waste treatment are municipalities/waste responsible and legislators.

Part 6. Energy demand

The market opportunities for energy from waste are not only a question of price, but a question of waste strategies in a community as well. District heating structures require a certain amount of fuel (waste) in order to satisfy the energy demand. The customers (consumers) have small opportunities, if any, to chose another supplier which is limiting an open market. The situation for power production is different since the numbers of suppliers connected to the grid are not limited. If power from waste would be seen as green electricity the market opportunities would increase. In fact, this must reasonably be the case. The major part of the combustible part of waste is normally biobased. The same arguments could be applied for motor fuel production. According to the EU biofuel directive the "*member states should ensure that a minimum proportion of biofuels and other renewable fuels is placed on their markets, and, to that effect, shall set national indicative targets*". Some fuels are more easily introduced while some requires adaptation of the vehicles and the distribution systems. Some fuels requires introduction of new technologies in vehicles and distribution systems. Anyhow, the biofuel directive opens up an opportunity for motor fuels from waste. This is though depending on measures from the governments. Only if energy prices, mainly concerning power and motor fuels, are at the same levels as for energy from traditional energy sources, energy consumers will chose waste (bio) energy.

7.3 Interviews

A questionnaire, formed as a basis for discussion, was sent to a number of persons in the field of waste management throughout Europe. Following persons answered the questionnaire. Some in written form and some preferred a discussion by phone.

Name		Organisation
Norbert	Bosman	VVAV, Netherlands
Björn	Dahlrot	KSL, Sweden
Kyra	Dreher	ITAD e.V., Germany
Bill	Duncan	ASSURE
Reil	Eberhardt	Fernwärme Wien GmbH, Austria
Dieter	Reimann	Müllheizkraftwerk Bamberg, Germany
Håkan	Rylander	SYSAV, Sweden
Weine	Wiqvist	RVF, Sweden
Staffan	Ågren	The Ragnar Sellberg Foundation, Sweden

As a basis for the questions three statements were given:

1. More waste-to-energy increase use of renewable energy and decrease fossil energy dependency
2. More than 50% of the municipal waste in EU are put on landfills
3. The amount of waste produced increases 2-3% per year

The questionnaire contained three questions:

1. What is your opinion on why so much waste is put on landfills in the EU instead of being incinerated or gasified for energy recovery?
2. Which actors are important to make an increase in the share of energy recovery from waste by thermal conversion? (e.g. governments, waste management companies etc?)
3. How can these actors cooperate in a network? What would be the main issues for this network?

The order of the answers given below does not correspond to the order of the names given in the list above.

Answers to the first question:

Person A. Landfill is actually a cheap and traditional method and the environmental impact has so far not been very strong. The immediate environmental impact is actually still quite small and confined to limited areas. In most countries incineration has mainly been used as a method to reduce volume in such cases where place for landfill is getting scarce. However place is getting more and more scarce and we are getting more and more information about long term effects.

To produce energy has so far not been anything but a small additional side possibility and then it has almost always been a question of producing some electricity and sometimes only for the consumption of the incineration plants themselves. Sometimes there has been a production of steam. Other forms of energy have been, and are still, very cheap. For a high use of the energy content in municipal waste it is necessary to have access to a district heating system based on distribution of hot water or steam.

To produce high quality (purity and heating value) gas from waste is more difficult than gasification of coal or oil and you must have some use of the gas. Industrial gasification in general is a dying industry with the advent of natural gas for the chemical industry and of cheap electricity for many other uses.

Person B. All possibilities concerning post-use recovery of products and materials should principally be considered and evaluated. This is still far from done, or only done in a way that does not support much common unity as regards desirable solutions (between politicians, the industry, and the public). What we can say is that there is at least much general agreement on recovery being superior to landfilling from a resource perspective. However, the optimal balance between material recovery and energy recovery under different conditions still needs to be much investigated and discussed. This is a problem for all, including material recyclers and incineration/gasification plants. On the other hand, it is a necessary stage of the development that takes its time, no matter what we think about it.

Person C. The situation is very different in European countries. In the northern parts the demand for heating is larger due to the colder climate than in the southern Europe. In Sweden waste have been used for a long time for energy production and the system for district heating have been built up successfully in parallel. In Sweden the landfill tax are set to encourage recycling and together with the prohibition of depositing outsorted combustible waste from 2002 and deposition of organic waste from 2005, the trend today is that less waste are deposited and the number of waste-to-energy plants will increase. The landfill directive regulate depositing of biodegradable waste and member states shall have set up national strategies for reducing biodegradable waste going to landfill. The grades of observance though, vary from country to country.

In many countries there is a strong public opinion against waste incineration e.g England where landfilling is the dominating management method.

Person D: The price for putting waste on landfills is much lower than incineration. Even if there are national regulations on putting combustible waste on landfills this is still going on and a price competition is in progress.

Politicians are more interested in alternative solutions than incineration. They are unsure of the effects of incineration and are influenced of the opinion against waste incineration. The common acceptance for incineration is low. The public needs to be informed about not only the low risks but the benefits as well.

Person E: Depositing on landfills is much cheaper than incineration and the incineration capacity is in relative terms low. There aren't enough waste-to-energy plants. Landfill tax is an important instrument of control. The new directive on landfilling will increase the landfill management costs and lead to higher gate fees. Waste intended for recycling is in some extent only recycled to some percent. The main part is put on landfill, which is cheaper.

District heating is in use in central Europe, e.g in Germany, Holland and Poland but normally not connected to a waste incineration plant. Existing plants are often old and remotely situated from the district-heating grid. There are also different approaches on the definition of biodegradable waste. Some countries define household waste as 100% biomass.

Person F: Landfilling is by far cheaper than incineration of waste.

Person G: This might have something to do with on the one hand the (not so positive) reputation waste incineration has in certain countries and on the other hand the substantial amounts of money which have to be invested in order to build a state-of-the-art energy-from-waste plant.

Person H: The costs for depositing waste on landfill sites are dramatically cheaper than for incineration. As long there are no clear regulations for thermal treatment (e.g. special tax for depositing; waste treatment such as incineration for municipal waste with more than 3% TOC is a must;..) energy recovery will not be compliable.

Person I: Landfill came first –remains cheapest. Reflects a disposal mentality. Often the nearest physical option.

Answers to the second question:

Person A. Power and district heating companies, material manufacturers, municipality councils, governments, politicians. And very important -The EU-administration, who must look seriously into the matter of waste as an energy resource with very small GWP and base their analytical work on facts that are relevant for the future instead of historical data and popular beliefs and with regard to that conditions in the various European countries are different. There is reason to question the waste hierarchy, which by many is being accepted as a dogma. The hierarchy is OK as an indication but one should accept, and in fact recommend, that it is investigated for each region and each city and town whether waste and material in waste should be reused, recycled, used as an energy resource or landfilled and in this process consider environment, all resources (including time) and money. It is also important to realise that the future is dynamic and what seems or is true today is not always true in 20 years. Internal trade within EU of waste or waste fractions for energy should also be recommended since North Europe has better possibilities for this than South Europe.

Another important actor is media who often are either badly informed or more interested in exploiting existing attitudes than informing about real facts.

Person B. The key issue is to make more research to get evaluation tools good enough to be used by the politicians and become widely accepted by the industry and the public. Then there can be a well-motivated price put on different alternatives that the market can take into concern. To increase the share of energy recovery is no end in itself but if it means replacing landfilling we already see policies (laws, taxes, producer responsibilities etc.) that will result in that change. Facts already point to that this is good resource policy.

Person C. Important actors are the EU Commission and National energy agencies.

Person D: Politicians and the European Commission.

Person E: There are many important actors. There have to be motive forces and will at the authorities to have a good working supervising administration over waste flow. More commercialism and private enterprises is needed to get a more cost-effective management. To erect a new waste-to-energy plant high investments are necessary. To reduce economical risks long-term contracts of fuel (waste) supply is required. Normally municipals are responsible for both waste handling in the municipality and energy supply but they have restricted investment capability.

Person F: The governments (EU included) are the most important actors, since there will be no investments in thermal conversion as long as there are no stable political conditions and frameworks and as long one can't foresee how the market will develop.

Person G: Waste management companies, governments and scientific bureaus.

Person H: Governments and authorities at first.

Person I:
1. EU institutions
2. Member state governments
3. Local governments

Need for clear signalling of acceptability, facilitation of planning permits, engagement with citizens.

Answers to the third question:

Person A. The European union could start a project with the intention to really clarify conditions and data that are relevant to use in the study of locally adapted future waste management and create a network for discussion and free flow of information and facts regarding the use of waste for various applications. And that this network will be consulted in early stages of writing suggestions for new directives and revision of old ones. The office responsible for the network should also have a home page with information and links which is accessible for all who want to have some information on waste, waste management and various ways of recycling and energy recovery etc. It is rather depressing to read document from the EU-parliament and find that they discuss whether plastic flowerpots are packages or products or whether the little brush in the eyeliner or eye shadow box is part of the package or not. This kind of "stupidity" is not creating a good image for either the EU-administration or its parliament. There is a lack of information and understanding.

In short - the network should be a source of information and open discussion and a help for the EU-administration and others.

Person B. The main issue is to increase research and co-operation as regards all-embracing questions within the waste sector and the energy sector in parallel. The industry needs to have a much more pro-active attitude in this respect to avoid bad and costly solutions put on them by badly informed/prejudiced authorities. Waste management is traditionally not an academic subject but needs to incorporate more of qualified knowledge to find practical solutions that fit into holistic systems thinking. Networking will be needed to fund research and spread all answers that single actors cannot tackle on their own.

Person C. It is important that waste must be seen as mainly a biofuel, which it in fact often is. Thereafter it could be given the same conditions as other biofuels. E.g. the interpret of the European Court recently (2003) that waste-to-energy in a waste incineration plant could not be seen as recycling while co-firing does. The system for green certificates for power is not including waste-to-energy plants.

Further, the regulations on emissions from energy plants must be equal irrespective of fuel used. Today waste-to-energy plants have to live up to more stringent emission levels than plants using other fuels (both fossil fuels and biofuels).

Person D: Landfill taxes would help. Information to politicians and EU-Commission.

Person E: A network needs to be adapted from region to region because the conditions are different. The networks ought to be initiated by those who have the legal responsibility for the waste. An important question is what is recycling and what is destruction? At present incineration with energy recovery is not recycling but destruction, according to the EU-court. This pleases both the cement industry and the environmental organisations but in different aspects. The cement industry uses different kind of waste as fuel and don't want competition from w-t-e plants. Environmental such as Greenpeace don't like any forms of incineration no matter which fuels are used.

Person F: By exchanging reliable information and willingness to really cooperate. Therefore the main issues for a network would be trustworthiness and reliability.

Person G: The main issues would be the financing of initiatives concerning energy-from-waste, the level-playing-field on a EU-scale, public relations.

Person H: The EU should actually give authorities and politicians enough facilities to cooperate.

Person I: Less need for a network than for a legislative driver (targets, timetables) and consequent engagement in implementation process.

7.4 Conclusions

There is one main reason why large amounts of waste are put on landfills instead of energy recycled. Landfilling is cheaper! That implies that other energy sources can be used to produce power and heat to a lower cost. There is also a strong public opinion against waste incineration in many countries due to its bad reputation concerning emissions. This may affect politicians and decision-makers to be more interested in other solutions than incineration. Gasification is in this aspect a more unknown technology having possibilities to get attention but it is not enough demonstrated and the investment costs are high.

The demand for heat is less in the southern Europe than in the north. That may be one reason why energy from waste in combination with district heating has been so successful in Sweden. A demand for heat is an important condition to a good plant economy even if power is produced. In general there are few waste-to-energy plants in Europe.

Participants in a network for increased use of energy from waste should represent waste management, energy companies, municipalities, governments, politicians and the EU-administration. Even the manufacturing industry should be represented as they are in FEAD. The main task for the network should be to clarify conditions and data as a source of information and open discussion. Politicians and the public need more information. Politicians need tools and facts to be able to make correct decisions on waste and energy issues. Therefore trustworthiness and reliability should be fundamental. The network should work for exchange of reliable information and support and fund research and cooperation between the waste sector and energy sector. Gasification technology for solid biofuels needs support for further development

The network should also work for equal market conditions for energy from waste by the following activities:

- Stimulate more commercialism and private enterprises.
- Stimulate internal trade within the EU
- Create stable political conditions
- Make it possible to utilise waste as mainly a biofuel
- Question the waste hierarchy
- Include power from waste in the system for Green certificates for electric power
- Introduce equal emission regulations for different energy plants
- Clearly define the difference between recycling and destruction
- Introduce landfill tax to direct waste quantities from landfills to recycling alternatives, e.g. incineration.

8 AUTOMOTIVE FUELS FROM WASTE

The gasification technology enables production of fuels suitable for automotive purposes. Several studies on fuel production from gasification of biomass have pointed out methanol, DME (Dimethyl ether) and FTD (Fischer-Tropsch Diesel) as the most economically and environmentally best fuels in a well-to-wheel perspective. Even hydrogen can be produced but are a much more expensive fuel.

Information given in this chapter is to a large extent based on references [23,24,25,26,27,28,29,30,31]

8.1 Fuel properties

Some relevant fuel properties for petrol (according to EU 2005 specification), diesel fuel (Swedish Environmental Class 1), methanol, DME, hydrogen and propane are shown in Table 22. Petrol and diesel fuels 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 22. Fuel properties

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)		<0.5 kPa	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	19.0	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 ($\%_m$)		unmisc	∞	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

8.1.1 Potential fuel converters for methanol and DME

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 23.

Table 23. 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

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.

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.

8.1.2 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.

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. 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. 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.

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. 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.*

An 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.

8.1.3 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.

Diesel fuel

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 also are developing filter systems. 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. 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.

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 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. 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.

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 in the fuel. 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. 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.

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

8.1.4 Fuel cells

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 are 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.

8.1.5 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.

8.2 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.

8.2.1 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. Since methanol is a commodity chemical and it is traded worldwide in large quantities, the regulations for this type of handling are well developed. The issues that might arise when methanol is distributed to the public are of main interest in this study.

Methanol is 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 but if exceeded, it could lead to blindness or death. 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 24**. As can be seen, 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 24. 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 suicides. 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.

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.

Use of methanol in windshield washer fluid

Methanol is used in in windshield washer fluid in North America, whereas isopropanol, and in some cases ethanol, is used in Sweden and Europé. The use of alcohols in windshield washer fluid is to avoid freezing.

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%. 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.

Health and environmental risk of DME

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.

8.2.2 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. 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. 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.

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.

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.

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.

8.3 Distribution

8.3.1 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).

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.

Methanol is dissolved 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.

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

8.3.2 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.

A Swedish company of fuel dispensers, Identic, is currently developing a new spill-free dispensing system for methanol. A prototype system has been installed in the Necar 5 prototype fuel cell car by DaimlerChrysler.

It could be of interest to show the potential incremental cost of distributing methanol in comparison to petrol. Evidently, there is an additional cost related to methanol. 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. 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.

The results from the mentioned study are shown in Table 25. As can be noted, 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 25. 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 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.

9 LEGISLATION OVERVIEW

9.1 EU

The Directive 1999/31/EG on landfilling is a comprehensive description of the operation of a landfill, with respect to the handling of waste, as well as continuous monitoring of leaching water and air emissions. The cost for depositing waste on a landfill is, however, not quantitatively expressed. The landfill principal should, however, claim a price that is sufficiently high for both the continuous operation of the unit and the close-down and post-treatment during at least 30 years.

The operation of waste incinerators is governed by Directive 2000/76/EC on the incineration of waste. The main objects are to eliminate or reduce the negative effects on the environment. To accomplish these targets the operation of waste incineration plants is thoroughly regulated with respect to what waste that may be processed, what operation conditions that must be fulfilled in terms of residence time and temperatures and emission threshold values and control procedures.

9.2 Sweden

As for the EU, the Swedish legislation comprises a number of directives on the incineration of waste as well as restrictions on landfilling. The technical operation is regulated through NFS 2002:28, which is an extension of SFS 2001:1063. Here, threshold values are given for emissions to air and water recipients. The contents of NFS 2002:28 are similar to the European Directive 2000/76/EC. Landfilling is regulated through SFS 2001:512, which is the Swedish version of the European Directive 1999/31/EG.

The new Directive on landfilling requires better barriers and sealing. Also, leaching water must be withdrawn and collected. The implementation of the new regulations on landfilling will result in that at least half of the domestic 500 waste disposals will be decommissioned. This will reduce a large number of facilities into a smaller number of large units with high standard and good control.

Taxes of EUR 27/tonne were introduced in the year of 2000 for landfill deposit[12], even so the total amount of waste is still increasing. This tax was increased in January 2003 and currently amount to EUR 41/tonne (SFS 2002:998). The total fee, including taxes, on waste depositing is EUR 44-1,100/tonne, where the lower figure is most representative for the major part of the handled waste. The waste that is deposited is decreasing and in 1994 amounted to 160 kg/capita and in 1999 103 kg/capita and the decreasing trend is continuing. A part of the current development is explained by the fact that deposition of combustible waste is prohibited from 2002 and deposition of organic waste from 2005.

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[12] There are, in some occasions, possibilities to get tax reductions on ashes being deposited, for instance utilisation as construction material within the plant area or used in order to stabilise other deposited material.

9.3 Norway

The situation in Norway is not different to Sweden with respect to the decrease in the number of landfills. The current waste deposit is expensive and may amount to EUR 110/tonne. The average cost is EUR 99/tonne, of which taxes constitute EUR 40.

Norway has since 2001 had a ban on depositing wet-organic waste. This is, however, not ultimately prohibited, but it is decided for every individual site. The total capacity of the Norwegian incineration facilities is not sufficient and currently, waste is exported to Swedish incineration plants.

9.4 Germany

Incineration of waste in Germany is performed under stringent safety standards. In 1990 the 17th Federal Imission Control Ordinance was adopted, which sets limits on dioxins/furans and heavy metals [32]. The EU directives on landfill of waste and the incineration of waste mentioned above, follow the basic principles developed in Germany and a few other European countries.

Germany has during the 1990's tried to gain better control of the waste problems, using economical mechanisms. There was an attempt to establish a Waste Charges Act, which required the operator of a disposal facility to pay a fee for each tonne of waste. This Act was never implemented but the work was instead further aimed at minimising waste in the Closed Substance Cycle and Waste Management Act. Simultaneously, the EC Framework Directive on Waste was implemented (75/442/EC). The new regulations and ordinances stipulate that landfills that fail to meet the required standards must be shut down by the year 2005, or with only small deviations, by 2009 at the latest. Some 200 landfills for waste now need to be decommissioned.

Currently, there are no restrictions on putting waste on landfills above the European Directive from 1999, neither are there any taxes on landfilling or incineration. There is, however, a fee on depositing of EUR 15-175/tonne. In the year of 2005 there will be a ban on depositing organic waste, similar to the Swedish conditions [33]. An estimation of the annual deficiency of German incineration capacity is 3-4 Mtonnes of waste.

10 SUMMARY, BARRIERS

This chapter summarises the most important barriers for increased utilisation of energy from waste through thermal conversion. Waste in this context is both Municipal Solid Waste (MSW) and Refuse Derived Fuels (RDF) from industrial waste.

10.1 Economy

The most important barrier, or motive force, is economy. Solutions to different kinds of barriers can almost always be found but if implemented or not is a question of costs and competitiveness to other alternatives.

Today landfilling in Europe is in general cheaper than incineration. It is therefore hard to find investors to incineration plants and distribution systems for district heating. However, in the northern and colder parts of Europe the demand for heating is high making it possible to utilise the energy in the waste as heat in a competitive way.

The high costs for Waste-to-Energy plants is mainly related to:

- Flue gas treatment
- Maintenance due to corrosion and erosion
- Capital costs due to the need of oversized plant design
- Disposal of by-products

A first solution to the problem would be to implement taxes on landfilling with the purpose to make thermal treatment more competitive.

Another way is to increase the quality of the waste fuel. This could be done by sorting out waste fractions at source making it possible to mix combustible fractions to a well-specified fuel with only small variations in composition and quality. The plant design could be made more cost effective since it will be less oversized. This solution requires long term political conditions and ambitions for waste sorting at source.

The market conditions for energy based on waste needs to be improved by making it possible to market energy from waste as Green energy in relation to the biomass content in the waste.

Concerning gasification the economic considerations is even more important. Product economics is by many identified as the most important determinant in gasification technology deployment potential [34].

However, the results of this study show that production of automotive fuels from waste has potential to be an environmentally and economically good solution in the future. With a gate fee of fully 50 EUR/ton the cost for the automotive fuel is in parity with the price of diesel oil. By further optimisation this can be improved to give margins to profit and fuel tax. Since the produced fuel is based mainly on biomass this part should be exempted from fossil fuel taxes.

Improvements would also be possible with a higher quality of the waste. A well specified waste raw material with small variations in composition make a more effective plant design possible with improved overall economy. Studies on automotive fuel production by gasification in a full scale demonstration plant using pure wood waste (forest residues), a much better raw material than waste, gives a price of 6.2 EURc/kWh [7] compared to 8.7 EUR/kWh in this study. This indicates the potential cost reductions possible by raising the quality of the waste.

As with most new technologies, gasification projects require a higher hurdle rate, or higher cost of capital, than projects using existing technology. That is, investors require a higher rate of return on their investment in a relatively new or untested technology to offset the risk in not knowing how the technology may perform in the marketplace. Unfortunately, gasification technology advantages with regard to reducing criteria pollutants, solid waste, and atmospheric mercury are non-monetized and do not provide any type of financial offset to the cost of gasification projects.

10.2 Technology barriers

Technology barriers could rather be seen as economical barriers. Especially in the case for incineration which is a well-proven application. Most technology problems can be solved. It is just a question of costs and the competitiveness to other energy production.

10.2.1 Technology barriers-Incineration

The major barriers within waste thermal treatment are non-technical. More stringent demands can technically be achievable to almost any level of the penalty of rapidly increased cost of treatment. However, alternative treatment procedures (composting, anaerobic digestion) entail the risk of even higher costs of treatment, as large masses of residues requiring post-treatment are generated. Incineration of these can become a necessary part of such Waste-to-Energy installations.

Emission control and flue gas cleaning systems are the necessary equipment within waste combustion for elimination of the risks of emission of environmental pollutants. There is a clear relationship between the amount of the pollutant released during combustion and the content of the pollutant precursors in the raw material. Because of variations in the quality of the raw material and uncertainties upon the amount pollutant precursors the capacity of the gas cleaning systems must be dimensioned in a manner for being able of handling a maximum possible emission.

Compared to other solid fuels, waste usually contains a considerable higher amount of inorganic material. A high inorganic content increases the total throughout of the ash trough the process resulting in faster erosion and wear out of tubs, vessels and filtering equipment.

Deposit formation during thermal treatment of waste occurs throughout different mechanisms but the formation of condensable products is a necessary step for initiation of depositing and fouling. In fluidised bed processes sever problems of bed material agglomeration and sintering occurres. Periodical interruptions in operation due to fouling and sintering is well known problem that decreases the reliability of the waste combustion process in energy production applications.

A total reduction of the sulphur and chlorine from the waste composition is practically impossible, hence, for minimising the corrosion rate the temperature of the heat exchanger surfaces is kept down in a lower level than that for the clean fuels. This also results in less potential for energy recovery as electric power typically to 20% compared to 30 – 40% for other fuel.

waste thermal treating plants suffer from serious problems related to corrosion on heat exchanger and superheater surfaces. The corrosion is dependent on the environment and the temperature. Increased temperature in a corrosive environment accelerates the corrosion rate. To suppress the corrosion the boiler and heat recovery systems in waste treating plants are normally operated at lower temperature than in the case with clean fuels. The low steam temperature (<420°C) and steam pressure result in an insufficient electrical efficiency for the whole process.

10.2.2 Technology barriers-Gasification/Fuel Production

The most important technology barriers for producing automotive fuels through gasification of solid waste are presented in this section. The following problems have been identified:

- Waste is a heterogenous feedstock. It is uncontinuous and unpredictable.
- Waste has low energy content.
- There is relatively little information on gasification of waste, and a lot of waste gasification projects in the past have failed.
- Gasification in general suffers from poor process reliability.
- Feeding systems for high-pressure gasifiers are not yet satisfactory.
- What to do with the ash/slag from the gasifiers.

Each of these issues is discussed in detail below.

1.) Municipal Solid Waste (MSW) is not a continuous and predictable feedstock. The composition of MSW [35]

- changes from country to country
- is very different for rural areas compared to urban areas
- can vary over the seasons and is changing over a long period of time as a country develops or implements different waste management strategies.

Gasification is an extremely complex and delicate process and may therefore not be well suited to treat the highly heterogeneous waste [36]. The following technical problems are reported to have been encountered when attempting to gasify waste:

- Syngas is an inflammable and explosive gas. This requires high safety measures.
- The syngas has to be cooled before it can be cleaned. This quenching results in an important loss of energy, which in turn results in a lower overall efficiency.

- After cleaning the syngas, it will still contain some impurities and pollutants. This will result in corrosion/erosion problems in the gas turbine or gas engine. In general, gas turbines and gas engines are designed for clean gaseous fuels like natural gas or syngas from oil.
- The process produces a char and tar which has to be taken care of.

In order to overcome the char and tar problem, additional air has to be introduced in the system. This results in a higher degree of oxidation of the syngas and therefore a lower calorific value. Some suppliers try to overcome this problem by using pure oxygen instead of air, which results in an increased operating cost (high power consumption). Often methane gas is mixed with the syngas in order to keep the calorific value constant and sufficiently high for the gas turbine or gas engine.

2.) Feedstock preparation issues in gasification focus mainly on the use of low-rank coals and alternative feedstocks such as waste, sewage sludge, and biomass [37]. Such feedstocks suffer from low energy density and high moisture content, making them uneconomical for transport over very large distances. In addition, physically handling and preparing many of these materials for use in gasifiers are impediments to their use. Even after dewatering some materials, problems with feeding have been experienced, especially for fibrous materials such as biomass.

3.) The gasification process was used with waste in the United States in the 1970s, but those plants have been shut down because of operating and financial problems. Some gasification plants were built and operated in Europe in the early 1980s. Los Angeles had a system designed to use dried sewage sludge. The gas was burned to drive a 10 megawatt steam turbine-generator [38].

4.) In July 2002, the U.S. Department of Energy investigated present and future gasification technologies and markets from an industry perspective, by interviewing expert teams from 22 prominent organizations across a wide span of the U.S. gasification industry [39]. For gasification as a whole, process reliability is identified by nearly all participants as the single most important technical limitation to be overcome in order to achieve widespread deployment of the technology.

5.) Operation and maintenance issues remain regarding erosion and corrosion of valves, pipes, and pumps. The development of new or improved feeding systems for high-pressure gasifiers remains fairly high on the list of priorities. For plants processing opportunity feedstocks, the feed system is typically the cause of reliability problems and developments are needed to improve performance with such feedstocks in high-pressure gasifiers.

6.) As the number of gasification plants continues to increase in the world, the disposition of the ash and slag becomes increasingly important. New markets and ways of utilizing the ash/slag from gasifiers need to be developed because disposing of this material in a landfill is expected to become a significant issue in years to come. Currently, it is difficult to find a market for the ash and slag where its value exceeds transportation costs. It is desirable for the ash/slag to be a revenue-generating stream and help drive the technology to full utilization of all waste materials.

Mr. Dirk Eeraerts, SEGHERS Better technology Singapore Pte. Ltd., concludes on gasification of municipal solid waste [40]:

"Gasification is successfully applied for thermal conversion of predictable and clean fuels such as coal, petrol and gas. The technology also has potential for power generation using certain biomass fuels (crop wastes) and dried/pelletized wastewater treatment sludge. For MSW, gasification remains unreliable, too expensive and too risky."

10.2.3 How to overcome the technology barriers

The U.S. Environmental Protection Agency (EPA) recently recognized the superiority of gasification in processing refinery wastes and the associated waste source reduction and the recycling of wastes into usable by-products [41]. Similar action on non-refinery-based toxic compounds, such as PCBs, is hoped for in the near future. It is considered that with some research and development on municipal solid waste (MSW) processing and injection, waste can also become a gasification feedstock subject to waste reduction and recycling, rather than continued treatment and disposal.

In contrast with many other energy technologies that require fuel to be purchased, waste facilities are paid by the fuel suppliers to take the fuel (known as a "tipping fee") [42].

Consequently, there appears to be a need to develop new or improved approaches for dewatering and increasing the energy density of waste. It would further be good to develop low-cost briquetting techniques including use of low-cost binders.

According to a recent U.S. Department of Energy report [43], there is a need to develop an affordable on-line analytical device that can provide the elemental composition of the gasifier feedstock for those situations where the composition is constantly varying, as with the heterogeneous waste feedstock, or co-feed applications.

The gasification block of a plant is of course very important. As an example, it can be mentioned that the gasification block constitutes about 15% of the capital cost of an IGCC plant. There is general agreement that the priority for gasification is to reduce the capital cost and increase the reliability of gasifiers. Numerous technology needs are identified to accomplish this. Nearly all of the participants identify the feed injectors and refractory liners used in gasifiers as the weakest links in the process for achieving high on-stream availability factors. The need for new process monitoring and control instrumentation for these weak links is of paramount importance.

10.3 Energy efficiency

Producing only heat from waste could be done with a high energy efficiency. Existing plants today have an efficiency of 70-75% but a state-of-the-art plant will reach efficiency of 90-95%, but of course to a higher cost. To utilise this high market demand over the year is required.

Power production from waste has lower energy efficiency in comparison to other "clean" fuels. To minimise the corrosion rate the temperature of the heat exchanger surfaces is kept down in a lower level than that for the clean fuels. This results in less potential for energy recovery as electric power typically to 20% compared to 30 – 40% for other fuel. To reach high total energy efficiency in a CHP-plant it has to be a demand for the surplus heat.

A waste-to-motor fuel plant has greater energy losses and as for a CHP-plant it has to be a demand for the surplus heat. However, the motor fuel product has a high exergy and is storable.

10.4 Transport

Transports of waste, when the waste once has been collected, is of very low importance considering consumption of energy resources, environmental impact and economy, if the transport is performed in an efficient manner [9]. Private transports of separated waste (from home to the collection site) can be of importance if the transport is made by car since energy use and emissions increase. According to the high demanding regulations on emissions from road transports emissions will not be a problem in the future.

10.5 Environment

Compared to clean fuels such as forest residue or natural gas, waste contains higher amounts of N, S and Cl, which are the precursors of NO_x, SO_x, HCl and dioxins. Other inorganic compounds of great importance in the waste are heavy metals. During thermal processing these compounds becomes concentrated in one of the output streams from the process. The content of emission precursors varies significantly in different fractions of waste. Though the emissions to air can be reduced to very low levels the pollutants formed during combustion ends up in the ash and the slag. Even unburned fractions in the slag are a problem has to be taken into consideration. The combustion residues have to be taken care of and landfilled under strict regulated conditions. Efforts are made to find use for the residues, e.g. roads etc., but the product have to be prepared to a stable form with no risk for leakage of pollutants.

Dioxins are formed during incineration and monitoring is a very costly procedure and requires specialists with expertise skill of both in sampling and in analysis. The high costs for measurement results in that the estimations upon the global emissions are often based on short time and periodical samplings within certain conditions. Since the quality of the fuel and the process conditions can be very different in different periods the results from such estimations can be regarded questionable.

Gasification is environmentally superior to incineration. Gasification is in many ways preferable to combustion for the destruction of municipal and industrial wastes, and especially because gasification does not emit dioxins or furans like incineration processes do.

The U.S. Environmental Protection Agency (EPA) recently recognized the superiority of gasification in processing refinery wastes and the associated waste source reduction and recycling of the wastes into usable by-products [44]. Similar action on non-refinery-based toxic compounds is hoped for in the near future. And, many believe that with some R&D on waste processing and injection, waste too can become a gasification feedstock subject to waste reduction and recycling, rather than continued treatment and disposal.

The perception that gasification plants are "dirty" because the feedstock are seen as "dirty" is impeding deployment by lengthening the permitting process. Public visions of dust, smoke, unclean water discharges, and solid waste disposal make siting a gasification plant very difficult.

10.6 Legislation

10.6.1 EU

The Directive 1999/31/EG on landfilling is a comprehensive description of the operation of a landfill. The cost for depositing waste on a landfill is, however, not quantitatively expressed. The landfill principal should, however, claim a price that is sufficiently high for both the continuous operation of the unit and the close-down and post-treatment during at least 30 years.

The operation of waste incinerators is governed by Directive 2000/76/EC on the incineration of waste. The main objects are to eliminate or reduce the negative effects on the environment. To accomplish these targets the operation of waste incineration plants is thoroughly regulated with respect to what waste that may be processed, what operation conditions that must be fulfilled in terms of residence time and temperatures and emission threshold values and control procedures. One may reflect over the different emission limits for incineration and co-firing respectively as shown in Figure 4. The emission limits should be independent on what kinds of fuel are used.

In Council Regulation (EEC) No 259/93 supervision and control of the shipments of waste within, into and out of the European Community is regulated. These regulations constitute not an important barrier but administrative routines and permits are normally required.

10.6.2 Sweden

As for the EU, the Swedish legislation comprises a number of directives on the incineration of waste as well as restrictions on landfilling. The contents of NFS 2002:28 are similar to the European Directive 2000/76/EC.

Taxes of EUR 27/tonne were introduced in the year of 2000 for landfill deposit[13], even so the total amount of waste is still increasing. This tax was increased in January 2003 and currently amount to EUR 41/tonne (SFS 2002:998). The total fee, including taxes, on waste depositing is EUR 44-1,100/tonne, where the lower figure is most representative for the major part of the handled waste. Landfilling of combustible waste is prohibited from 2002 and deposition of organic waste from 2005.

10.6.3 Norway

The situation in Norway is not different to Sweden with respect to the decrease in the number of landfills. The current waste deposit is expensive and may amount to EUR 110/tonne. The average cost is EUR 99/tonne, of which taxes constitute EUR 40.

Norway has since 2001 had a ban on depositing wet-organic waste. The total capacity of the Norwegian incineration facilities is not sufficient and currently, waste is exported to Swedish incineration plants.

10.6.4 Germany

Incineration of waste in Germany is performed under stringent safety standards. In 1990 the 17th Federal Imission Control Ordinance was adopted, which sets limits on

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[13] There are, in some occasions, possibilities to get tax reductions on ashes being deposited, for instance utilisation as construction material within the plant area or used in order to stabilise other deposited material.

dioxins/furans and heavy metals [45]. The EU directives on landfill of waste and the incineration of waste mentioned above, follow the basic principles developed in Germany and a few other European countries.

Germany has during the 1990's tried to gain better control of the waste problems, using economical mechanisms. Currently, there are no restrictions on putting waste on landfills above the European Directive from 1999, neither are there any taxes on landfilling or incineration. There is, however, a fee on depositing of EUR 15-175/ton. In the year 2005 there will be a ban on depositing organic waste, similar to the Swedish conditions [46].

11 CONCLUSIONS

High amounts of energy are lost today by not utilising the energy content in waste that are put on landfills. The dependency in Europe on imported fossil energy increases as well as the amounts of waste generated in society. This is not a sustainable development process and it need to be altered.

Waste recovery should be encouraged, primarily through sorting at source. Waste segregation at an early stage simplifies recycling of products and materials as well as the use of waste as raw material for motor fuel production. The latter is considerably simplified if the waste composition is well known with small variations in constitution. Sorted waste fractions make high quality requirements possible by continuos mixing the fractions to a suitable raw material.

Products that cannot be reused or material recycled should be used as fuel for energy recovery. The energy content is to valuable to be put on landfill to no use. Complex materials with less or no "second hand" use should be avoided. Such short-living materials are wastefulness of natural resources.

The main reason why waste with energy content still is put on landfills is economical. As long as landfilling is cheap there are no incentives for large investments in thermal treatment plants. The situation is though not the same all over Europe. In Sweden for example incineration in combination with district heating is well established.

The strongest arguments for energy from waste is connected to energy demand such as demand for biobased energy and security of energy supply. Even the opposition to waste incineration agrees on that energy utilising is better than landfilling but the anxiety over pollutants formed by incineration is a stronger argument against. The opposition advocates reuse and recycling. Since gasification is not well known by people in general it is regarded as incineration even though it has the benefit of not creating dioxins. Consequently, both sides have good and important arguments and they have one argument in common; reduction of pollutants and toxic substances in society.

Incentives must be created in order to make recycling and energy recovery more attractive then landfilling. Taxes are one way, regulations another. This study shows that both ways are necessary. There also has to be a demand for the products. The demand for heating is less in southern Europe than in the northern parts but electric power and automotive fuels are requested all over the world. The results of this study show that production of automotive fuels from waste has potential to be an environmentally and economically good solution in the future. With a gate fee of fully 50 EUR/ton the cost for the automotive fuel is in parity with the price of diesel oil. The assumed gate fee is not very high and in some countries waste fees of 100 EUR or more are common. By further optimisation these results can be improved to give margins to profit and fuel tax. Since the produced fuel is based mainly on biomass this part should be exempted from fossil fuel taxes.

The gasification technology for solid biofuels need to be further developed and the high investments required and the lack of demonstration plants are important barriers. The growing interest for gasification of pure biomass, such as forest residues, for automotive fuel production might though lead the way for waste as well.

Changes in the waste regulations are requested. For example, MSW is not accepted as a biofuel even though typically 80% of the content is biomass. This needs to be changed.

The major barriers within waste thermal treatment are non-technical, more stringent demands can technically be achievable to almost any level of the penalty of rapidly increased cost of treatment. However, alternative treatment procedures (composting, biogas) entail the risk of even higher costs of treatment, as large masses of residues requiring post-treatment are generated. Incineration of these can become a necessary part of such WtE installations.

The not utilised energy in MSW and industrial manufacturing waste put on landfills in Europe is estimated to have a potential to replace 4.5% of the diesel and petrol fuel in Europe. This is a large potential and could be increased in a long term if new waste-to-motor fuel plants replace old incineration plants.

Participants in a network for increased use of energy from waste should represent waste management, energy companies, municipalities, governments, politicians and the EU-administration. Even the manufacturing industry should be represented as they are in FEAD. The main task for the network should be to clarify conditions and data as a source of information and open discussion. Politicians and the public need more information. Politicians need tools and facts to be able to make correct decisions on waste and energy issues. Therefore trustworthiness and reliability should be fundamental. The network should work for exchange of reliable information and support and fund research and cooperation between the waste sector and energy sector. Gasification technology for solid biofuels needs support for further development

The network should also work for equal market conditions for energy from waste by the following activities:

- Stimulate more commercialism and private enterprises.
- Stimulate internal trade within the EU
- Create stable political conditions
- Make it possible to utilise waste as mainly a biofuel
- Question the waste hierarchy
- Include power from waste in the system for Green certificates for electric power
- Introduce equal emission regulations for different energy plants
- Clearly define the difference between recycling and destruction
- Introduce landfill tax to direct waste quantities from landfills to recycling alternatives, e.g. incineration.

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