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Opportunities for a 1,000 MW$_e$ biomass-fired power plant in the Netherlands

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CONTENTS

page

CONTENTS (continued)

FOREWORD BY THE AUTHORS

In researching this report we made a challenging journey in exploring the possibilities of sustainably building and operating a 1,000 MW_e biomass-fired power plant in the Netherlands. This exploration was conducted on behalf of Greenpeace Netherlands and was co-funded by E.ON Benelux. It was not an easy journey since much information had to be combined, weighted, extrapolated and presented in a way which will challenge stakeholders in the market to continue their own explorations towards a more sustainable society.

We are aware of the fact that many publications explore the sustainability of bio-energy in negative and positive ways. We encourage an open mind to all points of view in the debate in order to make well-balanced decisions during the journey to sustainable energy supply. However, we reject the attitude of looking only at negative aspects, since this denies new developments in technology and approach the chance to prove themselves. In this era of energy transition towards more sustainable systems, today's problems must be tackled without creating new problems. We hope that our study will be a contribution to the conversion from challenge to reality.

We thank Greenpeace Netherlands for their courage in launching the exploration towards a bigger role for biomass in Dutch society. We want it to be a sustainable role, and will do our utmost to contribute to that.

The authors

FOREWORD BY GREENPEACE AND E.ON

The report “Opportunities for a 1,000 MW_e biomass-fired power plant in the Netherlands” investigates a sustainable and renewable alternative for the new build of a conventional gas or coal fired 1,000 megawatt power plant in The Netherlands. Greenpeace initiated this study in the summer of 2004, following calls for new investments in base-load power production. Challenged by Greenpeace, E.ON Benelux co-funded this study.

To prevent dangerous human induced climate change, Greenpeace campaigns to achieve a 100% renewable and highly efficient energy system. Notwithstanding the focus of this study on supply-side and fuel, strong measures are needed on the demand-side to achieve 100% sustainability. Super-efficiency and energy-saving can prevent the need for an extra 1,000 MW_e power plant in The Netherlands[1]. Energy policy in The Netherlands should encourage this as a top priority.

Unfortunately, electricity companies all hint at the new build of conventional power plants, based on natural gas and coal. None of these are an acceptable option for Greenpeace. This study focuses on a renewable source of energy which can equally well meet base-load demand: biomass. Large amounts of energy are still wasted each year because the heat, which is produced when generating electricity, is not used for industrial, agricultural or domestic applications. This blind spot in the general orientation of energy policy sadly results in a low overall efficiency of *any* type of thermal conversion process, regardless of fuel-type.

Challenged by Greenpeace, E.ON Benelux co-funded this study. E.ON Benelux acknowledges that this study has shown that a 1,000 MW_e biomass-fired power plant is theoretically technically feasible. However, according to E.ON Benelux, extensive research is needed before the construction of such power plant can become a reality. E.ON does not endorse all the basic principles set by Greenpeace, mentioned in chapter 7.4.

Amsterdam, August 2005

Joris Thijssen	Kees Korevaar
Greenpeace Netherlands	E.ON Benelux

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[1] Source: ‘*Elektriciteitsbesparing als alternatief voor de bouw van nieuwe centrales*’, (Greenpeace/Ecofys, July 2004)

EXECUTIVE SUMMARY

An investigation carried out by KEMA on behalf of Greenpeace looked at the possibility of building a 1,000 MW_e power plant using biomass as a fuel. The motivation for starting the study was a discussion about to take place in the Netherlands on the necessity for expanding existing centralised power capacity. The investigation was intended to offer a CO_2-neutral solution to the discussion on power plant capacity extension. This report contains information useful for stakeholders involved in power production, with a summary giving answers to the questions put forward by Greenpeace. All information given here is based on existing knowledge available in the public domain. Within the scope of this report no in-depth investigation could be carried out and therefore many questions could not be answered in great detail. The main aim of the report is to give an overview of what the chances are for large-scale conversion of biomass to electricity, preferably in combination with heat-distribution.

Is it possible to build a 1,000 MW_e biomass-fired power plant within 10 years?

It is technically possible to build and operate a 1,000 MW_e power plant fired with biomass. The power plant would consist of four units of 250 MW_e each, based on fluidised bed technology. The largest (partially) biomass-fired power plant operating at present is the 240 MW_e plant of Alholmens Kraft in Pietarsaari, Finland. This power plant is regarded as the reference point. It started operation in 2001 with technology based on atmospheric circulating fluidised bed combustion and is able to fire a wide range of biofuels. A combination of wood residues, peat and coal (indication 10%) is burned. Since the plant is located at a pulp and paper mill, the heat is also used for paper processing and district heating. Based on the Pietarsaari model, a gross electric efficiency of 43% is possible. Since ash content and ash behaviour of biomass is less predictable than coal special attention has to be paid to the operational performance of the fluidised bed. A serious alternative, although no large-scale biomass-fired examples are available, is entrained flow combustion in combination with a fixed bed burn-out zone (grate), as used in (old) coal and lignite-fired power plants. The main advantage of this is the lower ash production. It is also expected that possibilities for reusing ash waste will increase. At the moment combustion technologies are the only large-scale solutions available for the conversion of biomass into electricity. Anaerobic digestion cannot operate at the demanded scale. Gasification, pyrolysis and several other upcoming technologies are not yet commercially available at the required scale.

Can a biomass-fired power plant be operated within acceptable emission levels?

In order to operate a power plant within the emission limits large-scale operation is an advantage. Temporary changes in the fuel quality are levelled and appropriate flue gas cleaning equipment can be installed. By selecting the biofuels in combination with a fuel certification system, the level of incoming potential polluting components can be controlled. Next to this primary measure secondary measures can be taken within the combustion process, lowering the levels of dust, CO, C_xH_y and more complex hydrocarbons, NO_x and SO_x. The flue gas cleaning takes care of the final emission reduction by a combination of dedusting, SNCR and SO_x capture. Adding some coal to the biomass improves the sulphur/chlorine ratio, thus enabling higher steam parameters without a considerable increase of SO_x due to limestone addition in the bed.

Is there enough biomass available to fire a 1,000 MW_e power plant?

Firing a 1,000 MW_e power plant requires a large amount of biomass. Assuming wood pellets to be the main fuel, each year 3.7 million tons of biofuel would be needed for one plant. The equivalent in coal would be 2.6 million tons. The potential of biofuels worldwide is big. In the most positive scenario it is estimated that in the long term, worldwide, 1,100 EJ (10^{18} J) could be produced for energy purposes on top of the production of biomass for feeding and material purposes. More realistic scenarios focusing on the short term biomass residues, both forest and agro, already available, lie in the range of 40 EJ. Using this amount around 550 power plants could be fired at a 1,000 MW_e scale. In Finland attempts have been made to harvest wood residues not used in other ways, for sustainable energy applications by 2010. An equivalent value of around 400 MW_e is expected to be harvested. To conclude, although the potential of biofuel is expected to be huge, this does not mean that the fuel is easily available. The development of an economically sound and sustainable supply chain is the biggest challenge involved in the development of a 1,000 MW_e biomass-fired power plant.

Challenge 1 Develop a large-scale (inter)continental sustainable biofuel supply chain

What is likely to be the most suitable biofuel for the power plant?

Due to the size of the power plant, national biomass resources in the Netherlands will not be able to meet the biofuel demand, fulfilling only 10% of the demand in the most positive scenario. Therefore imports will be needed, which are likely to be brought in by ship. Importing virgin solid biomass is neither economic nor energy-efficient, since its energy density is low. A densification process will be needed at the import source. Several technologies like pyrolysis and torrefaction are under development, but at present pelletising looks the most promising possibility. Large quantities of wood residues are produced by forestry, a sustainable industry. Wood residues appear to be the most suitable resource for pelletising. The Netherlands already has experience with this supply chain with Essent and several pellet suppliers. Besides imports of wood residues, the importation of agro residues can also be considered, such as palm fibres, cocoa husks and vegetable oils. Caution has to be taken with not interfering with food applications. The stability of prices is also lower. Therefore agro residues are not recommended to be the base load biofuel. In the long term (indication beyond 2015) energy crops can play a role in supplying the power plant with biofuels.

What is likely to be the most suitable supply chain?
In the supply chain three routes can be distinguished: the long-distance intercontinental route, the continental route and short national routes. Assuming that the power plant is located on the coast or on a large river, in all cases transport by ship is likely to take place, although transportation by train will also be possible.

Biomass residues of national origin can be transported by truck, train and/or river barges to the power plant. Densification will not be required. Caution will need to be taken on interfering with national small-scale applications with larger energy recovery rates achieved by co-generation.

In the case of continental transport, densification at the place of origin will be required, followed by transport by train, river barge and/or coastal carriers. Examples are the importation of wood residues from the Baltic States, Scandinavia, Poland, Canada or Russia. In case of agro residues, the importing of straw from northern France might be a possibility. Intercontinental transport will also require biomass densification at the place of origin, followed by ocean transport and, in addition, depending on the location of the power plant, transport by river barges.

How will the ash residues be used?
After combustion, ash remains in the range of 2 to 5% of the fired biomass’s mass. The ash contains most of the minerals originating from the biomass in a concentrated form, and its reuse as a fertiliser in the area where its biomass grew is the preferred option. Research on ash recycling in forestry and agriculture, thus reducing or making unnecessary the use of artificial fertilisers, is still in its infancy but will be of great importance when large-scale bio-energy applications become more common. Another, but less preferred, way of recycling ash is using it in building materials like cement and fillers. Again, research is required in order to

develop suitable applications. The least preferred way of disposing of the power plant's ash residue is landfill, which can be done in an environmentally sound way but does not reuse the rich material.

Challenge 2 Develop bio-ash recycling and mineral recovery chains

What is likely to be the most suitable location for the power plant?
Since the power plant will be fuelled predominantly with imported biofuels, a location on the coast is preferred, minimising transportation costs. A second advantage would be the availability of low-temperature cooling water, making it possible to operate the power plant at a higher electrical efficiency. However, an important pre-condition for a coastal location is a site large enough for the power plant and biofuel storage areas: at least 50 hectares for a 1,000 MW_e power plant. A brief survey showed that Maasvlakte and Eemshaven offer the best opportunities, followed by Beverwijk and Delfzijl.

Is it possible to operate the power plant in co-generation mode?
From the point of view of energy efficiency a power plant producing electricity and also selling heat would be preferable to a plant producing only electricity. The use of fossil fuels and thus the emission of greenhouse gases would be further reduced. Potential locations with large heat demands were therefore investigated in more detail. In the case of co-generation it is common to size the power plant to the heat demand. A size of 1,000 MW_e is too big for co-generation. A size of 100 to 400 MW_e is more likely to fit. Possible heat applications are district heating, greenhouses and industrial process heat. Either the co-generation plant would be located in areas where new heat demand is developing or in areas where existing heat supply systems can be replaced. Possible locations of interest, additional to the locations mentioned above, are Sloegebied, Geertruidenberg, Moerdijk, Dinteloord, Westland, and locations currently equipped with 'old' gas-fired co-generation plants located near rivers or canals and offering space between 5 and 25 ha, like Utrecht, Diemen or Harlingen.

Challenge 3 Bring heat demand and sustainable bio-energy supply together

What is the expected price of the electricity produced?
The cost of electricity production is the total of all the costs accrued by harvesting, processing, transporting, trading and conversion of biomass into electricity and saleable

heat. Aspects of financing, depreciation, rates, fuel contracts, construction and maintenance, subsidies and CO_2 credits also have an impact. Giving an expected price in this stage is therefore not possible. Some conclusions can be drawn:

- since the biomass import supply chain is more complex and decentralised than that of coal, the fuel costs per GJ are expected to be higher, although compared to natural gas the costs of biomass could be equal
- the costs involved with ash handling and flue gas treatment are expected to be lower or equal to coal, depending on the biofuel composition (assuming that useful applications of the ashes are feasible).

Indication electricity cost price 1,000 MW_e biomass-fired power plant at a fuel price of EUR 6 per GJ	8.2 EURcts/kWhe
Expected value of CO_2 credits on the long run	1 to 2 EURcts/kWhe
Value of MEP* in case of co-firing for a 10 year period (2006/2007)	6.6 EURcts/kWhe
Mean value selling price electricity in free market	3.2 EURcts/kWhe

* Dutch financial support scheme for renewable electricity

Based on the existing financial support scheme the concept is likely to be feasible. The MEP for a 1,000 MWe biomass-fired power plant can be equal to lower than the MEP in the case of co-firing.

The main drivers lowering the costs of bio-power production are:

- biofuel costs at the gate of the power plant
- net electric efficiency
- investment costs power plant.

Challenge 4 Develop mechanisms for lowering the costs of bio-energy in time

What is the sustainable performance of large-scale bio-electricity?

Greenpeace uses criteria to assess the sustainability of the use of biomass on a large scale for electricity production. A brief investigation of to what extent these criteria can be met has been performed. Attention has been paid to:

- energy balance in the bio-energy chain
- carbon neutrality
- bio-diversity
- use of GMOs (genetically manipulated organisms)
- sustainability of plantations and agriculture
- toxicity.

First, attention was paid to the energy balance covering the whole supply and conversion chain. First calculations indicate that the supply chain uses up 10 to 20% of the energy contained in the biofuel. Of the energy available in the biomass at the gate of the power plant, up to 43% can be converted in electricity.

Second, the carbon neutrality of the bio-energy chain was investigated. Since biomass in itself is carbon neutral the bio-energy chain in itself is as well. In the case of forest or agro residues, putrefaction on land and thus accompanying emissions like CH_4, CO_2 and N_20 are less. The use of bio-energy also prevents the emission of fossil origin CO_2. Using bio-residues for energy applications result in a CO_2 sink.

In the third place, attention was paid to the impact on bio-diversity. It was concluded that as long as bio-residues are the main source for fuelling the power plant the impact can be neutral. On the risks of being involved in or promoting genetically modified biomass, the survey was not able to draw clear conclusions. It is assumed that, especially in forestry, genetic modification is not a current trend and therefore is unlikely to influence fuel choice since forest residues are expected to be the main fuel. In the long term, since research is continuing, it may yet be a point of attention.

With respect to sustainable land use, the fifth criteria, it was concluded that in the first place a balance has to be found as to what extent biomass can be extracted from forestry and agriculture without causing soil depletion. In the case of forestry, nutrients and minerals are concentrated in the leaf and bark mass. Leaving these parts of the trees in the forest to a certain extent enables sustainable forestry. Secondly, by recycling bio-ash minerals the chain can be closed even further. Finally, toxicity was assessed as important criteria. Through the application of suitable technology the potential toxicity of the energy conversion process can be controlled. No explicit toxicity is expected within the supply chain, especially in the case of bio-residue use.

Challenge 5 Assess large-scale bio-electricity sustainable performance in more detail

What are the environmental benefits of a 1,000 MW_e biomass-fired power plant?

A 1,000 MW_e biomass-fired power plant operated in base load will result in benefits like:

- a CO_2 emission reduction of 5 Mton/a due to the replacement of 2.25 Mton coal (η=0.46), double the target of the Dutch Coal Covenant and roughly a 10% emission reduction in the power sector. The reduction is equal to 17% of the Dutch Kyoto target
- a renewable electricity production of 7 TWhe/a, almost 100% of the bio-energy target in 2010, 50% of the bio-energy target in 2020, 22% of the renewable energy target in 2020, and 2.2% of the demand for energy in the Netherlands in 2020.

Conclusions

- It is technically possible to build and operate a 1,000 MW_e biomass-fired power plant in the Netherlands, using today's environmental standards.
- The most likely technology to be used in the short term is fluidised bed combustion. Four units of 250 MW_e each would be required, the largest available at present worldwide.
- Since a large biomass volume of 3.7 million tons a year will be needed to fire the power plant, the biggest challenge will be to develop a sustainable supply chain.
- The most likely fuel to be used would be wood residue.
- The fuel would have to be imported. The most efficient way to transport fuel long-distance is to send the wood residues as pellets. Although the market is not able to supply the requested volume at the moment, there is enough potential to do so.
- Suitable areas of origin are the northern part of Europe and the Americas.
- In creating a sustainable bio-energy chain special attention will have to be paid to ash reuse in the countries of origin, optimising the energy consumption along the supply chain, and sustainable forestry.
- Suitable locations in the Netherlands for the power plant are situated on the coast. Maasvlakte and Eemshaven offer the best opportunities.
- Instead of building one big power plant it is preferable to build several smaller ones aiming at delivering electricity and heat at the same time. Although today's policy incentives to do so are poor, this is the best way to maximise energy efficiency and thus prevent CO_2 emissions.
- The electricity cost price of the 1,000 MW_e concept is lower than small-scale bio-energy and higher to equal than co-firing, with the potential to be competitive. When successful, a CO_2 emission reduction of 5 Mton/a and a renewable electricity production of 7 TWhe/a could be realized.

Fact sheet: 1,000 MW_e biomass-fired power plant

Topic	Figures
Land use	1.5 to 2.0 million ha (15,000 – 20,000 km^2), based on wood residues, (rough indication)
Fuel need	3.7 Mio ton biomass per year 530 ton/h 63 PJ energy content (assumed calorific value 17 MJ/kg, wood pellets)
Installed power	2,500 MW_{th}, heat input 1,000 MW_e, electricity output (assumed net electrical efficiency 40%)
Preferred technology	Fluidised bed combustion, 4 units of 250 MWe each
Power production	7 TWhe per year (in case of no heat production at 7,000 operating hours)
Co-generation Potential	4.4 TWh thermal per year and 5.3 TWhe (assuming 50% heat recovery efficiency and 3,500 operating hours)
Ash production	150 kton per year (assumed biomass ash content of 2% and contribution from the bed material 2% [lower than coal])
Emissions to air	Lower than / comparable to coal.
CO_2 reduction	5 Mton per year compared to a 1,000 MWe coal-fired plant 2.6 Mton per year compared to natural gas (indication).

ABBREVIATIONS AND DEFINITIONS

Anaerobic digestion **[in Dutch: Vergisting]**
A biological process converting biomass into biogas, a gas mainly consisting of CH_4 and CO_2.

Co-firing **[in Dutch: Bijstoken of meestoken]**
A type of process where either coal is replaced by biomass directly and the coal/biomass mixture is fired in the same boiler (meestoken) or where a separate unit for combustion, gasification or pyrolysis is build using biomass as a fuel (bijstoken). The energy content of the hot flue gases (in case of combustion) or biomass combustibles (in case of gasification or pyrolysis) is used to generate steam.

Co-generation **[in Dutch: Warmte-krachtkoppeling]**
A type of power plant where in addition to electricity useful heat is also produced, resulting in less wasted heat release and thus the need for less cooling water, realising a higher overall-efficiency of energy conversion. Examples of co-generation (CHP) are in small-scale gas engines in greenhouses; on a large scale power plants supplying heat to district heating systems or process industry.

Combined cycle **[in Dutch: STEG, stoom en gasturbine installatie]**
A type of power plant where a steam cycle is integrated with a gas turbine cycle, thus improving electricity efficiency up to 55% in the case of natural gas firing.

Combustion **[in Dutch: Verbranding]**
An exothermic thermal process where biomass is converted into a hot flue gas in order to produce steam or hot water. Combustion is done with excess air converting all organic compounds into mainly CO_2 and H_2O.

Entrained flow combustion **[in Dutch: Stofwolk verbranding]**
The biomass is combusted in a free vertical airflow. The biomass particle size is smaller compared to that used in fluidised bed combustion.

Fixed bed combustion **[in Dutch: Vastbed verbranding]**
Fuel is combusted in a slowly downward moving self-sustained bed. Drying, pyrolysis and combustion zone can be distinguished. Combustion air can be fed co-current (downdraft) or countercurrent (updraft) to the bed movement.

Fluidised bed combustion **[in Dutch: Wervelbedverbranding]**
The biomass is combusted in a fluidised state, floating on a vertical airflow within a sand bed. The biomass particle size is smaller compared to fixed bed.

Gasification **[in Dutch: Vergassing]**
An exothermic thermal process where biomass is converted into a combustible gas mainly consisting of H_2, CO, and CH_4. Gasification is a kind of incomplete combustion where just enough air, oxygen or steam is used to keep the gasification process going.

Grate firing **[in Dutch: Rooster verbranding]**
Fuel is combusted on a bed, and often during the combustion process is moved slowly in a horizontal way towards the ash pit.

Pyrolysis **[in Dutch: Pyrolyse]**
An endothermic thermal conversion process under the exclusion of air where combustible fluids, gases and solids are produced. Used as a thermal pre-processing step to improve the quality of the fuel.

Torrefaction **[in Dutch: Torrefactie]**
An endothermic thermal conversion process where mainly combustible solids are produced. Used as a thermal pre-processing step to improve the quality of the fuel. Torrefaction is less intense than pyrolysis.

MW_{th}	Megawatt thermal power representing the fuel input or heat available
MW_e	Megawatt electric power output
MVA	Mega volt ampere
EJ	1,000 PJ, energy value often used on world scale
PJ	1,000 TJ, energy value often used on country scale
TJ	1,000 GJ, energy value often used on plant scale
GJ	1,000 MJ, energy value often used on household scale
MJ	1,000 kJ
1 kWh	3.6 MJ
1 TWh	3.6 PJ
1 MJ	0.278 kWh
a	annual
ton	1,000 kg
M	Mega, 1×10^6, 1 million

G	Giga,	1 x 10^9, 1 billion
T	Tera,	1 x 10^{12}
P	Peta,	1 x 10^{15}
E	Exa,	1 x 10^{18}

ABFB	Atmospheric bubbling fluidised bed
AOO	Afval overleg orgaan (Dutch for ‘Waste consultation body’)
BAT	Best available technology
BEES	Besluit emissie-eisen stookinstallaties (Dutch for ‘Decree emission requirements for furnaces’)
BFB	Bubbling fluidised bed
BOOM	Besluit kwaliteit en gebruik overige organische meststoffen (Dutch for ‘Decree quality and use other organic fertilisers’)
BVA	Besluit verbranden afvalstoffen (Dutch for ‘Decree waste incineration’)
CBS	Centraal bureau voor statistiek (Dutch for ‘Central bureau of statistics’)
CFB	Circulating fluidised bed
CH4	Methane
CHP	Combined heat and power
CO	Carbon monoxide
CO_2	Carbon dioxide
C_xH_y	Hydrocarbons
EIA	Environmental impact assessment (in Dutch MER)
ELV	Emission limit values
ESP	Electrostatic precipitator
EWAB	Energiewinning uit afval en biomassa (Dutch for ‘Energy production from waste and biomass’)
GAVE	Gasvormige en vloeibare klimaatneutrale energiedragers (Gaseous and liquid climate neutral energy carriers)
GMO	Genetically modified organisms
H_2	Hydrogen
H_2O	Water
H_2S	Hydrogen sulphide
HCl	Hydrogen chloride
HF	Hydrogen fluoride
Hg	Mercury
HTU	Hydro thermal upgrading
IGCC	Integrated gasification combined cycle

IPCC	Intergovernmental panel climate change
IPPC	Integrated pollution prevention and control
IRR	Internal rate of return
LCPD	Large combustion plants directive
LHV	Lower heating value
MEP	Milieukwaliteit elektriciteitsproductie (Dutch subsidy scheme for electricity)
MSW	Municipal solid waste
N_2O	Nitrogen dioxide
NO_x	Nitrogen oxides
PCFB	Pressurised circulating fluidised bed
PkbNR	Nota Ruimte (Dutch for ‘Note on town and country planning’)
SCR	Selective catalytic reduction
SEV	Structuurschema elektriciteitsvoorziening (Dutch for ‘Structural scheme electricity supply’)
SGR2	Structuurschema groene ruimte (Dutch for ‘Structural scheme green space’)
SNCR	Selective non-catalytic reduction
SO_x	Sulphur dioxide
TEQ	Toxicity equivalent
VA	Vereniging afvalbedrijven (Dutch for ‘Association of waste companies’)
VOS	Volatile organic substances
WID	Waste incineration directive

1 INTRODUCTION

In the Netherlands, discussion of the necessity to extend power plant capacity is increasing. An important issue within this discussion is the type of fuel. Since Greenpeace's philosophy is that if more electric power is needed this should be generated in the most sustainable way possible, Greenpeace addresses the topic of large-scale power generation by biomass combustion. One of the large electricity producing companies in the Netherlands, E.ON Benelux, joined the project as a co-funder due to its involvement in bio-energy and due to the opportunities that their power plant site Maasvlakte offers for extension. Greenpeace asked KEMA to conduct a survey of the possibilities for a 1,000 MW_e biomass-fired power plant with an eye to the opportunities and issues to be taken into account during the development of the concept toward realisation.

Goal

The goal is to assess the feasibility of a biomass power plant by a considering the possibilities for a 1,000 MW_e biomass-fired power plant in the Netherlands. In the assessment Greenpeace's constraints for sustainable bio-energy projects were to be taken into account, and attention was to be paid to a more decentralised approach to create better conditions for co-generation.

Rationale of large-scale bio-energy in the Netherlands

Of the renewable energy sources, wind, geothermal and bio-energy offer the biggest potential in the Netherlands. Bio-energy is expected to fulfil 50% of the national renewable energy goal in 2010 (*Actieplan Biomassa, samenwerken aan bio-energie*; Ministerie van Economische Zaken, 2003). At present wind power is developing rapidly and it is expected that in the future all acceptable land locations will be used and that offshore wind generation will take the lead. Since biofuels can be stored and are always available for use, bio-energy can be produced when required. Bio-energy could be integrated widely in Dutch society without using too much land in the Netherlands for energy crops when import is considered. Its behaviour in terms of power-producing capabilities is therefore highly comparable with traditional power production by natural gas, coal or nuclear. When it becomes possible to realise a 1,000 MW_e biomass-fired power plant contributing substantially to CO_2 emission reduction goals without affecting existing power infrastructure too heavily, this will be a renewable energy option worth exploring in more detail.

Concept

Using biomass as a fuel for electricity and heat production on a 1,000 MW_e scale would be its largest use to date, as nowhere else in the world are power plants operated using biomass on this scale. The plant would need to be located at a site where huge amounts of biomass (indication: more than 4 million ton/a) can be handled. Cooling water has to be available in sufficient quantities. Waste heat should also be used in industry or for other heating purposes, thus increasing the efficiency of the biomass in energy conversion. The biomass itself must be of sustainable origin, not competing with the food chain or other product chains. It has to be as clean as possible and well graded to guarantee the proper operation of the plant and low emissions. The plant would use well-proven technology available on the world market today. To be able to meet the latest emission standards, in this case normal for large-scale coal-fired power plants, proper flue gas cleaning equipment needs to be included in the plant's design.

Project approach

The main aim of this project is to get a general idea of all aspects involved when biomass is used for electricity production on a 1,000 MW_e scale. Based on the literature and practical experience the following topics are addressed:

- biofuel and logistics
- power plant technology
- economics
- location(s) and permits
- sustainability
- alternative approaches.

The approach of this report is not an in-depth investigation of the feasibility of a biomass-fired power plant, but to describe the concept as completely as possible by addressing the opportunities it offers for renewable energy in the Netherlands and biomass trade worldwide. By addressing the issues for further investigation the report aims to be the first step towards the realisation of a biomass-fired power plant comparable in size to planned conventional power plants, either on one location or in a more decentralised way, on a smaller scale at several locations, aiming at co-generation as much as possible. The defining points of reference for a 1,000 MW_e biomass-fired concept are examined below.

2 FUEL

2.1 Types of fuel

The fuel for the biomass-fired power plant should preferably be of 100% biomass origin and have a short CO_2 cycle, preferably yearlings or energy crops. Eligible types of biomass are agro residues such as olive residue, cocoa shells, sunflower residues, and wood or wood-derived fuel such as sawdust and wood pellets.

The biomass may be used directly in the energy conversion system, or can be converted to a more suitable form. When considering a type of fuel, one should take into account whether it is in solid, liquid or gaseous form. An advantage of liquefied fuels (bio-oil) is their higher energy density compared to the original solids, thus requiring less space when being transported. However, liquefied fuels are considered more appropriate as transport fuel. Long-distance transport of gases such as methane, hydrogen and carbon monoxide is expensive when no pipeline is available. Since solid biomass fuel is most abundant it is justified to focus on solid fuels.

A list of potential types of solid biomass and residue streams for the biomass-fired power plant is given below.

Examples of energy crops:
- short rotation wood
- cole seed (from rape)
- *Miscanthus*.

Examples of biomass residual streams:
- wood from fruit sector and tree nursery
- wood by-products from wood industry
- forestry by-products
- agro by-products (straw, hay, hemp and flax).

Examples of biomass, possibly polluted:
- (fresh) clean residue wood, including bark
- roadside grass
- garden and fruit residues (separately collected)
- construction and demolition wood.

2.2 Potential and availability of biofuels

Firing a power plant at a 1,000 MW_e scale will require a large effort where fuel is concerned. More than four million tons of biofuel (17 MJ/kg) will have to be harvested, collected and transported to the plant each year. To give an indication of what such a figure means, in the Netherlands combustible household waste is fired in eleven waste-to-energy plants. Their total capacity is 5.5 million ton/a (VA, AOO, CBS, 2003). The coal-fired power plants in the Netherlands consume approximately 7.5 million ton/a coal (EnergieNed, CBS). The annual production of wood pellets worldwide is roughly three million ton/a (Wood pellet conference, 2004) with growth expectations up to 200% in 2010 resulting in a capacity of nine million ton/a. The principal question concerning biofuel is whether there is enough fuel available at an acceptable price to fire a 1,000 MW_e plant? In order to answer this question a deduction has to be made from international potential to indicate national actual availability.

International potential biomass for energy applications.

The GRAIN study on biomass availability for import to the Netherlands investigated the potential the Earth offers for biomass production (UU, NOVEM 2001, EWAB/GAVE). Table 2.1 gives an overview of the main results. The overall result shows a very wide range from 40 to 1,100 EJ. The lower figure is based on residues already available but not used in an optimal way. The upper figure is the result of a ‘redesign’ of worldwide land use in which more space is created for energy farming and less space for food farming, without jeopardising the world’s food supply and need for biomass materials.

Table 2.1 Biomass potential of the Earth (GRAIN, 2001)

Topic	Figure, range
Energy consumption worldwide	390 – 410 EJ/a
Bio-energy consumption (mainly firewood)	35 – 55 EJ/a
International potential worst case	40 EJ/a, residues only
International potential best case	1,100 EJ/a, including intensive energy farming
Indication forest residues worst case	14 EJ/a, limited use of forest residues, 25%
Indication forest residues best case	110 EJ/a, technical potential

The international potential in the best-case scenario for biofuels is 1,100 EJ/a. This is almost three times today’s worldwide total energy consumption.

Actual international potential

The actual international potential within the framework of this study focuses on the availability of residues. These biomass streams are likely to be made available in the mid-term (within five years) without having to arrange the use of land in another way. The figures are based again on the 2001 GRAIN study. Four categories of biomass residues are distinguished:

– forestry residues	14 – 110 EJ/a
– food production residues	approximately 15 EJ/a
– manure	5 – 55 EJ/a
– organic waste (including MSW)	5 – 50 EJ/a

(The import of biogas from, for instance, Russia is not feasible since a separate pipeline needs to be constructed which would be very expensive. The biogas needs to be methane without corrosive components such as CO_2 or H_2S. This would require an expensive gas treatment plant. The gas would also be generated from many small plants, expensive to connect to the main pipeline and difficult to control for constant gas quality.)

Forestry and food production residues are the two most promising categories because of their energy content and chemical composition.

For large-scale applications manure is not suitable since manure is mainly used for anaerobic digestion purposes on a small scale. The energy content of manure is low, which indicates that it would be more efficiently used in energy applications close to where the producing animals are. Import of manure for energy purposes is thus not likely to happen.

Organic waste streams consist of a large variety of residues, often heterogeneous in nature and containing potentially hazardous components. It is therefore preferable to convert these waste streams to electricity and/or heat in dedicated plants like Municipal Solid Waste (MSW) incinerators when material reuse is not possible. For large-scale applications such as investigated in this study organic and residual streams are therefore excluded as a fuel.

The actual international potential based on forest and food production residues is approximately 29 EJ/a in a worst-case scenario. A study conducted by SEI/Greenpeace in 1993 (Stockholm Environmental Institute, 1993) indicated a potential of 10 EJ/a of food production residues. In order to fire the 1,000 MW_e plant with biomass, 63 PJ/a (1 EJ = 1,000 PJ) would be needed. The actual international potential of biomass residues is thus far more than the fuel demand of the power plant.

Actual international availability

The actual international availability can be subdivided into food residues and forest residues. Today, coal-fired power plants in the Netherlands already import biomass, in the form of, for example, wood pellets, food residues, olive cake and palm oil. It takes a considerable amount of effort for Dutch power plants to collect biomass for co-firing applications at a reasonable price and quality. Biofuel prices are increasing since demand-side developments are going faster than supply-side developments. However, it is expected that a balance between supply and demand will be possible at a reasonable price level since growth at the supply-side is still possible to a considerable extent. As an example, a study *Identifying environmentally preferable uses for biomass resources* (Envirochem, 2003) indicates that in Canada 92 Mton/a of non-stem wood is available each year as biomass. These wood residues are not harvested at present. It is obvious that for economic reasons and the sustainability of the mineral and nutrient cycle not all residues can be used for energy applications (see also section 7.4). The timber industry also produces residues, estimated at approximately at 6 Mton/a in Canada alone. But long transportation distances can make the use of these residues unfeasible. Agro residues are available worldwide at an amount of 18 Mton/a and not used. The conversion from ‘potential’ to being available is a matter of supply chain development within the boundary limits of economics and sustainability.

Next to Canada, other continents of interest for biomass supply are:

- Northern America
- Southern America
- Western Africa.

In all cases special attention has to be paid first to the local biomass demand for energy applications. Countries with a relatively high wood production per capita are likely to be the most promising export countries on the long run. Tropical countries offer big biomass growing rates but require special attention to sustainable forestry.

Availability of biomass in Europe

Looking for biomass in Europe, several areas of interest can be identified, such as:

Finland	forestry residues
Sweden	forestry residues
France	agricultural residues
Baltic states	forestry residues
Russia, Poland	forestry residues.

In the Scandinavian countries the use of biomass is optimised to a high extent, but the use of biomass for energy applications can be extended further. In Finland a national programme (Wood Energy Technology Programme 1999–2003) aimed at an increased production of wood chips. An extension potential of 8 TWh/a (29 PJ/a) was indicated from a present use of 23 TWh/a in 2001 (VTT ENERGY, 2001, figure 27, p31). The source of the potential is wood residues not yet harvested. The amount is limited by economic conditions and sustainability constraints. Some effort is made to assess the impact of biomass removal on forestry.

In Sweden it was concluded that full use of all sawmill by-products, such as bark, dry chips and sawdust, offers a potential of 6.9 million ton/a (Renewable Energy World, 2003). The actual production is 0.7 million ton (Journey through Europe, publication of pellet conference, Wels, Austria, 2004).

Although the potential is huge, the market for the production of pellets in the Baltic States, Russia, Poland and other eastern European countries is still developing. Production is only for export, and depends on the world demand for wood pellets developed by these new pellet-producing countries. As an example: for Estonia it is estimated that roughly 4 PJ of wood residues are available which are still not used.

Next to forestry residues agricultural residues offer opportunities. For example, straw is an energy source used in Denmark to a high extent. In 2004 0.8 million ton of straw, equivalent to 12 PJ, was used for energy applications. In France however the potential available in the northern part of France is hardly used. Since straw is less dense, resulting in higher transportation costs per GJ compared to wood pellets, it makes sense to use straw at a national level. However, the import of straw pellets by the Netherlands from France is conceivable.

In 2000 88 million tons (as received) forest residues and 112 million tons agricultural residues like straw was produced (EWAB 2000). The direct availability, however, was limited since residues are already used or not available due to the lack of demand.

Availability of biomass in the Netherlands

Compared to other countries the forest industry in the Netherlands is small. The Netherlands has wood reserves of 52 to 55 million m^3 with a growth of about 2.2 million m^3 per year. The amount of wood that can be harvested in a sustainable manner is approximately 1.4 million m^3 per year which is about 60% of the total growth in forests (Stichting Bos en Hout / Stichting Probos, 2002). Only part of this amount is, in principle, available for energy applications. Other sources are agricultural residues and wood residues from the wood processing industry. Often applications are already there or expected to be developed, not only for reuse but also in dedicated bio-energy plants of relatively small scale. It is expected that in the long run (NOVEM 2000a) the national availability of wood and agro residues available for large scale applications in the Netherlands will be limited to approximately 0.4 million ton/a.

2.3 Amount of fuel needed for 1,000 MW_e

A 1,000 MW_e power plant with a net electrical efficiency of 40% demands 2,500 MW thermal input. When the plant is operated for 7,000 equivalent full-load hours per year, 63 PJ/a is needed. The amount of fuel needed can be calculated knowing the heating value which may vary depending on the type of fuel.

Based on a heating value of 17 MJ/kg (wood pellets), about 3.7 million tons of biomass are needed. Since this amount is not available in the Netherlands as a sustainable fuel, imports are needed.

The cost of transport is usually linked to either the bulk weight or the bulk volume. Both weight and volume are related to the bulk density, which in turn is related to whether or not the fuel is compacted as well as to the moisture content. Table 2.2 below shows that the bulk density has a great impact on the volume of the amount of fuel.

Fuel long-distance transport is usually by ship. Even when a power plant is built inland, a location nearby or at the riverside is often chosen for cooling water availability. Sea-going ships can transport about 100,000 tons and river-vessels have a capacity of about 1,000 tons. So, depending on the fuel, 50 to 200 sea-going ships are needed and/or 5,000 to 20,000 river-ships (100 river-ships per sea-ship).

Fuel supply logistics is thus a major issue. Densification of the energy content of the biomass is one way to solve the problem of mass and costs. This can be accomplished by physical methods such as drying and pelletising or by thermal pre-treatment such as torrefaction, carbonisation or pyrolysis. Thermal pre-treatment methods have the additional added value of retarding the decay processes. The technology for these processes has not yet been proven on the required scale in an environmentally sound way.

Table 2.2 Biomass fuel density and calorific value

fuel type	bulk density	energy density (LHV)	energy density (LHV-bulk)	volume for 63 PJ
	[kg/m^3]	[GJ/ton]	[GJ/m^3]	[million m^3]
Sawdust (wet)	367	8.0	2.9	21.5
Sawdust (air dry)	267	14.0	3.7	16.9
Woodchips (wet)	550	8.0	4.4	14.3
Woodchips (forest dry)	400	12.0	4.8	13.1
Wood pellets	705	17.0	12.0	5.3
Forest residues	340	11.6	3.9	16.0
Torrefied wood pellets	650	22.0	14.3	4.4
Straw	130	14.5	1.9	33.4
Straw pellets	600	15.0	9.0	7.0
Charcoal (ground)	500	30.0	15.0	4.2
Coal (bituminous)	1,100	24.4	26.8	2.3

2.4 Worldwide availability and prices

Agro residues

Agro residues such as palm fibres, olive cake, cocoa shells, soy bean and sunflower residues are available in considerable amounts on the world market. Their main application is the animal food and the compost and fertiliser industries. The price depends on availability, which can vary per year and per region.

Typical prices vary between 75 EUR/ton and 150 EUR/ton with a heating value of about 17 MJ/kg, resulting in a price between 5 and 10 EUR/GJ. Soy residue with prices above 200 EUR/ton is the most expensive due to its high added value for the animal food industry. Normally, the prices of agro residues in combination with their availability are too high to be of interest for large-scale power applications. The market price is very sensitive, and occasionally the spot market offers low prices and is therefore interesting to power plants. Long-term contracts are not common. In section 4 attention is paid to biofuel prices and contracts.

Wood and wood-derived fuel

Wood for energy applications is available in many forms using virgin material or as a residue stream. Sawdust and wood pellets are currently used as co-firing fuel in large-scale applications in the Netherlands.

Typical prices for wood pellets are around 100 EUR/ton at 17 MJ/kg and range from 85 to 110 EUR/ton. Wood residues qualified as polluted biomass vary from 0 to 20 EUR/ton depending on the quality and contamination (not 100% biomass). Although cheaper, they require a more expensive energy conversion system resulting in electricity production costs which are equal to higher compared to wood pellets (ECN, 2004b).

2.5 Purpose-grown biofuel

In the Netherlands willow, poplar, *Miscanthus* and hemp are the main energy crops grown. All purpose-grown fuel is directly used and not available for sale to third parties. All the projects can be identified as demonstration projects. No large-scale energy crop applications are known. Energy crops are used in small-scale biomass-fired co-generation plants or district heating plants (NOVEM 2000c).

2.6 Conclusion

Based on the information on biofuels expected to be available on the world market for large-scale applications and the criteria put forward by Greenpeace, a biomass hierarchy has been defined for fuelling the 1,000 MW_e power plant.

Step 1 Base load with imported wood residues

The base-load of the power plant would be preferably taken care of with wood residues, meaning residues which are already available in today’s forestry industry but not used to a large extent. Due to the high demand (inter)continental import would be required. This can be done in the most efficient way by using wood pellets. Continental import would be preferred above intercontinental import, since the transport distances are smaller and thus the economic and environmental performance would be better. However, to be flexible in trade intercontinental import is likely to occur too as far as the efficient harvesting and processing of the biomass makes it possible. In principle, wood residues, although the market is not developed, would be able to fulfil the fuel demand of 3.7 million ton/a (based on wood pellets, 17 MJ/kg). Scandinavia, the eastern part of Europe and the northern part of America are likely to be the initial import countries.

Step 2 Nationally available biomass residues

In addition to imported wood residues nationally available biomass, not already used in food or product chains and with a fuel quality comparable to or to a certain extent lower than wood residues, can be used. The important conditions are that the biomass residues have to fit within the operational window of the power plant and that these residues are not already applied elsewhere with high energy conversion efficiencies like for example co-generation. It is expected that national available and suitable biomass will never exceed 0.4 million ton/a.

Step 3 Internationally available agricultural residues

Wood residues can be replaced by agricultural residues if there is a surplus of agro residues in the world market with no efficient local applications. Only in this way will negative interaction with the food chain be avoided, and prices of agricultural residues are likely to be competitive with wood residues. In comparison with wood residues agricultural residues availability is less predictable, since supplies of high quality agro biofuel like, for example, palm oil may change without warning, leading wildly fluctuating prices. For example, the price of palm oil differed from 345 EUR/ton to 450 EUR/ton in 2004 (SenterNovem, 2004).

Production of agro residues is determined by the seasons, which make transport and storage more complicated. It is expected that the available agro residues based on spot market purchase never will exceed an amount of, as an indication, 1 million ton/a. Agro biofuel can be both solid and liquid, like for example straw, palm fibres and palm oil. Importation is likely to take place from Europe (straw) and other continents as long as it is cost-effective and environmentally sound.

Step 4 Energy crops in the long term

In time it is likely that energy crops, when available residues are reused in the most efficient way and production costs are brought down to acceptable limits, can play an important role in fueling the power plant. Development of the energy crops market has to be carried out with great care, not only because of potential unwanted interaction with the food and bio-material chains but also in relation to the development of a sustainable way of using the soil for energy crop purposes. That is why a long-term approach, beyond 2015, is recommended. At the moment the interest in energy crops is increasing all over the world. In some countries, for example Brazil, with the production of bio-ethanol, the market is already well established.

Finally, it is conceivable, depending on the exact composition of the biofuel package, to co-combust with coal. Sulphur in coal has the ability to abate the risk of corrosion of power plant components caused by the chlorine present in the biomass.

In order to handle such a biofuel package the technology to convert biomass to electricity, although based on wood residues, has to be flexible within limits with respect to heating value, ash content and ash properties and contamination levels. Only in this way can a proper and economic sound operation of the power plant be guaranteed over a long time.

3 TECHNOLOGY

3.1 Introduction

The technological concept has to be proven. This implies that the technology is commercially available. In principle, data from an existing similar plant should be available for accurate operational performance data. Furthermore, the capacity of the individual units (it is unlikely that 1,000 MW_e will be realised as one single unit) will be designed to take advantage of economies of scale and the Dutch regulatory framework to support electricity generation from renewable fuels (MEP-reimbursement).

Conversion technologies

Biomass can be converted to different forms of energy including heat, power, combined heat and power or liquid fuels. There are a number of processes that can be used to convert energy from biomass fuels:

- thermal processes: direct combustion and upgrading of a solid biomass to solids, liquids and/or a gas via pyrolysis or gasification (KEMA, 2002)
- biological processes: decomposition of solid biomass to liquid or gaseous fuels by processes such as anaerobic digestion and fermentation (NOVEM, 2000b).

Thermal processes

Direct combustion

Direct combustion is the most common way of converting biomass to energy, heat as well as electricity, and worldwide it provides over 90% of the energy generated by biomass. The following combustion technologies can be distinguished: fixed bed, fluidised bed and entrained flow combustion (IEA Bioenergy, 2003). Fixed bed combustion systems include, for example, grate furnaces. Primary air passes through a fixed bed, in which, during drying, gasification and charcoal combustion takes place. The combustible gases produced are burned after the addition of secondary air, usually in a zone separated from the fuel bed. In fluidised bed combustion (figure 3.1), the primary combustion air is injected from the bottom of the furnace with such high velocity that the material inside the furnace becomes a seething mass of particles and bubbles (VTT Energy, 2001).

This seething mass consists of both the fuel and a granular inert material (common bed materials are silica sand and dolomite). The basic fluidised bed types are atmospheric bubbling- (ABFB), atmospheric circulating fluidised beds (ACFB) and pressurised circulating fluidised beds (PCFB). Entrained flow combustion is suitable for fuels available as small particles (< 1 mm). Fuels like sawdust and fine shavings are pneumatically injected into the furnace, while the transportation air is used as primary air.

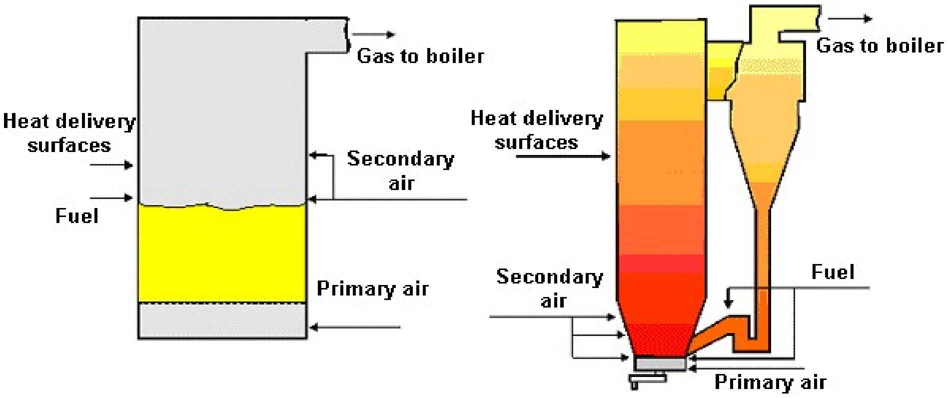

Figure 3.1 Bubbling bed- (left) and circulating fluidised bed combustion (CRES, 2001)

Gasification

During biomass gasification the fuel is converted with a less than stoichiometric amount of oxygen. Solid and liquid intermediates are converted through partial oxidation in a flammable gas. Gasification can be performed at either atmospheric or increased pressure with air, pure oxygen, steam or mixtures of these. The technology options for biomass gasification include fixed bed-, fluidised bed- and entrained flow gasifiers (Juniper, 2001). In fixed bed gasifiers (figure 3.2), the fuel is gasified in a bed layer. The fuel goes through different zones (drying, pyrolysis, oxidation and reduction) where the gasification reactions take place.

Fluidised bed gasification makes use of the positive features of a fluidised bed regarding reaction kinetics, gas-solid contacts and heat transfer. The bed material mainly used is silica sand or the ash of the fuel. The relatively long residence time of the solid fuel (several minutes) and the intensive mixing are the reasons why very high conversion rates are achieved. The basic fluidised types are bubbling- (BFB) and circulating fluidised beds (CFB). Entrained flow gasifiers are practically empty vessels (i.e. do have a small fuel hold-up, residence time several seconds), where small fuel particles are converted at high temperatures (ECN, 2004a).

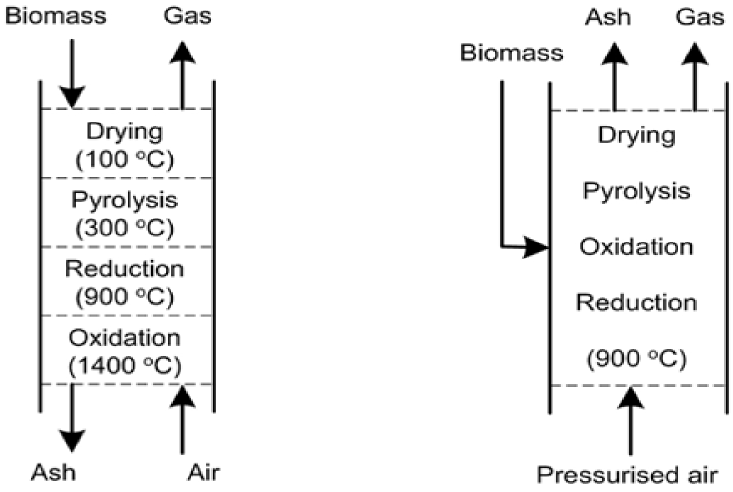

Figure 3.2 Operating principles fixed bed- (left) and fluidised bed gasifiers (CRES, 2001)

Pyrolysis

Pyrolysis is where biomass is exposed to high temperatures in the absence of air, causing the biomass to decompose. The products of pyrolysis always include gas ('biogas'), liquid ('bio-oil') and solid ('char') with the relative proportions of each depending on the fuel characteristics, the method of pyrolysis and the reaction parameters, such as temperature and pressure. Lower temperatures produce more solid and liquid products and higher temperatures produce more biogas (ENSYN, 2001). The various types of pyrolysis technologies are classified by the residence time, particle size and heating range and are summarised in table 3.1. From these technologies, carbonisation and conventional pyrolysis are matured and commercially proven.

Table 3.1 Pyrolysis technologies, process conditions and major products (Juniper, 2001)

Technology	**Residence time**	**Heating rate**	**Temp (°C)**	**Major products**
Carbonisation	hours – days	very low	300 – 500	charcoal
Conventional pyrolysis	hours	low	400 – 600	char, liquids, biogas
	5 – 30 min.	medium	700 – 900	char, biogas
Vacuum pyrolysis	2 – 30 sec.	medium	350 – 450	liquids
Flash pyrolysis	0,1 – 2 sec.	high	400 – 650	liquids
	< 1 sec.	high	650 – 900	liquids, biogas

Others

Hydrothermal upgrading (HTU) converts biomass at a high pressure (approximately 160 bar) and at moderate temperatures (approximately 300 °C) in water to biocrude, resembling crude oil. Biocrude contains far less oxygen than the bio-oil produced by pyrolysis (NOVEM, 2000b). This technology has not yet graduated from the laboratory and therefore will not be considered further.

Torrefaction is a feasible method for improving the properties of biomass as a fuel (higher energy density, friable, hydrophobic). It consists of a slow heating of biomass in an inert atmosphere to a maximum temperature of 300 °C. The treatment yields a solid product with lower moisture content and higher energy content compared to those in the initial biomass. This technology can be described as a mild form of pyrolysis and in principle could be deployed on a large scale. However no commercial plants have been built at the required scale.

Biological processes

Thermal process technologies are preferred for biomass feedstock materials with relatively low moisture content. For very wet biomass materials the alternative for conversion into suitable energy carriers is biological conversion. The biological conversion processes are anaerobic digestion and fermentation.

Anaerobic digestion

Anaerobic digestion is the bacterial fermentation of organic material (breakdown of organic waste by bacteria in an oxygen-free environment). This produces biogas which is typically made up of 65% methane and 35% carbon dioxide with traces of nitrogen and ammonia. All organic matter is suitable for biogas production, including manure, domestic waste and wastewater (Evans, 2000). Purified biogas produced by anaerobic digestion can be used for heating purposes and for electricity generation.

Fermentation

Fermentation refers to the process by which plants of high sugar and starch content are broken down with the help of micro-organisms to produce ethanol and methanol. The end product is a combustible fuel (e.g. can be used in vehicles).

3.2 Production of electricity

The technologies for the conversion of biomass for electricity production are (direct) combustion, gasification, pyrolysis and anaerobic digestion (CRES, 2001). Figure 3.3 shows the different routes to produce electricity from biomass. However, few of these options can be considered as proven technology for a 1000 MW_e power plant (see paragraph 3.4).

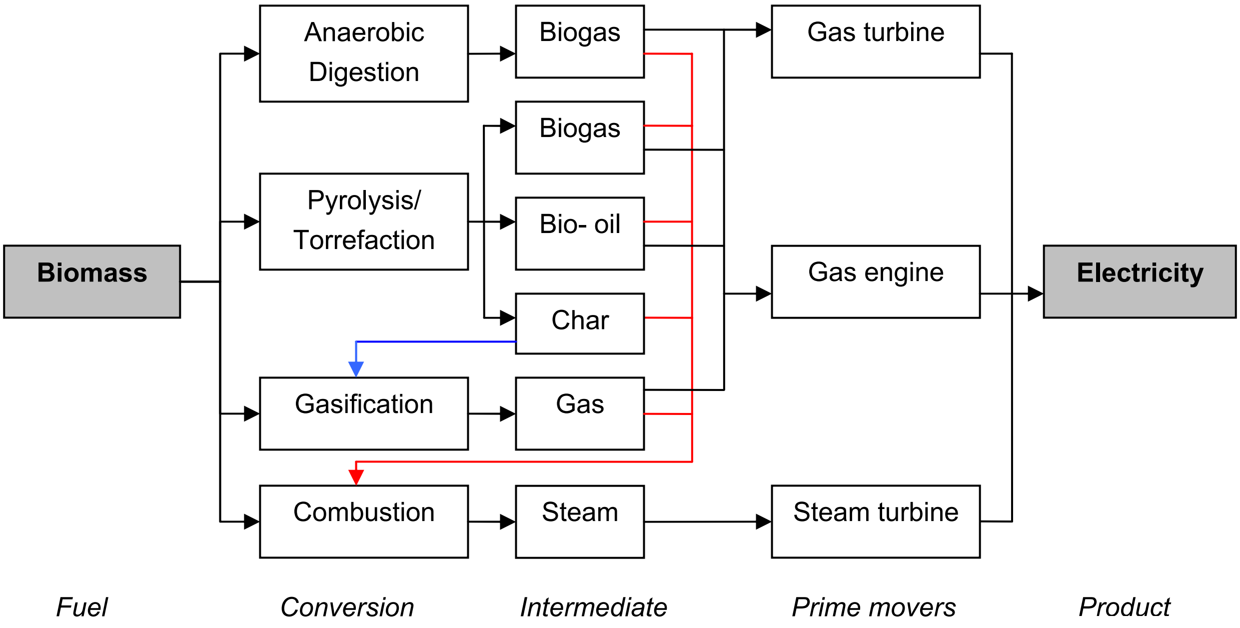

Figure 3.3 Overview of biomass conversion routes for power production

Prime movers

Depending on the conversion product, e.g. steam or biogas, different types of prime movers are used to generate electric power: gas engines, gas turbines, steam turbines and combined gas- and steam turbines. The output range (MW_e) of the prime movers and some of the (main) manufacturers are listed in table 3.2.

Gas engines
Gas engines are engines in which the motion of the piston is produced by the combustion or expansion of gas.

Gas turbines/steam turbines

Gas turbines and steam turbines are a class of electricity generation devices that produce high-temperature, high-pressure gas/steam to induce shaft rotation by contact from the gas/steam with a series of specially designed blades. The shaft rotation (combination of torque and speed) is the output power of the turbine.

Table 3.2 Output range prime movers

Prime mover	Output [MW_e]	Manufacturers
Gas engines	< 3	Caterpillar, Jenbacher, MAN
Gas turbines	0.2 – 237	Alstom, Dresser, General Electric, Kvaerner, Siemens, Solar
Steam turbines	> 1 - 1300	Alstom, Kuhnle Kopp & Kausch, Kvaerner, General Electric, Siemens

Fuel pre-treatment

Vast quantities of a wide variety of biomass fuel, or biofuels, exist. Biofuels have some unique characteristics that require considerable specialized knowledge and care for their procurement and use. Fossil fuels are produced by large energy firms that provide a consistent, standardised fuel that has usually undergone considerable upgrading. However, the majority of biomass fuels are given little refinement, are typically generated locally and a long-term supply may not be guaranteed. The quality may vary between sources or even between deliveries. Because of this variability, it is important to assess a biofuel supply for baseline characteristics of, for example, moisture content, ash content, heating value and particle size, since these will have an impact on the price and design of the power plant.

The calorific value of fuels varies with moisture content. Where the moisture content is above the value specified for a specific plant, there will be an adverse effect on output and efficiency. There will also be an increase in emissions (IEA Bioenergy, 2003). Ash does not contribute to energy and represents an energy loss if disposed of. Major problems can occur when excessive contaminant levels form lumps of slag that can block or jam grates and cause erosion. Particle size is also important. Oversize material and fines are normally the main problem: this can cause bridging and hang up in silos, and can block conveyer systems and equipment feeders.

The technical specifications of various conversion technologies are listed in table 3.3. For example grate furnaces are appropriate for biomass fuels with a low calorific content (Lower Heating Value: LHV), a wide range of particle sizes and high ash content.

Table 3.3 Technical specification conversion technologies

Conversion technology	**Ash content [wt%]**	**Moisture Content [wt%]**	**Particle Size [mm]**	**L + B + H [mm]**	**LHV [MJ/kg]**
Combustion					
Fixed bed (grate furnace)	max. 30	max. 50	--	max. 300 + 100+ 50	6 – 15
Fluidised bed (ABFB)	max. 25	max. 65	--	max. 100 + 100+100	> 10
Fluidised bed (ACFB)	max. 25	max. 35	--	max. 100 + 30 + 20	> 12
Fluidised bed (PCFB)	max. 5	max. 25	5 - 25	--	> 10
Entrained flow	max. 25	max. 10	0,05 - 0,5	--	> 10
Pyrolysis					
Carbonisation	max. 20	max. 50	> 10	max. 300 + 100+ 50	> 8
Conventional pyrolysis	max. 20	max. 50	> 10	max. 300 + 100+ 50	> 8
Gasification					
Fixed bed	max. 20	max. 30	10 -100	max.100 + 100 +100	> 10
Fluidised bed (BFB)	max. 25	max. 50	0,5 - 20	max. 150	10 – 25
Fluidised bed (CFB)	max. 20	max. 20	0,5 - 20	max. 150	> 10
Entrained flow	max. 25	max. 10	0,05 - 0,5	--	> 10
Anaerobic digestion	neutral	max. 90	max 10	--	1 – 6

3.3 Technology choice

To investigate the possibilities for a large-scale (1,000 MW_e) stand-alone biomass-fired power plant based on current technology the fuel conversion method has to be related to comparable large-scale examples in operation worldwide. An overview of the key examples is given.

The world’s largest ‘biofuel’ power plant

Located in Pietarsaari (Finland), Alholmens Kraft Ltd has built the world’s largest biomass fuelled power plant (OPET Finland, 2001). The plant is an industrial combined heat and power (CHP) plant producing steam and electricity for the forest industry, and also produces district heat for the town of Pietarsaari (figure 3.4).

Figure 3.4 Alholmens Kraft biomass power plant, Pietarsaari (Finland)

Technical details of the Pietarsaari power plant

Parameters	**Unit**	**Specifications**
Power output (gross, full condensing mode)	MW_e	240
Capacity to produce process steam	MW_{th}	100
District heating capacity	MW_{th}	60
Heat production	GWh/a	700
Electricity production	GWh/a	1,300

The boiler is a circulating fluidised bed boiler with natural circulation and reheating. The boiler is designed to generate steam by burning bark, saw dust, wood residues, commercial biofuel and peat. Heavy fuel oil is used during start-up as an auxiliary fuel.

Technical details of the boiler

Parameters	Unit	Specifications
Boiler capacity	MW_{th}	550
Steam production	kg/s	194
Steam pressure	Bar	165
Steam temperature	°C	545
Boiler efficiency	%	92

Fuel package

Fuel	Source	Share (%)
Wood-based fuels	Pulp and paper mill	30 - 35
Sawing and forest residues	Sawmills within short distance, forestry sector	5 - 15
Peat	Production sites close to the plant	45 - 55
Coal or oil	Imported fuel, mostly for started-up or support fuel	10

The power plant's turbo generator is a three-casing, reheated, condensing turbine with extractions to district heat and process steam. The condenser is cooled with sea water. The hydrogen cooled generator has an output rate of 306 MVA.

Technical details of the steam turbine

Parameters	Specifications
Live steam	194 kg/s, 165 bar, 545 °C
Reheat	177 kg/s, 37 bar, 545 °C

Environmental performance

The plant uses in-bed lime dosing to bind sulphur and selective non-catalytic reduction to NO_x emissions.

Economical data

The total investment cost was about EUR 170 million (year 2000 price level).

Builder and main manufacturers

Parameters	Company
Power plant	Alholmens Kraft ltd. (Finland)
Boiler, peripheral equipment and the boiler house	Kvaerner Pulping Oy (Finland)
Fuel handling system	Roxon Oy (Finland)
Electrification	ABB Installaatiot Oy (Finland)
Automation	Automation DCS (Finland)
Steam turbine	LMZ (Russia)
Generator	VA Tech (Austria)

Other examples of large units worldwide:

- grate fired unit: waste to energy plant Ivry, Paris, 125 MW_{th}
- entrained flow fired power plant: Zimmer coal-fired plant Ohio, USA, 1,300 MW_e
- grate fired biomass unit: Avedøre, Denmark, integrated with fossil fired, straw, 40 MW_e.

Examples of largest gasifiers operating worldwide:

- coal-fired combined cycle, Buggenum, Netherlands, 253 MW_e
- coal/petcokes-fired combined cycle , Puertollano, Spain, 330 MW_e
- coal-fired combined cycle, Tampa Polk power plant, USA, 250 MW_e
- coal-fired combined cycle, Wabash River, USA, 262 MW_e
- biomass/peat fired CFB gasifier, Lahti, Finland, 60 MW_{th}
- lignite/waste-fired, Schwarze Pumpe, Denmark, 40 MW_e.

Examples of largest pre-treatment facilities:

- wood pellets, 180 kton/a plant in Køge, Denmark, EUR 52 million (Bioenergy Research 1 (3), August 2004).

Conversion technologies fuel flexibility

Based on the technical specifications of the various conversion technologies (see table 3.3), including particle size, heating value, moisture and ash content, and the specifications of the biomass fuels available for the Dutch market (NOVEM, 2000b), the suitability of the conversion technologies for the various biomass fuels can be determined. The results are listed in table 3.4.

Table 3.4 Suitability conversion technologies for different biomass fuels

Conversion technology	**Combustion**					**Pyrolysis.**			**Gasification**				**Anaerobic digestion**
Biomass fuels	Fixed bed (grate furnace)	Fluidised bed (ABFB)	Fluidised bed (ACFB)	Fluidised bed (PCFB)	Entrained flow	Torrefaction	Carbonisation	Conventional pyrolysis	Fixed bed	Fluidised bed (BFB)	Fluidised bed (CFB)	Entrained flow	
Short rotation wood	🟩	🟩				🟩	🟩	🟩		🟩			
Cole seed (from rape)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩		
Wood pellets (imported)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩		
Miscanthus	🟩	🟩	🟩			🟩	🟩	🟩	🟩	🟩	🟩		
Wood from fruit sector and tree nursery	🟩	🟩				🟩	🟩	🟩		🟩			
Forestry by-products	🟩	🟩				🟩	🟩	🟩		🟩			
Wood residue from wood industry (imported)	🟩	🟩				🟩	🟩	🟩		🟩			
Agro residues (imported)	🟩	🟩	🟩			🟩	🟩	🟩	🟩	🟩	🟩		
Straw (grain)	🟩	🟩	🟩			🟩	🟩	🟩	🟩	🟩	🟩		
Straw from rape	🟩	🟩	🟩			🟩	🟩	🟩	🟩	🟩	🟩		
Hemp and flax, short fibres and stem fibres	🟩	🟩		🟩		🟩	🟩	🟩	🟩	🟩	🟩		
Hay from grass seeds	🟩	🟩	🟩	🟩		🟩	🟩	🟩	🟩	🟩	🟩		
(fresh) Clean residue wood including bark	🟩	🟩	🟩	🟩		🟩	🟩	🟩	🟩	🟩	🟩		
Garden and fruit residues (separately collected)													🟩
Residues from nutrition industries													🟩
Roadside grass													🟩
Separately collected old and used wood, including demolition wood	🟩	🟩	🟩		🟩	🟩	🟩	🟩	🟩	🟩	🟩		🟩

Scale

In terms of economies of scale, the conversion technologies addressed in this section vary widely. The scale of various conversion technologies are listed in table 3.5.

Table 3.5 Scale conversion technologies, commercially available

	Conversion technology	Scale [MWth]*	Manufacturer(s)
Combustion	Fixed bed (grate furnace)	10 - 100	AE & E - Von Roll
	Fluidised bed (ABFB)	20 - 300	Kvaerner, Foster Wheeler
	Fluidised bed (ACFB)	50 - 600	Kvaerner, Foster Wheeler
	Fluidised bed (PCFB)	50 - 600	Kvaerner, Foster Wheeler
	Entrained flow	30 - 3000	Kvaerner, Foster Wheeler
Pyrolysis	Carbonisation	< 200	Lurgi AG, Lambiotte
	Conventional	< 200	Lurgi AG, Lambiotte
Gasification	Fixed bed	< 10	Kvaerner, Foster Wheeler
	Fluidised bed (BFB)	< 170	Kvaerner, Foster Wheeler
	Fluidised bed (CFB)	< 170	Kvaerner, Foster Wheeler
	Entrained flow	30 – 800	Kvaerner, Foster Wheeler
Anaerobic digestion	Anaerobic digestion	< 4	ANM, BTA, BWSC

* All values are based on internet and literature searches

Ranking

As a prerequisite the technological concepts for biomass energy production have to be proven and mature. A conversion technology is assumed to be proven when its availability (duration of actual power production i.e. total time minus planned maintenance and forced outages) exceeds 90% (≥ 7,884 hrs/a). Furthermore the capacity of the individual units has to be optimised to take advantage of economies of scale, for example when thermal power output passes 100 MW_{th}. The conversion technologies also have to be able to use various types of biomass fuel, as availability will change. Based on economy of scale, technical maturity and fuel flexibility, the suitability of the various technologies for a 1,000 MW_e biomass power plant can be determined. The results are listed in table 3.6.

Table 3.6 Ranking conversion technologies

Conversion technology		**Scale (MWth)**	**Maturity**	**Fuel flexibility**	**Suitability**	**Overall Score**
Combustion	Fixed bed (grate)	+	++	++	++	**2**
	Fluidised bed (ABFB)	+	++	++	++	**2**
	Fluidised bed (ACFB)	++	++	+	++	**1**
	Fluidised bed (PCFB)	+	+	o/-	+/-	9
	Entrained flow	++	+	o/-	o/+	6
Pyrolysis	Carbonisation	o/-	+	++	o/+	7
	Conventional pyrolysis	o/+	+	++	o/+	7
Gasification	Fixed bed	-	o	+	-	11
	Fluidised bed (BFB)	+	+	++	++	4
	Fluidised bed (CFB)	+	+	+	++	5
	Entrained flow	++	+/-	--	+	10
Anaerobic digestion	Anaerobic digestion	--	++	+/-	--	12

As shown in table 3.6 the most promising concepts for the 1,000 MW_e biomass power plant are: grate combustion, fluidised bed combustion, fluidised bed gasification, entrained flow combustion and carbonisation (as pre-treatment) combined with fluidised bed combustion, fluidised bed gasification and entrained flow combustion.

Clarification of table

Biomass gasification combined with the use of syngas in a gas turbine cannot be considered as a proven technology on the scale envisaged. Thus there is no incentive in applying more complex gasification as a conversion technology since the ultimate benefit of increased net electrical efficiency of the power plant is not yet within reach.

With respect to processes for increasing fuel energy density (pelletising, torrefaction, carbonisation, pyrolysis, HTU), only pelletising can be considered as proven on the scale envisaged.

Mild heat treatment processes such as torrefaction and carbonisation may show potential in the near future, not only for increasing energy density and thus reducing transport costs, but also with respect to grindability thus making entrained flow technology concepts more viable. The environmental aspects of large-scale installations need to be addressed in particular.

More severe heat treatment will result in more than 50% loss of the energy content of the original biofuel without specific added value over mild heat treatment processes.

Entrained flow combustion technologies cannot be excluded. Large lignite-fired plants with net electrical efficiencies of up to 43% (Niederauβem, 2003) are operated nowadays. Although lignite is different from biomass, in principle the technology should also be applicable. A big advantage would be the pure ash production, originating from the biofuel only, which might facilitate the reuse of the ash.

Fluidised bed combustion is definitely the most promising technology. It is also favoured over entrained flow technology for its fuel flexibility. However the production of ash consisting of a mixture (approximately 50/50) of bed material (including additives) and bio-ash may be a severe drawback.

3.4 Concepts for a 1,000 MW$_e$ biomass power plant

Combustion

A simplified process flow diagram of a biomass combustion power plant is showed in figure 3.5. After preparation, e.g. carbonisation (charcoal) and/or mechanical pulverising, the biomass is used to fuel the boiler (grate furnace, BFB/CFB or entrained flow). The boiler supplies steam to a steam turbine-generator unit. Exhaust steam from the turbine is condensed in the condenser, the resulting condensate, is reheated (feed water preheater) and is finally returned to the boiler.

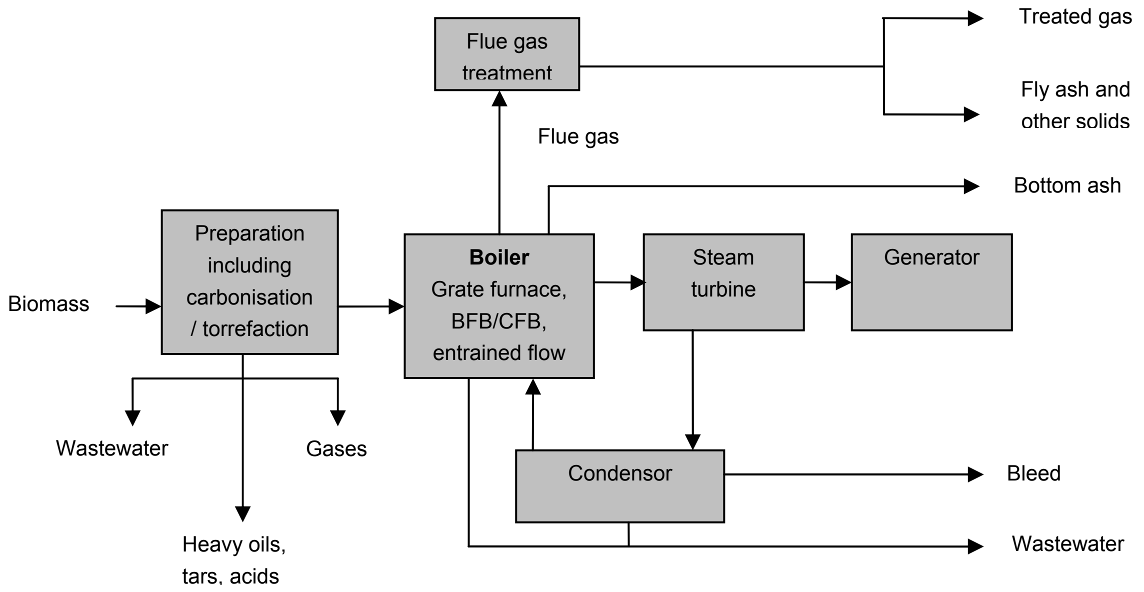

Figure 3.5 Process flow diagram combustion power plant

Concept summary:

- grate furnace: 8 units, maximum fuel flexibility, almost no pre-treatment required
- fluidised bed: 4 units, large fuel flexibility, mechanical pre-treatment required
- entrained flow: 2 units, fuel specific design, mechanical and possibly thermal pre-treatment required.

General aspects:

- all concepts are able to operate in co-generation mode
- a mixture of concepts is also possible, fuel availability (price/quality) is determining
- all concepts are full-scale proven.

Gasification

A simplified process flow diagram of a gasification power plant is shown in figure 3.6. The product of gasification, syngas, contains impurities. Depending on the application, the type of gasifier and fuel composition, particle removal / cooling / scrubbing is required before the gas can be supplied to the gas turbine-generator. The most important impurities are tar, dust, ammonia, sulphur, chloride and alkali metals. Furthermore heat from the exhaust of the gas turbine can be recovered and used to generate steam. The steam is used to power the steam turbine and generate more electricity, leading to a higher overall thermal efficiency of the process (integrated gasification combined cycle, IGCC).

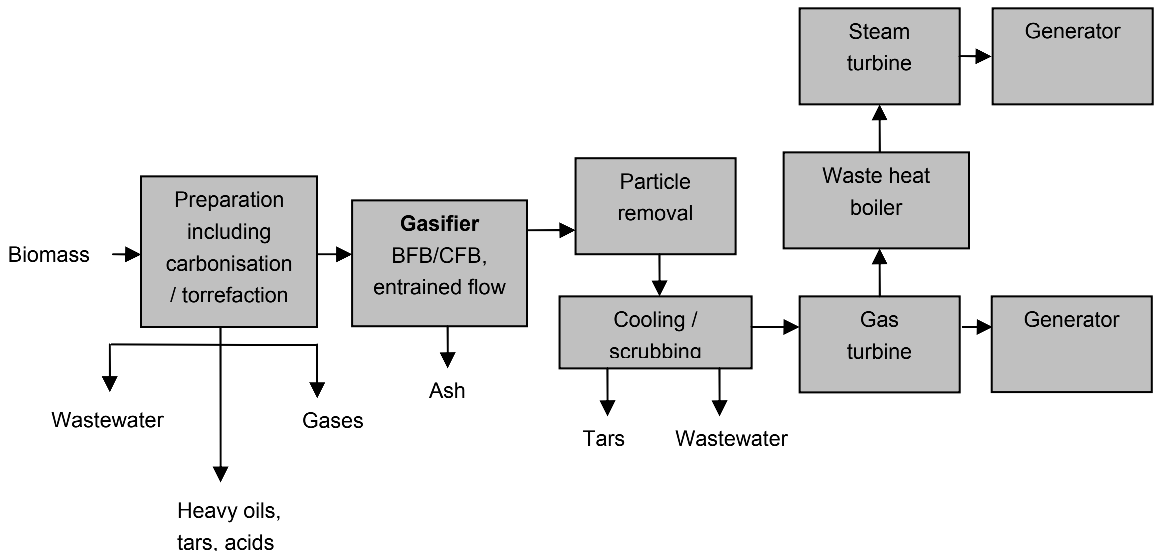

Figure 3.6 Process flow diagram of a combined cycle gasification power plant

Concept summary:

- entrained flow gasification IGCC.

Environmental impacts combustion/gasification

Gaseous emissions

The major gaseous toxic emissions from gasification/combustion processes are SO_x, NO_x, and particulates. Furthermore HCl, HF, volatile organic substances (VOS), CO, heavy metals, dioxins and furans can be formed as can, of course, carbon dioxide. The latter is considered as neutral with respect to influencing climate change when it originates from fuel containing only carbon absorbed from the atmosphere a ‘short’ time ago, so-called short cyclic carbon.

Biomass such as wood contains only minor amounts of sulphur, thus emissions of sulphur dioxide will be low. When necessary this can be further decreased by wet lime/limestone scrubbing (expensive, but also effective for HCl and HF) or in-bed addition of lime/limestone for fluidised bed technology.

The formation of NO_x depends on combustion technology and fuel nitrogen content. Due to low combustion temperatures, fluidised bed NO_x emission levels are relatively low. Further reduction can be obtained by selective non-catalytic reduction (SNCR) or selective catalytic reduction (SCR) technology.

Particulates can be removed with great efficiency with electrostatic precipitators (ESP) and / or bag filters. VOS and CO can be minimised by good combustion conditions resulting in complete combustion. Volatile heavy metals such as mercury (Hg) and complex hydrocarbons such as dioxins can be removed by active carbon injection in the cold flue gas stream.

Carbon dioxide removal will be discussed further in Chapter 7. It is technically possible but expensive and at the cost of a significant (30%) decrease in overall plant efficiency. The storage of the captured CO_2 is in the early stages of investigation.

By-product quality

The inert material (ash) in the biomass results in the production of bottom ash and fly ash. When fluidised bed technology is used, a considerable amount of ash will originate from attrition of the bed material (sand, dolomite etc). Due to the normally small amount of ash in clean biomass, elements will be concentrated in it. In order to close the mineral loop the ash should be returned to the country of origin. The speciation of the elements might, however, be changed. In the Netherlands the BOOM regulation (BOOM, 1998) prevents application of biomass ash as a natural fertiliser, see also section 7.4.

Other residues can result from wet flue gas scrubbing and spent activated carbon which most probably will have to be disposed of as chemical waste.

Efficiency

The electrical efficiency of a power plant depends on the type of generation (simple cycle steam- or gas turbine, combined cycle, CHP), operating conditions (full- or part-load, ambient conditions), and the design of the power plant (including flue gas clean-up technology installed). Efficiency will increase gradually in the future, either due to gas turbine developments (higher expander entrance temperatures) or to boiler developments (ultra supercritical steam parameters).

Based on the identified cases a net electrical efficiency for the base case is 40%, with a perspective on mid term for entrained flow combustion net electric efficiency 42%, perspective 52%.

Emission regulations

The emission regulations for the 1,000 MW_e biomass plant are mostly implementations of European directives. At the top of the hierarchy of European legislation is Directive 96/61/EC concerning integrated pollution prevention and control (IPPC), which is applicable to all energy installations of at least 50 MW_{th}. The core element of the IPPC is that environmental permits ultimately must be based on the principle of best available technology (BAT). According to the IPPC this principle has priority over the emission standards in other directives.

Directive 2001/80/EC (LCPD) sets emission limit values (ELVs) for large combustion plants (>50 MW_{th}). The LCPD is applicable to all fuels, including pure vegetable biomass. The LCPD has been implemented in the Dutch national regulation ‘Besluit emissie-eisen stookinstallaties’ (BEES).

Directive 2000/76/EC on the incineration of waste (WID) sets ELVs for energy installations in which impure, polluted biomass or biomass from animal origin is co-fired. The WID has been implemented in the Dutch national regulation ‘Besluit verbranden afvalstoffen’ (BVA).

Application to the proposed biomass plant

Clean biomass

If the plant is to burn pure biomass exclusively, according to the LCPD definition (in Dutch terminology: ‘clean biomass’), the following ELVs as given in the BEES apply.

Table 3.7 Emission Limit Values according to BEES (mg/m^3 at 6% O_2, dry flue gas)

Component	**mg/m^3 at 6% O_2, dry flue gas**
SO_2	200
NO_x	200
Dust	20

Implication: a well-designed and operated biomass combustion system in combination with an ESP can meet these ELVs.

Polluted biomass

If the plant is also to burn impure, polluted biomass or biomass from animal origin the following ELVs as given in the BVA apply.

Table 3.8 Emission limit values according to BVA (mg/m^3 at 11% O_2, dry flue gas)

NO_x	70*
SO_2	50
Dust	5
HCl	10
HF	1
VOS	10
CO	50
Cd + Tl	0.05
Hg	0.05
Heavy metals	0.50
Dioxins and furans (ng TEQ)	0.10

* monthly average

It is clear that ELVs for clean biomass applications are less stringent for the three main components. Moreover, there are no ELVs set for the other components and heavy metals, as is the case for polluted biomass. On the other hand it must be noted that applying the principle of BAT, the ELVs could be set to a more stringent level in the permit. For example, the installation of SCR will result in lower emissions than the BEES-ELV of 200 mg/m^3 for NO_x.

Implication: a $DeNO_x$ installation is required together with combined end-of-pipe technology.

It is also very well possible that for clean biomass the application of BAT will also be required.

4 ECONOMICS

The cost of electricity production is the sum of all the aspects involved in the harvesting, processing, transportation, trading and conversion of biomass into electricity and saleable heat. Aspects of financing, depreciation, rates, contract on fuel, construction and maintenance, subsidies and CO_2 credits also have an impact. Giving an absolute indication at this stage is therefore not possible. Some general lines however can be drawn pointing at the relative costs in comparison with:

- a new stand-alone coal-fired power plant in a range of 400 to 1,000 MW_e
- co-firing biomass in existing coal-fired power plants, bio-power range 50 to 100 MW_e
- a new small-scale biomass-fired power plant, installed power 20 MW_e.

Some remarks on the economic performance of biomass-derived energy, based on experience with solid fuel power production and renewable energy in the Netherlands, can be made in advance. The final outcome for the economics of the operation from these remarks can be significant in both positive and negative ways:

- since biomass (except waste streams) is often a more expensive fuel than coal the need for high conversion efficiencies is even greater then in conventional power production. Therefore investments to reach high efficiencies are likely to pay off
- the reuse possibilities of ash and its related costs or profits can have a great impact on the economic performance of the original fuel, especially when the fuel contains a high ash percentage
- measures to minimise the environmental impact, especially end-of-pipe techniques, always have a negative impact on economic performance. A trade-off is recommended to select environmental measures with maximum effect at minimum costs based on up-to-date technology. When burning clean biomass, only BEES demands need to be met; no additional BVA demands (see paragraph 3.4.1)
- the bigger the units the lower the investment cost, and also operational costs per MW_e. Above roughly 400 MW_e, specific investment costs in the power plant itself are not likely to fall further. However specific costs of infrastructure and operations will still decline as installed power at one location increases
- although technology is available for large-scale biomass-fired power plants it is expected that the investments in the first project of its kind in the Netherlands will be relatively high. Financing is also expected to be more expensive
- biomass needs to be stored in silos to shield it from rain and fire (unlike the requirements of coal) and to prevent complaints about its smell

- since investment costs are a significant cost factor in solid fuel fired power plants it is important to organise the project in such a way that it is clear how the project pays off, tolling (biomass supplier is share holder/partner in the project), for example, can be a solution. Long-term fuel contracts are preferred together with base load operation
- when co-generation takes place the impact on additional investments within the power plant is often relatively small. However the heat transport infrastructure can be very expensive. When heat has to be delivered at temperatures above 60 to 100 °C electricity production will decline, as will plant income and subsidies on electricity also. Therefore the economic performance of heat supply has to be assessed independently of power production economics. Base load performance and large heat demand is required to perform in a profitable way
- the most likely governmental support scheme applicable in the Netherlands, is the MEP. Since the impact of 1,000 MW_e is huge compared to other renewable energy sources in the Netherlands it is likely that a dedicated MEP will be designed, taking care of the non-profitable project part. If applicable, a fixed subsidy for a period of 10 years for each kWhe produced will be granted. Fiscal instruments like Vamil/MIA or EIA may improve the financial performance too. If applicable, sale lease-back construction could be required in combination with fiscal instruments leading, in the most positive scenario, to a virtual investment reduction of around 10%
- at the moment heat delivery is not advertised to the same extent as renewable electricity, although it will have an impact on CO_2 reduction and energy saving. The development of an MWP (Milieukwaliteit WarmteProductie, governmental support scheme for heat supply) subsidy analogous with MEP could be considered seriously.

4.1 **Fuel costs**

The cost of biofuel is the most unpredictable aspect of power plant economics. Costs can be negative, with a gate fee in case of residual streams of up to -10 EUR/GJ, or positive, up to 12 EUR/GJ in the case of vegetable oils. However some indication can be given, based on the fuel hierarchy as described earlier, of the most likely fuel to be used in a 1,000 MW_e biomass-fired power plant. Imported wood pellets are likely to be the most common fuel. It was recommended to design a flexible system in order to be able to handle other biofuels too. In terms of costs this will only happen when the alternatives are cheaper. Looking at the present market for wood pellets, which is moderately small-scale, a biofuel cost indication can be given. Important existing examples help to get some grip on the topic:

- the experiences of Essent in Geertruidenberg, co-firing wood pellets, the Netherlands
- the experiences of Energi E2 in Avedøre, co-firing wood and straw pellets, Denmark.

Both examples operate with an existing coal-fired power plant and are using biomass in a range of 80 to 300 kton/a, roughly 2 to 8% of the volume required for a 1,000 MW_e power plant. At present the price of wood pellets has risen to between 6.5 and 7 EUR/GJ, depending on quantities, seasonal effects, contracts and transportation costs. For a long time a price around 5.6 EUR/GJ was common in Denmark. Due to the increased interest in wood pellets in Europe and above all the increased transporting costs by ship, the price has risen. Stabilisation is expected in the long term to a value between 5.5 and 6 EUR/GJ for imported wood pellets, depending on fuel quality and transportation costs. In case of large-scale applications and the development of dedicated supply chains in combination with long-term contracts the price may be even lower then 5.5 EUR/GJ. However more detailed research is required to investigate the probability of price decreases.

4.2 Investment costs

In many aspects a biomass-fired power plant will look the same as a coal-fired power plant. But some differences cause higher investments. Due to the fact that the heating value of solid biomass (range 10 to 18 MJ/kg) is lower than coal (24 MJ/kg), and due to its behaviour in combustion and the increase in flue gas production the biomass-fired power plant will be bigger in size than the coal-fired version. More storage capacity will be needed, especially when seasonal effects play a role. Handling and transportation systems are bigger. A bigger boiler will also be needed, and the flue gas cleaning system will have to be bigger. In table 4.1 an overview is given of typical power plant investment costs.

Table 4.1 Investment cost solid fuel fired power plants

System description	**Size**	**Investment**	**Reference, remarks**
Coal-fired power plant Net electric efficiency 47 %	400 MW_e	990 EUR/ kWe	AD 700 project Extension on existing site, 1 unit
Biomass-fired power plant Net electric efficiency 25 to 35%	20 MW_e	2,300 EUR/ kWe	Lahmeyer, MPS, September 2003 Based on FBC technology, 1 unit
Biomass-fired power plant Net electric efficiency 30%	30 MW_e	2,900 EUR/ kWe	MEP 2006-2007 report, 2004 Based on grate technology, 1 unit
Co-firing in existing power plant Net electric efficiency 37.5%	50 to 100 MW_e	590 EUR/ kWe	MEP 2006-2007 report, 2004 Direct co-firing
Biomass-fired power plant Gross electric efficiency 43%	240 MW_e	710 EUR/ kWe 2000 price	Alholmens Kraft, Pietarsaari, 2001 Based on FBC technology, 1 unit

Remarks on the table

The first impression from table 4.1 is it recommends building a biomass-fired power plant similar to the paper mill in Pietarsaari. However, that investment was for a plant which started operation in 2001, built where biomass handling already takes place, resulting in low infrastructural costs. In addition, the flue gas cleaning system is rather simple and consists of limestone injection in the fluidised bed, SNCR and an electrostatic precipitator. In a Dutch situation in the near future a more extensive system will be needed. The upper limit is given by the investment costs involved in small-scale stand-alone biomass-fired power plants which are popular in Europe. To build such a plant in the Netherlands would require an investment of around 2,900 EUR/kWe. More comparable in size is the coal-fired power plant, offering a good starting point for assessing the investment range of the 1,000 MW_e biomass-fired power plant. A first indication of the investment range is expected to be 1,200 to 1,500 EUR/kWe (educated guess based on fit with investment figures in table 4.1) based on a four-line power plant using fluidised bed technology.

4.3 Operational costs

Operational costs cover all the costs to run the power plant, except fuel and capital costs. The costs of maintenance, operational staff, chemicals needed to operate the flue gas cleaning system, ash removal etc. are all covered by the operational costs. In comparison to coal combustion the costs involved with ash handling and flue gas treatment are expected to be lower or equal, depending on the biofuel composition. The operational costs of handling the biofuel are expected to be significantly higher compared to coal. Based on experience a rough estimation can be made of the operational costs as shown in table 4.2.

Table 4.2 Operational cost (OC) of solid fuel fired power plants

System description	Size	OC	Reference, remarks
Coal-fired power plant Net electric efficiency 46 %	400 MW_e	0.43 EURct/kWhe	AD 700 project Extension on existing site, 1 unit
Biomass-fired power plant Net electric efficiency 25 to 35%	20 MW_e	Not known	Lahmeyer, MPS, September 2003 Based on FBC technology, 1 unit
Biomass-fired power plant Net electric efficiency 30%	30 MW_e	3.33 EURct/kWhe	MEP 2006-2007 report, 2004 Based on grate technology, 1 unit
Co-firing in existing power plant Net electric efficiency 37.5%	50 to 100 MW_e	1.20 EURct/kWhe	MEP 2006-2007 report, 2004 Direct co-firing
Biomass-fired power plant Gross electric efficiency 43%	240 MW_e	Not known	Alholmens Kraft, Pietarsaari, 2001 Based on FBC technology, 1 unit

The operational costs for the 1,000 MWe biomass fired power plant are expected to be less than co-firing, since operational risks are expected to be lower. A first indication of the operational costs range is expected to be 0.7 to 1.1 EURct/kWhe (educated guess based on fit with operational cost figures in table 4.2) based on a four-line power plant using fluidised bed technology.

Economic performance

In calculating the economic performance two approaches are possible:

- the economic model (ECN, 2004b) used for MEP calculation, Dutch context
- the economic model (KEMA, 2005) used for cost price calculations, European context.

The economic performance is only for comparative purposes and is not intended for making a final judgment, calculated using the ECN economic model for the costs of renewable energy sources for the purpose of MEP. The stand-alone biomass-fired power plant was used. The results, based on the ranges mentioned above, are given in table 4.3.

Table 4.3 Economic performance 1,000 MW_e biomass-fired power plant
The result in EURct/kWhe is given in terms of MEP, meaning the subsidy needed over a period of 10 years in order to make the project profitable

Case description	Low value	High value	Remarks
Starting point . fuel 6.0 EUR/GJ . investment 1,350 EUR/ kWe . operations 0.9 EURct/ kWhe	5.8 EURct/kWhe at 8,000 hours and 40% net electric efficiency	6.2 EURct/kWhe at 7,000 hours and 40% net electric efficiency	7,000 hours/a is nowadays standard
Fuel cost variation at 8,000 hours	5.7 EURct/kWhe at 5.5 EUR/GJ	6.6 EURct/kWhe 6.5 EUR/GJ	Variations can be even bigger
Investment cost variation at 8,000 hours	5.8 EURct/kWhe 1,200 EUR/kWe	6.5 EURct/kWhe 1,500 EUR/kWe	None
Operational cost variation at 8,000 hours	6.0 EURct/kWhe 0.7 EURct/kWhe	6.4 EURct/kWhe 1.1 EURct/kWhe	None
Efficiency variation at 8,000 hours	5.1 EURct/kWhe 50% net electric	6.2 EURct/kWhe 40% net electric	No high efficiency biomass available
Best case, all low values	3.8 EURct/kWhe		Low values at 8,000
Worst case, all high values		7.2 EURct/kWhe	High values at 7,000
Bio-energy stand alone	9.7 EURct/kWhe (< 50 MWe)		MEP 2006 - 2007
Co-firing	6.6 EURct/kWhe		MEP 2006 - 2007

The calculated figures indicate how high governmental financial support has to be for a period of 10 years in order to make the project feasible with an IRR of 12%.

Remarks to the table:

- long-term average price electricity is 3.2 EURct/kWhe[2]
- CO_2 credits are not taken into account
- debt/equity ratio is 2
- return on equity is 12%
- loan period 10 year at 6%
- economic lifetime 10 years, equal to period of MEP support
- net electric efficiency 40%, 4 units fluidized bed combustion 250 MW_e each.

The results as presented in the table indicate that a 1,000 MW_e biomass-fired power plant can be competitive with a coal-fired power plant co-firing biomass, given the Dutch circumstances and assuming MEP support. The big difference in the economic approach between co-firing and the biomass-fired power plant is that in the case of co-firing coal is replaced. Costs not spent on coal are taken into account. In case of biomass firing (installed power < 50 MWe) the electricity is directly sold to the national grid at a price of 32 EUR/MWh. The equivalent value of unused coal is 15 EUR/MWh. This effect brings co-firing and stand-alone biomass combustion closer together than expected at first impression. When only the electricity cost price is taken into account this difference in approach is excluded, leading to different results.

In calculating the electricity cost price, a comparison can be made between the costs of coal firing and biomass combustion assuming no taxes and financial support. The calculation is based on the data in table 4.4, being common for European power plants starting operation in 2009.

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[2] It is likely that in the case of large-scale power plants the long-term average electricity price will be higher than 3.2 EURct/kWhe, depending on the contract. In the ECN report on MEP (ECN, 2004b) it is stated that a price of 3.7 EURct/kWhe is achievable.

Table 4.4 Assumptions made for calculating electricity cost price

life-time, evaluation period	20 years
full load operating hours	7,000 hours a year (capacity factor 80%)
debt/equity ratio	2
return on equity	9.2%
installed capacity	1,000 MW_e
fuel price	2 EUR/GJ for coal and 6 EUR/GJ for biomass
key figures bio-energy plant	1,350 EUR/kWe investment1), 9.0 EUR/MWhe operational cost
key figures coal-fired plant	975 EUR/kWe investment, 3.8 EUR/MWhe operational cost

1) see the discussion at the end of paragraph 4.2

Indication electricity cost price 1,000 MW_e coal-fired power plant At a fuel price of EUR 2 per GJ, lifetime 20 years	3.3 EURct/kWhe
Indication electricity cost price 1,000 MW_e biomass-fired power plant At a fuel price of EUR 6 per GJ, lifetime 20 years	8.2 EURct/kWhe
Indication production cost co-firing in existing power plants At a fuel price of EUR 6 per GJ, lifetime 20 years and using MEP data	7.8 EURct/kWhe

The first indications show that large-scale biomass combustion can be almost competitive with co-firing although the investment costs are considerably higher, due to higher efficiency and lower operational risk. Financial support, like MEP, is required. The expected value of CO_2 credits in the long run of 1 to 2 EURct/kWhe are not enough to fill the financial gap (IEA, Ecoal 48, January 2004), which is equal to 10 to 20 EUR/ton CO_2. Even in this case MEP is required.

5 LOCATION

This section assesses the feasibility of locations, both absolute terms and relative to each other. The following criteria are addressed:

1. access for deep-sea ships
2. availability of terrain
3. availability of cooling water
4. grid connection
5. heat sale potential
6. sensitive receptors
7. regional policy.

In finding a suitable location for a large-scale biomass-fired power plant, the issues are not different from those of a conventional power plant.

5.1 Access for deep sea ships

Given the huge quantities required and the restricted availability in the Netherlands and neighbouring countries it is certain that the biomass fuel will have to be imported largely from overseas. Accordingly, inland locations without access for large sea vessels are not realistic. Besides, the scale of the project virtually excludes the possibility of finding a suitable location elsewhere. In the Netherlands, only coast or deep waterway locations like Sloegebied (Scaldia haven), Moerdijk, Maasvlakte (plus extension), Europoort/Botlek, Beverwijk, Eemshaven and Delfzijl are within the scope for further consideration.

5.2 Availability of land

The generation, grid connection, storage, logistic and infrastructural facilities of the proposed biomass plant require a large piece of land. To estimate how much, we can use the examples of large existing coal-fired power generation sites in the Netherlands, like the Amer plant and the Maasvlakte plant. These sites occupy sites of approximately 0.35 to 0.45 km^2 (35 to 45 hectares), excluding the harbours. The biomass plant would be expected to cover at least the same space but probably more, given its configuration into several units and the necessity for large storage capacities for biomass and by-products. Taking all this into account it seems appropriate to take 50 hectares (approximately 1,000 by 500 metres) as a rough estimate as the space required. All locations mentioned above but two (Moerdijk and Europoort/Botlek) have the physical space available for accommodating the biomass plant. The total available area in Moerdijk is 50 hectares but it consists of several lots scattered over the area (Port Authority information). The Europoort/Botlek area is almost completely used; the only possibility would be buying land from existing companies. For the purposes of this study however, this site falls outside the scope.

All remaining locations are large harbour and industrial areas with the correct zoning for harbour, logistical and industrial activities. All locations are in use already as power production sites, except for Beverwijk. This site must be taken into further consideration because it appears to meet the physical requirements. It is a plot north of the harbour inlet of the Noordzee canal, between the dunes and the existing Corus site. The availability of sufficient space on this site depends on the possibility of using Corus premises as well. The site has been designated as a suitable large-scale production site in the Electricity Master Plan (SEV) (EZ/KEMA, 1992), although shipping facilities would still have to be constructed. In the past, Corus (formerly Hoogovens) has shown interest in establishing a large power or waste-to-energy plant.

5.3 Availability of cooling water

Large power production plants are best located next to water with enough cooling water capacity. The application of *once-through cooling* is cost-effective, as the investment and operation cost is much lower than for air-cooled condensers and/or cooling towers, and the net efficiency of power production is higher. Once-through cooling is to be considered as best available technique (BAT) for power production sites on sea coasts (EIPPCB, 2000). These locations generally need large cooling water capacity, whereas the environmental impact is relatively limited. The so-called ‘cooling water guidelines’ pose limits to cooling water outlet temperatures (max. 30 °C) and temperature increase (max. 10 °C in summer). At present a tailor-made assessment system for cooling water discharge for individual locations is being introduced.

In this scenario, the cooling water capacities of subsequent locations can be differentiated as follows, based on indicative approaches. An extension in addition to existing capacity is assumed. The actual capacities and the permissible discharges must be determined in the permit procedure (EZ/KEMA, 1992).

Sloegebied

The Westerschelde should have sufficient cooling capacity, also taking into account actual (EPZ nuclear and coal-fired plant) and projected discharges (Delta's Sloe plant). However, extra provisions against recirculation are likely to be necessary, e.g. an inlet and/or outlet system at considerable distance from the existing discharge points.

Maasvlakte

The cooling capacity of the North Sea is abundant, but the layout of the cooling water system needs attention. The existing E.ON Benelux units discharge cooling water into the Breakwater, an artificial lagoon separated from the North Sea by a water-permeable dam. The land reclamation for Maasvlakte 2 may possibly frustrate additional discharges from new plant. An option is to situate the biomass plant at Maasvlakte 2, for which development is not scheduled before 2013 (see Annex C for indicative map). The decision making is not finalised, however (see paragraph 5.7).

Beverwijk

Potentially, the cooling capacity of the North Sea at this location is enormous. However, in the present situation there is no direct connection to the North Sea. The construction of cooling water ducts implies the crossing of the dune ridge. Locally, the dunes are not assigned as a protected nature reserve (Habitat Directive), unlike the dunes up north, near Wijk aan Zee.

Eemshaven

The Eems-Dollard estuary has sufficient cooling capacity, but with a constraint. The existing production capacity (owned by Electrabel) is extensive and so is the existing discharge (> 2,000 MW). In order to diminish recirculation of cooling water and prevent impermissible temperature rises, it will be necessary to position the inlet and/or outlet ducts at a considerable distance from the coastline, as is the case for the discharge from the existing Electrabel units. With respect to the environmental impact of the cooling water discharge and other emissions, the status of the nearby Waddenzee as nature reserve (nature reserve, Wetland, and Habitat and Bird Directive areas) is a very important factor. Environmental impact assessment has to make clear that there are no significant detrimental effects for this ecosystem.

Delfzijl

The once-through cooling option is less viable in Delfzijl than it is in Eemshaven. Given the smaller water surface and the existing discharge of the chemical industry (Akzo Nobel) and of power units (Delesto), recirculation of cooling water is very likely. Other cooling options (air condensers, wet cooling towers or hybrid systems) should also be considered.

5.4 Grid connection

The possibilities for connecting a 1,000 MW_e biomass power plant to the Dutch electricity grid are reviewed here. Assuming all units of the power plant are connected to one voltage level, only the 220/380 kV National Grid operated by TenneT qualifies. Connection to two grids (e.g. 150 and 380 kV) is not considered in this review.

This review is based on a survey of nominal transport capacities of overhead lines and power transformers, taking into account the redundancy requirements of the Dutch Grid Code. In summary these requirements state that the grid must operate with voltage within limits and without overloads in case one or two components in the grid are unavailable, commonly referred to as N-1 and N-2 respectively. We stress that this is a very rough calculation, only suitable for obtaining a first impression.

Based on the supply of biomass and cooling water four 380 kV substations qualify for the connection of the 1,000 MW_e power plant: Borssele, Maasvlakte, Beverwijk and Eemshaven. For these substations the redundant transport capacity will be calculated.

Borssele

At this substation 2x450 MVA 380/150 kV transformers are installed. The total transport capacity of the 380 kV circuits Borssele-Geertruidenberg and Borssele-Zandvliet is 2x450 MVA (as a result of the configuration of substation Borssele). This implies that during an N-1 or N-2 situation respectively 1,350 MVA (3x450 MVA) or 900 MVA (2x450 MVA) will be available to transport the power of the biomass plant. This implies in any case that during maintenance of one of the mentioned transformers or overhead lines, the generated power of the biomass plant must be limited.

Maasvlakte
At this substation 2x450 MVA 380/150 kV transformers are installed. The total transport capacity of the Maasvlakte-Crayestein circuits is 2x1,218 MVA. Two power plants of approximately 2x600 MVA are also connected with the Maasvlakte substation. Because of the planned 380/150 kV transformer in Westerlee for the end of 2005 the transport capacity of Maasvlakte will be expanded with at least 450 MVA.

The specified configuration of the 380 kV Maasvlakte substation means that in case of a N-1 or N-2 situation the minimum transport capacity is respectively 2,568 MVA (1,218+3x450 MVA) or 1,350 MVA (3x450 MVA) at the end of 2005. This implies in any case that during maintenance of one of the mentioned transformers or overhead lines, the generated power of the biomass plant must be limited.

Beverwijk
A planned expansion of the 380 kV grid in the short term is the realisation of the Beverwijk substation with one 380/150 kV transformer in 2006. After finalising the 380 kV ring structure in the north-western and south-western parts of the Netherlands, connection of the 1,000 MW_e biomass power plant at Beverwijk is an option. In this case the redundant transport capacity of Beverwijk is determined by the number of 380/150 kV transformers and 380 kV circuits at Beverwijk-Oostzaan and Beverwijk-Bleiswijk.

Eemshaven
At the 380 kV Eemshaven substation there is one 750 MVA 380/220 transformer installed. The total transport capacity of the 380 kV circuits for Eemshaven-Meeden is 2x2,633 MVA. Two power plants of approximately 2x400 MVA are connected with this substation. The specified configuration of the 380 kV substation Eemshaven means that in the case of a N-1 or N-2 situation the minimum transport capacity will be respectively 3,383 MVA (2,633+750 MVA) or 750 MVA. During maintenance of one of these transformers or overhead lines, the total generated power at the 380 kV substation Eemshaven will be limited.

General remarks
Due to the connection of the biomass power plant at 380 kV, power flows in the grid will change. An important aspect of this is the amount of power generation at 150 kV or 220 kV. If more power is generated at these voltage levels, the loading of the 380 kV circuits, which are connected with the substation at which the biomass power plant is installed, will increase. This means that less power of the biomass power plant will be exchanged by the transformers in the substation. This implies that during a contingency the surplus transport

capacity will become less. This aspect has not been investigated in this survey as it is the responsibility of the network operator.

TenneT (TenneT, 2003) states that in the future HVDC cables could be connected to the Maasvlakte or Eemshaven substations. If the biomass power plant was also connected to one of these substations, the total power injection would increase even more.

5.5 Heat / CO_2 sales on a large scale

In terms of energy efficiency and CO_2 reduction there are substantial benefits to be gained in the marketing of waste heat. Whether this is an economically viable option, taking into consideration the MEP subsidies system, is not assessed here. In general, the options for the selected locations are limited, as far as district heating is concerned. Residential areas of newly planned urban areas are at a distance and the required investments in the delivery system cannot be accounted for under present conditions. In section 5.6 the possibility of using smaller biomass units is investigated. The costs per ton of CO_2 reduction are far too high. Looking at other, more cost-effective options, we can specify the following for the selected locations.

Sloegebied
The Sloegebied site contains process industry with modest steam requirements. It must be realised, however, that the Sloe plant is already projected to supply this steam demand. Earlier plans to establish a greenhouse complex near Borssele have been abandoned, which rules out the possibility of selling heat and/or CO_2.

Maasvlakte
The Maasvlakte site does accommodate some process industry but this industry is already supplied with steam from E.ON Benelux's co-generation facility. The planned Maasvlakte 2 development could favour new process industry but this is uncertain at the time of writing.

Beverwijk
Corus, a steel mill located in IJmuiden close to Beverwijk, is a big energy consumer but this refers predominantly to electricity. The real potential for heat supply to Corus is unclear.

Eemshaven
This site has no process industry. However, there have been plans for some time to develop a greenhouse complex to the southwest of the site, but it is proving to be problematic.

Delfzijl
The Delfzijl site has energy-intensive industries, but steam demand from the chemical industry is already met by Delesto's co-generation facility. There is potential for future development but this remains uncertain at the moment.

The possibilities for heat sales appear limited because of:

- distances to (new) urban sites and the high cost of infrastructure
- supply of process industry by existing co-generation facilities
- slow development of new greenhouse complexes
- making heat sales possible requires significant changes in the attitudes of both the authorities and the market. The development of the ‘heat act’ (promoting the delivery of heat) can help bringing supply and demand together.

5.6 Downsizing the biomass plant, optimising co-generation

Downsizing the plant to much smaller dimensions, in the range of 100 to 400 MW_e, would theoretically bring more sites with (potential) heat demand within reach of the project. As transport implications will be more limited with a larger number of sites, a plant of this size can be located more inland, although access to a waterway remains an absolute precondition. The more limited space requirements and the smaller range of environmental impacts should offer a wider range of possibilities.

Ideally, the plant should be located near existing or planned urban sites, greenhouse complexes and industrial parks. Future developments in these areas are projected in national plans like Structuurschema Elektriciteitsvoorziening (SEV), Structuurschema Groene Ruimte (SGR2) and the Nota Ruimte (PkbNR).

However, in general, the number of options remains rather limited, as before. The development of new large industrial parks where heat demand is concentrated is stagnating; see for example the recent ruling of the Raad van State on Maasvlakte 2, the opposition of the Tweede Kamer against the Hoeksche Waard and the local opposition against the Moerdijkse Hoek. The large VINEX –urban developments have left the drawing board and are being built. Greenhouse complexes in developments like Zuidplaspolder, Berlikum, Emmen, Grootslag, Californië/Siberië (Province Limburg), Luttelgeest, Bergerden and IJsselmuiden are not located next to waterways. The likelihood of situating a large biomass co-generation plant in a greenfield setting seems very limited.

One should be aware of the fact that power-/co-generation plants (> 50 MW) are rated as category 5 (maximum is 6) in the VNG 'Environmental zoning' model. An indication of the alleged environmental impact is that the preferred distance from residential areas is 700 metres (this is for coal-fired plants: biomass-fired plants are not yet included in the zoning model). Nevertheless; taking a smaller biomass plant as starting point, the following locations could be taken into consideration as well:

1 Moerdijk

This large industrial park with deep sea access can accommodate a new plant of this size. According to SGR2/PkbNR a large extension is projected south of the park, as well as a new large-scale greenhouse complex, the so-called Moerdijkse Hoek. From an energy point of view, the realisation of both plans would be close to ideal. It should be borne in mind, however, that locally and amongst environmental groups there is resistance to the plans

2 Westland

In 1992 the SEV identified a co-generation location on the north shore of the Nieuwe Waterweg between Hoek van Holland and Maassluis, which could also serve energy (and CO_2) needs of Westland and the new Den Haag suburb Ypenburg. Whether this site is still realistic is an open question, taking in mind that the suburb was constructed without district heating infrastructure and that CO_2 is to be supplied to Westland by Shell (OKEP). Moreover, provincial and municipal zoning would have to be established from the beginning

3 Dinteloord

This location is situated near Stampersgat along the Dintel, with good access to the Volkerak and the Hollandsch Diep. The municipality is attempting to create an 'Agro Industrial Complex' next to the Suiker Unie sugar factory, which in itself is a seasonal activity. Companies conducting activities with possibilities of synergy with the sugar factory (e.g. in relation to energy conversion of by-products) are welcome.

Because of the uncertainties and the constraints mentioned above, it is advisable also to take into consideration existing sites with co-generation capacity which at some point in time will need replacement. In this respect the sites of Geertruidenberg, Lage Weide (Utrecht), Diemen and Harlingen (near the Frima salt factory) are also options.

5.7 Sensitive receptors

Sensitive receptors are residential areas or buildings, schools, hospitals, nature protection zones, or adjacent industries with conflicting interests. These sites are sensitive for aspects such as noise, emissions, nuisance etc. In general, the selected locations are among the best imaginable in the Netherlands, since they are situated in large industrial areas without sensitive receptors ‘next door’. Nevertheless, the following remarks must be made:

- all locations are adjacent or close to protected areas (Habitat and Bird Directive, wetland areas, nature monuments etc). Consequently any proposed power plant is not allowed to have any significant impact. In case there is significant impact the ‘advantage and necessity’ ("nut en noodzaak") of the project must be made clear in the environmental impact assessment and the licence procedure. Failing to do so would make the project unfeasible. Because of the accumulation of all possible protection regimes, the Waddenzee probably has the highest status, which affects negatively the position of Eemshaven as a location for a power plant
- some locations are closer to residential areas than other. As a consequence, the Sloegebied (northern part), Beverwijk and Delfzijl (eastern part) dispose of little "noise space" compared to Maasvlakte and Waddenzee. The Sloegebied is most critical
- even when applying the best available techniques, the emissions to air could conflict with air quality standards for dust (Besluit luchtkwaliteit). The most critical location related to air quality is Maasvlakte because of the relatively high background concentrations of air pollutant compounds.

5.8 Regional policy and public acceptance

Maasvlakte and Eemshaven hold preferential positions when looking at provincial (regional) policy on industrial development. The Rotterdam port authority is promoting the development of Maasvlakte 2, and is actively seeking companies interested in establishing new businesses there. For this reason the regional authorities would very much welcome the initiative to realise a biomass-fired power plant. The procedures for land reclamation were begun this year, but the go / no go decision will be taken in a few years time, depending on interest and how the application process goes. Presuming a positive outcome, it is obvious that Maasvlakte 2 offers excellent opportunities for establishing the biomass plant. Should the land reclamation not happen, the existing Maasvlakte site still offers possiblities, but these will run out in the medium to long term.

A large biomass plant would also fit well within the public-private Energy Valley initiative in the northern provinces. The objective there is to create a business and knowledge centre in the field of energy, and in general and sustainable energy in particular. Obviously Eemshaven and Delfzijl could play a key role in the field of biomass transshipment and conversion to energy. These industrial areas have been promoted for some time as motors for economic development of the north. Plans for a large biomass plant will certainly receive support from authorities, trade and industry and the public.

5.9 Ranking of locations

Reviewing all criteria it can be concluded that Maasvlakte and Eemshaven are the best locations for establishing the 1,000 MW_e biomass plant, followed by Beverwijk, Delfzijl and Sloegebied (see table 5.1). The ranking is necessarily crude, but it gives a good indication. The ranking does not rule out the possibility that, when proceeding through a detailed site selection process, lower ranked locations will come out better than previously higher ranked locations.

Table 5.1 Ranking of selected locations

	exclusive criteria		**ranking criteria**					
	access for deep sea ships	**availability of land**	**availability of cooling water**	**grid connection**	**heat sale potential**	**sensitive receptors**	**policy**	**overall ranking**[*]
Sloegebied	X	X	2	4	2	4	2	5 (14)
Moerdijk	X	O						
Maasvlakte	X	X	1	1	2	2	1	1 (7)
Europoort/ Botlek	X	O						
Beverwijk	X	X	1	3	2	2	2	3 (10)
Eemshaven	X	X	2	2	2	1	1	2 (8)
Delfzijl	X	X	3	5	1	3	1	4 (13)

[*] the higher the number, the less preferable the site

6 PERMITS

6.1 Permits required

For the construction and operation of the 1,000 MW_e biomass plan, permits will be needed to comply with:

- Environmental Management Act (Wet milieubeheer: Wm)
- Housing Act (for the building permit)
- Pollution of Surface Waters Act (Wet verontreiniging oppervlaktewateren: Wvo)
- Water Economy Act (Wet op de waterhuishouding: Wwh)
- Groundwater Act (Grondwaterwet: Gww) (in case of groundwater extraction)
- Wet beheer Rijkswaterstaatswerken (Wbr) (in case of crossing of the coastal barrier and/or construction on the coastline for cooling water purposes).

The municipality must grant the building permit under the Housing Act. The licences, required under the terms of the Wm and the Gww, must be applied for from the provincial authorities. The Wvo, Wwh and Wbr permits must be applied for from the Minister of Traffic and Public Works (Rijkswaterstaat RWS), more specifically one of the Regional Boards. It must be emphasised that all permits and licences must be valid in order to make use of any of them.

Moreover, approvals from local sea port authorities will be required for the construction of piping, cabling etc. If the biomass plant is to be constructed with an option of auxiliary gas firing, gas transport to the installations has to be arranged by Gasunie or another gas company.

6.2 Timetable

The procedure for granting a licence under the terms of the Wm and the Wvo starts with an environmental impact assessment (EIA), which is integrated in the licence procedure. The detailed legal timetable for both the EIA and the licensing procedures is given here in annex D. Normally the Wm permit must be issued within seven months of the first application, but in practice this period is much longer: in extreme cases it takes a few years. All decisions with respect to licences are preceded by periods for public comments and advisory procedures. Appeal is possible on all decisions and is standard for all large-scale bio energy initiatives.

The experiences of the last years with large (biomass) power plants indicate that the total period for obtaining the indefinite permits could take four or more years (NOVEM, 2004. SenterNovem, 2004). The construction and commissioning of this scale of plant will take three years, which would bring the timeframe from start to realisation to approximately seven years. Table 6.1 gives a simplified but realistic timetable.

Table 6.1 Most realistic timetable for the realisation of a 1,000 MW_e biomass plant

year **stages**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
preparation EIA, permit applications	■							
preparation draft permits		■						
preparation definite permits			■					
appeal and irrevocable permits				■				
construction					■	■		
commissioning							■	
commercial operation								commercial operation

6.3 Consideration of CO_2 reduction

The permit process for a 1,000 MW_e biomass-fired power plant will bring up the crucial issue of how to consider CO_2 reduction and savings in fossil fuel compared to negative impacts e.g. toxic emissions. This issue has caused much controversy in permit procedures for bio energy projects so far.

Until recently the administrative court (Raad van State) has taken a very rigid position in its interpretation of the law (Wet milieubeheer) by stating that CO_2 reduction can never put aside existing standards or reduction goals for other emissions (see ABRvS, 200203258/1). The transposition of the IPPC directive into Dutch law which is now taking place, will introduce the possibility of balancing CO_2 reduction and other emissions (Tweede Kamer, 2004). The IPPC explicitly underlines the need to consider all emissions (including CO_2) integrally.

7 MISCELLANEOUS

7.1 Macro-economic impact

It is evident from section 2 that a large part of the necessary biomass fuel will have to be imported, most likely from developing countries.

It is essential that the fuel bought for biomass combustion is grown in a sustainable way, i.e. without depleting the soil or using artificial fertiliser. A sustainable approach also makes it necessary to recover the minerals contained in the ash from the biomass fuel, for reuse as fertiliser in the country of origin. This requires good housekeeping of mineral balances in the entire process (see also section 7.4).

7.2 Carbon dioxide capture and storage

A biomass-fuelled power plant will be almost completely carbon dioxide neutral (see section 7.4). The amount of CO_2 emitted during fabrication of power plant parts and the construction is very small compared to emissions during plant operation. A typical figure for the energy pay-back time is around four months (160 MJ/MWhe at lifetime of 20 years and 7,000 operational hours a year), equal to wind turbines (KU Leuven, 1999). The CO_2 emissions from harvesting and transport of biomass fuel could be zero when bio diesel is used. Otherwise the amount of energy used for harvesting, preparation, handling and transport will be less than 20% (worst case, long-distance intercontinental transport) of the biomass energy content.

There is an option to operate the plant as a negative CO_2 source by capturing and storing the neutral CO_2. Technically CO_2 capture is feasible and storage should be possible too, but a recent report (VGB, 2004) concludes that this is not feasible at the moment and will need 10-15 years of development. The estimated cost, applicable to large-scale power plants in general, varies widely from 20 to 60 EUR/ton CO_2 which may be (in part) balanced by the value of CO_2 credits (VGB, 2004).

The overall net efficiency of the electricity generation process, independent of the fuel used, will fall dramatically due to the large amount of energy required for capture and storage of carbon dioxide. Estimates for conventional combustion plants are a decrease of approximately 12-15 percentage points. Thus the amount of necessary biomass fuel will increase by one third to deliver the same power output.

7.3 Electricity price development

The price of electricity produced from natural gas and coal will be determined to a large extent by fuel price development (including transport cost) and by the price of CO_2 emission rights.

The price of natural gas is coupled with the price of oil. It is expected that present high levels will continue and are sensitive to political uncertainty in the short run and depletion of easily recoverable reserves in the long run.

The price of coal has been very stable in the last decades, although an increase has been noticed from increased transport costs. This is likely to remain the case for some time due to economic growth and demand, especially from China.

The price of CO_2 emission rights is expected to rise to 20 EUR/ton CO_2 (IEA, Ecoal 48, January 2004). For the moment the assumption in the Dutch situation for the value of carbon allowances is 7.6 EUR/ton (ECN, 2004b (table 3.2)), roughly one third of the IEA assumption.

7.4 Compliance with Greenpeace boundary conditions

The general boundary conditions which Greenpeace sets on all sustainable biomass projects are: a positive energy balance, carbon neutrality, no biodiversity impact, GMO-free, sustainable plantation/agriculture, and no additional toxicity (see annex E).

Positive bio-energy chain energy balance
Looking at the whole chain from growing, harvesting, processing, transportation until the thermal conversion of biomass in the power plant and disposal of ashes, the energy balance is positive. The loss in the supply chain has a value of 10 to 20% (SUURS, 2002) of the biomass energy content when wood residues are used as a biofuel. The loss is relatively high when the harvesting takes place far away from the seashore, when intercontinental transport is required by ship over a distance exceeding 10,000 km and biofuel use in a power plant not located near the coast. When locally available biomass is used the loss will be around 10% and can be even smaller. The conversion of biofuel to electricity can be done with an efficiency of 38 to 43% depending on the conversion technology, the fuel properties and cooling possibilities. When heat can be reused due to operation in co-generation mode the overall fuel efficiency will increase to a figure between 45% and 85%, depending on the

distance to the heat demand, temperature level and the heat volume demanded the whole year around.

CO_2 equivalent neutral

Though CO_2 is produced in considerable amounts when biomass is combusted, the complete bio-energy chain is to a high extent CO_2 neutral, certainly when bio-energy is compared to the use of fossil fuels for energy applications. The CO_2 originating from biomass is CO_2 neutral since it is produced in a short time cycle of up to around 50 years. Fossil fuels are not CO_2 neutral due to their long time cycle of formation and depletion. Due to the large-scale application aimed at in combination with up-to-date combustion and emission control technology the emission of N_20 and other potential greenhouse gases is minimised and certainly lower than small-scale and inadequately controlled combustion processes. When bio-residues from forestry or agriculture are used in such a way that nutrient and mineral depletion does not take place then excessive putrefaction, and thus the emission of CO_2 and $CH_{4,}$ are also prevented. On the other hand, harvesting, processing and transportation of biomass causes CO_2 emissions from the use of fossil fuels. In this stage it is hard to say to what extent the bio-energy supply chain is negative or positive. Therefore a more detailed comparison is needed with the case of when biomass is not used as a fuel in a power plant.

No impact on bio-diversity

In order to fuel a 1,000 MW_e power plant with biomass a significant amount of land is required. When forestry residues are used an area is needed of five to ten times (VTT/Tekes, 2003) the forestry area of the Netherlands (274,000 ha in 1996, (CBS, 2000)). For energy crops the factor is around 1 for the Netherlands (NOVEM, 2000c) or even smaller than 1 when grown in tropical areas. So in order to harvest enough wood residues, an area, by rough indication, of at least 100 km^2 is required. The use of land has to be extensive enough to prevent depletion and to have no negative side effects on biodiversity in order to guarantee for a number of decennia sound biomass harvesting. Intensifying the land use by application of fast-growing energy crops, for example Miscanthus and eucalyptus can increase the yield by a factor of 10. However the risk of depletion and of affecting the bio-diversity increases too. A balance has to be found between yield and sustainability. At the moment it is not known in enough detail where the optimum might be found. Therefore it is wise to start with a more extensive approach focusing on the use of wood residues. In tree harvesting normally 40 to 60% of the tree is used. Part of the remaining wood, the residue, stays in the forest because it is not profitable to use and it is part of the mineral and nutrient chain of the forest. In bio-energy reuse of ashes can contribute to the balance of minerals required for a sustainably managed forest. How much of and which parts of the tree have to stay in the forest in order to create nutrient and mineral balances is being researched worldwide. It is expected that in countries where forests are already exploited to a high extent and over a longer period (> 60 years), for example Scandinavia, the production of wood residues can increase with 30 to 40% without negative long-term effects on the forest's health and not harming the use of wood for paper pulp and construction applications.

Operated without GMO

Greenpeace wishes to promote only bio-energy chains which are free of Genetic Modified Organisms (GMO). It is a fact of life that GMO is applied in more and more cases all over the world, mainly in food, fodder plants and ornamental plants, but also with increasing interest in forestry. The Food and Agriculture Organization stated that the forestry sector is far behind agricultural crops with respect to GMO applications and can perhaps benefit from experiences in the agricultural sector (El-Lakany 2004, *The Economist*, 2005).

For the time being developments are hard to assess in relation to energy crops and wood residues. It will need more as the bio-energy market becomes more mature, but it is expected that wood residues or energy crops will give the best guarantee of using non-GMO biomass at power plants.

Sustainable forestry and agriculture

For each entrepreneur in the bio-energy chain sustainable land use and sustainable cycles are ultimately the best guarantee for long-lasting healthy business. These ensure a future for the Earth's forests and all the life dependent on them. Due to the high investments involved in the power plant a long-term approach is required to be ultimately profitable. Therefore the development of a bio-energy chain should be carried out preferably with countries, organizations and companies with a good track record in fair trade. Chain certification, such as already is happening with construction wood (FSC) and the wood pellets used by Essent for co-firing (IEA fair bio-trade), is a powerful instrument to control the sustainability of the bio-energy chain. When a bio-energy chain has to be developed on a 1,000 MW_e scale it is recommended to use existing experience. In the long run, teaming up with fair trade organizations (for example, Max Havelaar) can create new business opportunities for developing countries. In addition, the dependence on fossil fuels supplied only by a limited amount of regions worldwide could decline, contributing to an increase in the stability of the world economy and geopolitical relations.

No toxic side-effects along the bio-energy chain

When the use of biomass residues and more specific wood residues are considered, it is expected that toxicity levels will not increase since residues are additional products of an activity already taking place. This is also the case with agricultural residues. Potential toxicity sources are the bio-ash release during combustion and emissions to the air of flue gases. By building the power plant according to up-to-date technology standards toxic side-effects from emissions to air can be prevented. By a deliberate choice of the combustion technology in relation to the biofuel, if necessary complete with final treatment techniques, bio-ash will be prevented from having unacceptable levels of toxicity, making the reuse of the ash as a fertiliser in forestry or agriculture more likely.

Note: E.ON does not endorse all the above mentioned Greenpeace criteria.

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ANNEX A PROPERTIES OF FUELS

Proximate and ultimate analyses

The proximate and ultimate analyses are provided below for a selection of biomass types, obtained from the Phyllis database developed by ECN. These values are averages of total streams. Take into account that the analyses of single streams may differ.

Proximate and ultimate analysis of several biomasses (Phyllis/ECN)

component		untreated wood	grass/plant	*Miscanthus*	other grasses and plants	straw (stalk/cob /ear)	husk/shell/ pit
proximate analysis							
Water content	wt% wet	18.8	30.1	29.1	44.1	15.4	10
Volatiles	wt% daf*	81.9	82.6	82.6	84.6	81.1	76.7
Ash	wt% dry	2.2	6.9	3.6	9.4	7.4	5.7
Ultimate analysis							
C	wt% daf	50.7	49.2	49.6	48.6	48.6	50.2
H	wt% daf	6.06	5.95	5.74	6.07	5.96	6.16
O	wt% daf	42.8	43.5	43.9	43	43.2	42.6
N	wt% daf	0.37	1.21	0.52	1.98	0.91	1.12
S	wt% daf	0.07	0.17	0.08	0.3	0.15	0.16
Cl	wt% daf	0.054	0.351	0.213	0.694	0.53	0.086
F	wt% daf	0.004	0.002	0.002	0.008	0.002	0.001
Br	wt% daf	-	-	-	-	-	-
Calorific Value							
HHV	kJ/kg daf	20125	19590	19726	19385	19346	20424
LHV calc*	kJ/kg daf	18779	18288	18480	18023	18007	19055
LHV ar*	kJ/kg	14443	11149	11903	8025	13722	15922

*ar = as received
*calc = calculated
daf = dry ash free

Quality

The quality of the fuel not only depends on the calorific value, but also on the effect it has on the installation. For example, a fuel with high chlorine content may damage the installation over time with excessive corrosion. The sulphur in a fuel is released into the flue gas requiring appropriate flue gas cleaning.

Physical appearance

stream	**shapes**	**most likely to be combusted in:**
short rotation wood	chips	decentralised-large
cole seed (from rape)	grain	decentralised-large
Miscanthus	chips	decentralised-large
wood from fruit sector and tree nursery	chips, blocks	decentralised-small
forestry remainder products	chips, blocks	decentralised-large
straw (mostly from grain)	bale	decentralised-large
straw from rape	bale	decentralised-large
hemp and flax, short fibres and stem fibres	short fibres	centralised-large
hay from grass seeds	bale	decentralised-small
(fresh) clean residue wood including bark	sawdust, chips, blocks, fine dust	decentralised-large
roadside grass	bale	decentralised-large
garden and fruit residues (separately collected)	various sizes and shapes	decentralised-small

ANNEX B SELECTION OF FUELS BY RANKING

The fuels to be used in the 1,000 MW_e power plant should preferably be 100% biomass and have a short CO_2 cycle, preferably wood, yearlings or energy crops. The types of fuel that are eligible are agro residues such as olive cake, cocoa shells, sun flower residues, and wood or wood-derived fuel such as saw dust and wood pellets.

When considering a type of fuel, one should consider whether it is in a solid, liquid or gaseous form. An advantage of liquefied fuels (bio-oil) is the higher energy density compared with the original solids, thus requiring less space when transporting. However, liquefied fuels are considered more appropriate as transport fuel. Long-distance transport of gases such as methane, hydrogen and carbon monoxide is expensive when no pipeline is available. Therefore it is justified to focus on the solid fuels.

A list of types of solid biomass and residue streams and their ranking based on criteria defined for this project (Greenpeace, 2004) is provided in the table below.

The streams are ranked according to the following mandatory criteria:

- the stream must be 100% biomass and have a short CO_2 cycle
- the stream must not be taken from other applications such as waste incineration plants or specialised manure incineration plants
- the lower heating value (LHV) of the fuel must be at least 8 MJ/kg to limit transport costs.

The remaining streams are then ranked according to the following criteria:

- the stream should have a low impact on the environment. Preference is given to energy crops
- the quantity of fuel should be substantial, therefore mainly large streams (> 400 kton) are considered.

The remaining streams are ranked according to distance and equity:

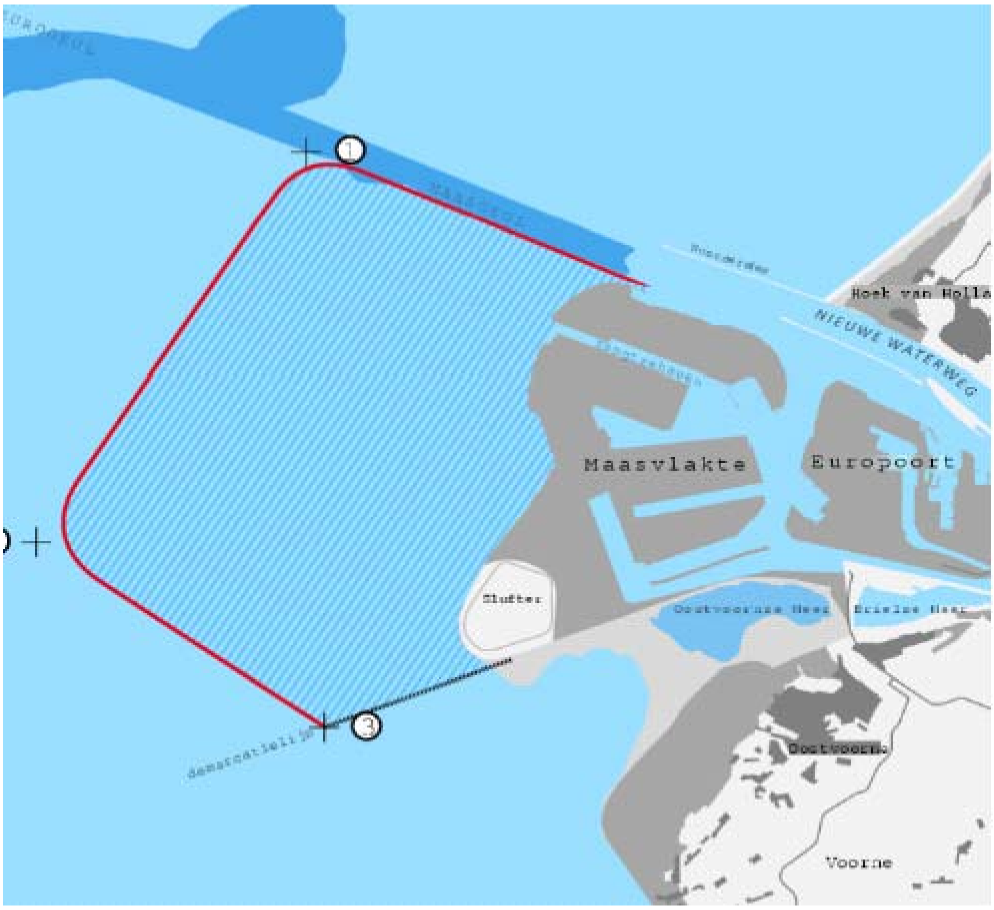
- streams within a limited transport distance
- cheap streams, that are available long term and grown in a sustainable way.

Annex B page 2

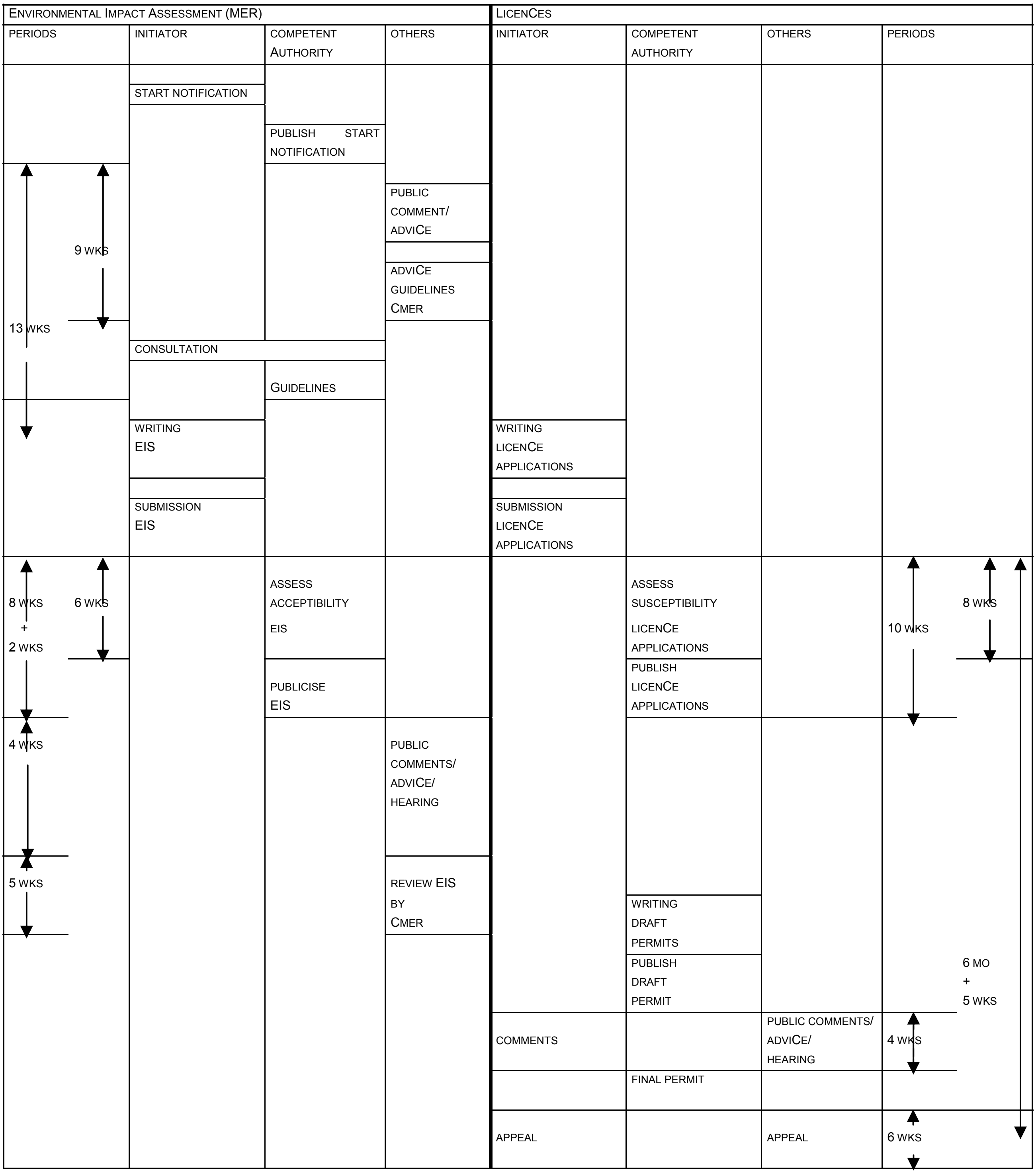
Stream	100% biomass	Availability	min 10 MJ/kg	environmental impact	min 0,4 mill ton / 400 kton 2000	min 0,4 mill ton / 400 kton 2020	min 7 PJ in 2020	NL,EU, nearby	cheap, long term, sustainable grown
Energy crops									
short rotation wood (i.e. poplar, willow)	+++	ok	ok	+++	---	++	+	+	+
cole seed (from rape)	+++	ok	ok	+++	---	-	---	+	-
wood pellets (imported)	+++	ok	ok	++	++	+++	++	+	++
Miscanthus	+++	ok	ok	+++	---	+	-	+	+
Biomass residual stream									
wood from fruit sector and tree nursery	++	ok	ok	+++	---	-	--	+	-
forestry by-products	++	ok	ok	+++	++	+	-	+	++
wood residue from wood industry (imported)	++	ok	ok	++		+++	++	+	+
agro residues (imported)	++	ok	ok	++		+++	++	-	+
straw (grain)	++	ok	ok	+++	-	---	---	+	-
straw from rape	++	ok	ok	+++	-	---	---	+	-
hemp and flax, short fibres and stem fibres	++	ok	ok	+++	---	---	---	+	-
hay from grass seeds	++	ok	ok	+++	---	---	---	+	-
(fresh) clean residual wood including bark	+++	ok	ok	+++	--	+	+	+	-
Biomass, possibly contaminated									
garden and fruit residues (separately collected)	1)	ok	2)	++	--	---	---	+	-
residues from nutrition industries	1)	ok	3)	+	++	+++	---	+	-
roadside grass	1)	ok	2)	+++	-	+	--	+	-
separately collected used wood, demolition wood	1)	4)		---	+	++	++	+	+

1) may be contaminated
2) depends on storage time
3) depends on stream
4) ok; "B hout" not in municipal waste incinerator

ANNEX C PLANNED LAND RECLAMATION MAASVLAKTE



ANNEX D LEGAL PROCEDURES / TIMETABLE EIA AND ENVIRONMENTAL LICENSING



ENVIRONMENTAL IMPACT ASSESSMENT (MER)				LICENCES			
PERIODS	INITIATOR	COMPETENT AUTHORITY	OTHERS	INITIATOR	COMPETENT AUTHORITY	OTHERS	PERIODS
	START NOTIFICATION						
		PUBLISH START NOTIFICATION					
13 WKS 9 WKS			PUBLIC COMMENT/ ADVICE				
			ADVICE GUIDELINES CMER				
	CONSULTATION						
		GUIDELINES					
	WRITING EIS			WRITING LICENCE APPLICATIONS			
	SUBMISSION EIS			SUBMISSION LICENCE APPLICATIONS			
8 WKS + 2 WKS 6 WKS		ASSESS ACCEPTIBILITY EIS			ASSESS SUSCEPTIBILITY LICENCE APPLICATIONS		10 WKS 8 WKS 6 MO + 5 WKS
		PUBLICISE EIS			PUBLISH LICENCE APPLICATIONS		
4 WKS			PUBLIC COMMENTS/ ADVICE/ HEARING				
5 WKS			REVIEW EIS BY CMER				
					WRITING DRAFT PERMITS		
					PUBLISH DRAFT PERMIT		
				COMMENTS		PUBLIC COMMENTS/ ADVICE/ HEARING	4 WKS
					FINAL PERMIT		
				APPEAL		APPEAL	6 WKS

ANNEX E GREENPEACE’S PRECONDITIONS

Positive energy balance*

The net energy produced by the biomass cycle (i.e. released solar energy) must be greater than the energy used in its germination-to-generation lifecycle. That is, when all the energy from other sources used to produce, process and transport the biomass are aggregated, this must be less than the amount of energy that is derived from the combustion of the biomass. Only the energy derived above and beyond this threshold may be considered renewable.

Carbon neutral*

The net (carbon) greenhouse gas emission of the biomass cycle used must be zero or negative. That is, the carbon, and carbon equivalent of nitrous oxides, methane and other greenhouse gases released to the atmosphere by the full germination-to-generation cycle must be less than, or equal to, the carbon absorbed or fixed by the biomass itself – including carbon removed or fixed within the soil, sequestration by forest or live crop, greenhouse gases emitted through land use change or net depletion, and greenhouse gases released due to transportation and production of fertilisers and pesticides.

Biodiversity impacts

Biomass production involves production over significant land areas, and this requires careful consideration of potential for biodiversity impacts. Biomass productions must aim to maintain and restore indigenous biodiversity, taking particular account of rare, threatened and endangered species and ecosystems, complement biodiversity conservation strategies, entail no conversion of natural ecosystems, and are guided by the results of environmental impact assessments and on-going monitoring.

GMO-free

The biomass plants, or enzymes used in the processing of the biomass, must not include genetically modified plants or other organisms. This includes agricultural and forestry residues as well as purpose-grown ‘energy crops’ and their conversion to other energy forms.

Sustainable plantation/agriculture

The processes for producing the biomass must be sustainable with respect to water, nutrient and mineral balances within the soil. Biomass production must be constrained to existing agricultural croplands and the restoration of degraded or abandoned land. The production process must also be socially sustainable and therefore responsible in terms of its social impacts. Specific criteria for land-use sustainability are contained within Greenpeace plantations policy documents.

Toxicity

The biomass conversion processes and its secondary effects (i.e. any non bio-organic substances processed along with the biomass) should cause:

- no additional toxic matter – solid, liquid or gaseous
- no net increase in the toxicity of the matter
- a net reduction of the impact of toxic materials with respect to the environment – i.e. improved containment relative to the toxic matter relative to the input material
- no external emissions not related to the carbon combustion process. Emission of pollutants related to the basic carbon combustion process, such as NO_x and $SO_{x,}$ should be equal to best available technology levels.

* Many organic waste streams or residues do not meet the positive energy balance and carbon neutral criteria defined above. However it is useful to recognise that residues which were not designed to be energy sources may be useful sources of energy which are otherwise wasted. In this case it may be appropriate to recognise that the extra energy/carbon which has been spent in the processing has been expended for its primary purpose, not its waste value. Provided that this energy has been expended for the primary purpose of the material, then it may be appropriate to ignore the energy balance and carbon balance before the time of processing when the waste stream was created.

Source: Request for proposal, Greenpeace, 14th October 2004