Air pollutant emissions from stationary installations using bioenergy in the Netherlands

BOLK Phase 2

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Acknowledgement/Preface
This study has been performed for the Netherlands Environmental Assessment Agency/Planbureau voor de Leefomgeving (PBL) (contact: Pieter Hammingh) within the framework of the BOLK program (Beleidsgericht Onderzoeksprogramma Lucht en Klimaat) 2008-2009 for the Dutch Ministry of Housing, Spatial Planning and Environment (VROM) (contact: Jan Wijmenga). This study has been performed by ECN and TNO.

Abstract
This study provides a further inventory of NEC emission factors, population and cost associated with the use of biomass fuels in stationary sources and the production of biofuels in the Netherlands. The study is performed within the BOLK program (Beleidsgericht Onderzoeksprogramma Lucht en Klimaat) 2009-2009 for the Ministry of Housing, Spatial Planning and Environment (VROM) of the Netherlands. The following is concluded:

- Up-to-date, detailed statistical/measurement data on the actual emissions of biomass installations, medium-scale fossil-fired CHP, biofuel production and biomass storage and transhipment is lacking. The population scenarios of technology categories presented in this study are based on 'what-if' scenarios. Data presented in this report contains therefore a relatively large uncertainty and should be used with care.
- For the expected installed biomass capacity in 2020, the range is found to be 80-252 PJ/a, depending on the assumptions made. This is could be 2-6% of the total projected primairy energy use for 2020. Estimations of future contributions of specific bio-energy applications and medium-scale CHP is strongly dependent of subsidies and/or future obligations as these technologies are *1)* currently not competative compared to large-scale fossil applications, *2)* depending on future policys on subsidies or obligations which are currently unknown/uncertain as well, and *3)* dependent on technological and market development.
- The estimated, updated annual emissions in 2020 determined in this study originating from the combustion of biomass in stationary applications, are in the range of 4-11 kton/a for NO_x, 0.3-2 kton/a for SO_x, 1.2-2.5 kton/a for particulate matter, 0.1-0.6 for ammonia and 6-13 for NMVOC under the assumptions for the different scenarios. Significant to observe is that whether or not co-firing will take place on a large scale in 2020 can have a significant impact on the total emissions of NO_x and SO_x from biomass use. However more specific information about fossil fuel replacement and associated emissions is required to determine the substitution effect of fossil fuels by biomass.
- For the pollutants NMVOC and dust, small-scale biomass combustion (wood stoves) contributes a significant part of the total expected emissions of these componenents from biomass use.

Keywords
Biomass, biofuels, biofuel production, combustion, digestion, NEC-emissions, emission factors, flue gas cleaning, populations, BOLK, costs, wood stoves, CHP, gas engines, NO_x, SO_x, NMVOC, dust, PM10, NH_3

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Main messages

- Up-to-date, detailed statistical/measurement data on the actual emissions of biomass installations, medium-scale fossil-fired CHP, biofuel production and biomass storage and transhipment is lacking. The population scenarios of technology categories presented in this study are based on 'what-if' scenarios. Data presented in this report contains therefore a relatively large uncertainty and should be used with care.
- For the expected installed biomass capacity in 2020 the range is found to be 80-252 PJ/a, depending on the 'what-if' assumptions made. This could be 2-6% of the total projected primairy energy use for 2020. Estimations of future contributions of specific bio-energy applications and medium-scale CHP is strongly dependent of subsidies and/or future obligations as these technologies are 1) currently not competative compared to large-scale fossil applications, 2) dependend of future policys on subsidies or obligations which are currently unknown/uncertain as well, and 3) dependent on technological and market developments (*e.g.* second generation biofuels).
- The estimated, updated annual emissions in 2020 determined in this study originating from the combustion of biomass in stationary applications are in the range of 4-11 kton/a for NO_x, 0.3-2 kton/a for SO_x, 1.2-2.5 kton/a for particulate matter, 0.1-0.6 for ammonia and 6-13 for NMVOC under the assumptions for the different scenarios. Significant to observe is that whether or not co-firing will take place on a large scale in 2020 can have a significant impact on the total emissions of NO_x and SO_x from biomass use. However more specific information about fossil fuel replacement and associated emissions is required to determine the substitution effect of fossil fuels by biomass.
- For the pollutants NMVOC and dust, small-scale biomass combustion (wood stoves) contributes a significant part of the total expected emissions of these componenents from biomass use.

Introduction

In the first phase of BOLK (Beleidsondersteunend Onderzoeksprogramma Luchtkwaliteit en Klimaat) a first screening was presented on the NEC emissions (the pollutants NO_x, SO_x, dust, NMVOC, NH_3) of the use biomass in stationary applications. This study deepens and widens the knowledge obtained in the previous phase of the BOLK program on populations, emission factors and costs. As it is expected that the use of biomass and medium-scale fossil fired CHP will increase the coming years due to climate policies, additional information has been collected in the following workprograms (WP), focused on the situation in the Netherlands:

WP1 Estimation of the population of biomass stationary applications now and in 2020, as well as medium-scale fossil fired installations;

WP2 Inventory or estimation of NEC emission factors of biofuel production, medium-scale biomass installations, fossil CHP, and small-scale wood stoves as well as the storage and transshipment of biomass;

WP3 Estimation of the costs of flue gas cleaning for medium- and small-scale biomass applications and biofuel production.

The data presented in this study is based on literature study, internet sources and contacts with relevant companies/authorities. No emission measurements and extensive market consultations/modelling/statistical investigations were performed nor were foreseen. The information generated in this study is also usable as input for a model assessing the relations between climate polity and air quality [ECN, 2009] that will be used during the integration phase of BOLK II in 2010.

Populations
The populations (also called activities) of medium- and small-scale biomass installations and fossil-fired CHP have estimated for 2020 based on the Updated Reference Projections and the two 'what–if' Scenarios Low and High of this study. The results are summarized in Table 1.1, Table 1.2 and Table 1.3 below. Significant to know is that in the Updated Reference Projections co-firing and bio-oil/fat-fired engines are set to zero due to the current absence of SDE subsidie and as a result, these applications are assumed not to be feasible in 2020. Compared to this reference projection, the Scenarios Low and High in this study for 2020 assume more bioenergy use by co-firing in large-scale installations and in small-medium scale installations and more residential stoves (the latter only in the Scenario High).

Based on the different scenarios, the total contribution of stationary bioenergy applications could be 2-6% of the total primairy energy use for 2020 as being estimated in the Updated Reference Scenarios (Daniels and Van der Maas, 2009), depending on the used assumptions. The Dutch renewable target set by the EU is 14% [REN Directive]. The currently known biodiesel, bio-ethanol, and bio-methanol plants represent a total fuel production that is equivalent to approximately 108 PJ/a. This is approximately 2.8% of the primary energy demand projected for 2020, and equal to approx. 16% of the primary energy use in transport.

Table 1.1 Summary of (projected) the use of biomass in stationary applications (in PJ/a input)

	2007	**Updated Reference Projections 2020**	**Scenario Low 2020**	**Scenario High 2020**
Co-firing gas/coal fired power plants	15	0	89	89
Waste incineration (only biogenic)	28	48	41	41
Small-scale biomass combustion/stoves	12	8	8	16
Medium-scale biomass combustion	7	11	49	51
Large-scale biomass combusiton	0	0	0	0
Biogas engines from waste tips	*2*	*0*		
Biogas enginess from AWZI/RWZI	*2*	*8*		
Agricultural biogas plants	*2*	*2*		
Other biogas plants	*1.5*	*2*		
Total anaerobic digestion	7	13	37	50
Bio-oil/fat-fired engines	0.5	0	6	6
Cement industry	-	0	0	0
Total	**71**	**80**	**224**	**252**

Table 1.2 Summary of (projected) capacity of biofuel production in the Netherlands

[kt/a]	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Biodiesel	127	197	1,256	1,256	1,356	2,156	2,156
Bio-ethanol				384	459	459	619
Bio-methanol				200	200	200	800
Fischer-Tropsch biodiesel [a)]				N/A	N/A	N/A	N/A
[PJ/a]	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Biodiesel	4.7	7.3	46.8	46.8	50.6	80.4	80.4
Bio-ethanol				10.3	12.3	12.3	12.3
Bio-methanol				4.0	4.0	4.0	15.9
Fischer-Tropsch biodiesel [a)]				N/A	N/A	N/A	N/A

a No concrete plans with regard to biodiesel production based on Fischer-Tropsch synthesis are available.

Table 1.3 Summary of medium-scale fossil-fired CHP in PJ/a fuel input

	2007	Updated Reference Projections 2020	Scenario Low 2020	Scenario High 2020
Gas engines	97	102	123	150
Gas turbines	3	5	5	5
Total	**100**	**107**	**129**	**156**

Emission factors

Medium- scale biomass and fossil-fired installations

Emission factors for these categories of installations were estimated. It was observed that there is a lack of statistical date correlating relevant parameters required for determining accurate emission factors. The introduction of the new emission legislation BEMS (=Besluit Emissie-eisen Middelgrote Stookinstallaties) will in general have a nivillating and emission reducing effect of the NEC emissions in 2020. In general, the highest emission factors can be found for biomass-fired installations compared to gas-fired installations. This is due to the relatively clean combustion character of natural gas (low sulphur content, low dust, availability of low NO_x combustion). The following tables summarize the results for biomass fired and fossil-fired medium scale installations:

Table 1.4 Estimated NEC emission factors medium-scale biomass installations, 'max' indicates an emission limit, bold = used value for impact analysis 2020

Type of installation	Period	NO_x [g/GJ]	SO_x [g/GJ]	Dust/ PM10 [g/GJ]	PM2.5 estimate [fraction of PM 10]	NMVOC [g/GJ]	NH_3 [g/GJ]
Solid biomass boiler	2008/2009	67 [a)] 100[k)] max 70-130 [d)]	10 (range 6-40) [g)] 5[j)] 0-2 (installation Cuijk)[j)]	5 [a)]	0.79 [f)]	3.3-48 [g)] 60 [g)] 100 [i)] (for Belgium, GAINS data)	-without deNOx: 0 -with deNOx: 1,7 g/GJ [d)] (Installation Cuijk)
	2020	max **35** [b)] or 40 [k)]	**10** (range 6-40) [a)] max 68 [b)]	max **1,7** [b)]	0.79 [f)]	**60**, assumed to be the same as in 2009	**1,7** (SCR assumtion)
Bio-oil/fat in dieselengine	2008/2009	30-150[n)] max 130[e)] max 400-1200 (diesel)[d)]	0[a)], 1-22 [n)] max 9 [e)]	25[a)] 2-4[n)] max 13-17 [e)]	N/A	100 [h)] 31 (CxHy) [e)]	max 4.4 [e)]
	2020	max **130** [b)]	**9** [e)] max 69-70 [c)]	max **17** [c)]	N/A	**31**, assumed to be the same as in 2009, worst case	max **4.4** [c)], SCR assumption
Biogas in gas engines	2008/2009	max 140 (new)-800 (old)[a)] 175-195[p)]	0,5[a)] 2 [l)] 10 [m)]	0,5[a)] 2 [l)]	*1 (estimate based on natural gas) [f)]	4-14 [g)] 14 [j)]	-without De-NOx: 0 -with SCR 0.10-0.15 g/GJ (natural gas) [o)]
	2020	max. **30** (intention VROM for three years after introduction BEMS, until then: 100 [c]	**2** [l)] max approx 70 [b)] .	No limit, **0.5** assumed	*1 (estimate based on natural gas) [f)]	**14**, assumed to be the same as in 2009	All SCR assumed: **0.15**

References: a) Daniels, 2008; b) VROM, 2008; c) VROM, 2009; d) Kroon, 2008; e) BIOX, 2007; f) Visschedijk, 2007; g) EMEP, 2009; h) NERI, 2007; i) De Groot, 2008; j) De Wilde, 2006; k) Kroon, 2009a; l) Guis, 2006; m) Gijssen, 2001; n) Toom, 2009; o) Olthuis, 2007; p) Engelen

Table 1.5 Estimated NEC emission factors medium scale fossil-fired installations, ('max' indicates an emission limit)

Type of installation	Period	NO_x [g/GJ]	SO_x [g/GJ]	Dust/PM10 [g/GJ]	PM2.5 estimate [fraction of PM 10]	NMVOC [g/GJ]	NH_3 [g/GJ]
Gas engine	2008/2009	Average 16 (greenhouses, with SCR on)[k)] 166-333 (greenhouses with SCR off)[k)] 174 greenhouses [e)] 200 other [e)]	0.22 [a)]	0.15 [a)] 0.19 [g)]	*1 [e)]	117 [b)] (no oxycat) +/- 0 (with oxycat) 46 (incl 5% gas oil) [c)]	approx. 0.10-15 with SCR[j)] 0 without SCR [j)] Average: 0.05-0.07
	2020	>2,5 MW_{th}: max 30 [f)] <2,5 MW_{th}: max 30 (intention VROM after three years, until then: 80. [f)]	0.22 [a)] max 67 [f)]	No limit, 0.15 assumed	*1 [e)]	117 (no oxycat > worst case)	0.15 assuming SCR
Gas turbine	2008/2009	58 [h)]	0.22 [a)]	0.15 [a)]	*1 [e)]	1.4 [b)]	0 (assumed no SCR needed)
	2020	max 40 [f)]	max 67 [f)] 0.22 [a)]	No limit, 0.15 assumed	*1 [e)]	1.4, assumed to be the same as in 2009	0 (assumed no SCR needed)
Gas fired boiler	2009	40 [h)]	0.22 [a)]	0.15 [a)]	*1 [e)]	1-4 [b)] 1-3 [c)]	0 (assumed no SCR needed)
	2020	max 20 [f)]	max 67 [f)] 0.22 [a)]	No limit, 0,15 assumed [a)]	*1 [e)]	4, assumed to be the same as in 2009	0 (assumed no SCR needed)

References: a) Guis, 2006; b) NERI, 2007; c) EMEP, 2009; d) Kroon, 2008; e) Visschedijk, 2007; f) VROM, 2008; g) De Wilde, 2006; h) Kroon, 2009; i) Kroon, 2008a; j) Olthuis, 2007; k) Engelen, 2009

Small scale biomass combustion - wood stoves

The found emission factors in this study for current and future wood stoves are presented in Table 1.6. To convert the emission factors in g/kg fuel to g/GJ the factors have to be multiplied by 34.1 for waste and 64.5 for wood fuels. This multiplication is based on the assumed net heating values (LHV) as used in the Dutch emission inventory. Only the emission factors of wood have been used in this study, as the contribution of waste is relatively low compared to wood.

Table 1.6 Emission factors used by the Dutch emission inventory [www.emissieregistratie.nl]

Fuel	Compound	Unit	Approved stoves	Unapproved stoves	Open fire places
Waste	CO_2	kg/GJ	109.6[a]	109.6 [a]	109.6 [a]
	NMVOC	g/kg	3 [b]	5 [c]	5 [c]
	NO_x	g/kg	2 [c]	2 [c]	2 [c]
	PM_{10}	g/kg	20 [b]	40 [c]	11 [c]
	$PM_{2,5}$	g/kg	12 [b]	24 [c]	6.6 [c]
	SO_2	g/kg	2 [d]	2 [d]	2 [d]
	NH3	-	No data	No data	No data
Wood	CO_2	kg/GJ	109.6 [a]	109.6 [a]	109.6
	NMVOC	g/kg	6 [e]	12 [e]	20 [c]
	NO_x	g/kg	2 [c]	2 [c]	1.2 [g]
	PM_{10}	g/kg	1.5 [f]	3 [f]	2.5 [c]
	$PM_{2,5}$	g/kg	1.4 [f]	2.8 [f]	2.4 [c]
	SO_2	g/kg	0.2 [g]	0.2 [g]	0.2 [g]

References: a) Vreuls,2006; b) Schatting TNO; c) Slob,1993; d) van Dijck; e) Veldt, 1995; f) CEP-MEIP 200; g) EPA,1996b et al., 1993

Biomass transshipment and storage
In the long term, the storage and transshipment of biomass could be in the order of respectively 13-20 Mton/a [Schonewille, 2009] and 6 Mton/a for the harbour of Amsterdam [Gorris, 2009]. The expected main biomass stream is wood pellets, but some wood chips can be imported as well, depending on the economic conditions. However, it is also indicated that torrefaction pellets can be of importance in the future, which maybe stored outside. Not much information is available on the (fugitive) particulate matter emissions during storage and transshipment.

Assuming that 20 Mton wood pellets per year will be imported using an emission factor for closed systems (transport and storage), a first order estimation of PM_{10} emissions for 2020 is around 0.016-0.020 kton/year. This represents around 1.6-2.0% of the total emissions from bulk storage and transshipment and 0.04-0.05% of the total national dust emissions in 2008. When wood chips instead of pellets are assumed, based on a typical S5 emission factor of the NeR, the estimate of the emissions is around 0.01 kton/a (= 1% of current the bulk storage and transshipment emissions and 0.03% of the total emissions), without any abatement. The current total dust emission of transshipment and storage activities is reported to be around 1 kton/a [Daniels, 2008]. Total dust emissions for the Netherlands in 2008 are 37 kton [Natuur en Milieu Compendium, 2009]. Therefore, the contribution of this possible source of dust appears to be not very large. However, it is possible that locally the dust concentration can be increased due to biomass transshipment and storage activities. The uncertainty in these numbers is assessed to be large, due to lack of reliable data.

Biofuel processes
The emissions for the various types of biofuel production processes have been estimated based on permit and can vary widely. This can be attributed to the variation in types of processes and also the type of permit (with or without combustion plant). The indicated emissions are allocated int this study to the biofuel product. Due to the complexity of biofuel plants (often multiple (wet) input and multiple output), this study provides a first indication of expected emissions. Emissions arising from production utilities (boiler, CHP) are often not known or available.

With respect to the expected NEC emissions of biofuel production: NMVOC emissions will arise mainly from the biofuel production/storage itself and are found in the range of a maximum of 0.26-1.4 g/GJ fuel. Especially NO_x and SO_x emissions will arise from the required heat and power utilities for the biofuel production process, although SO_x emissions are expected to be very low when natural gas is used for firing. Per GJ product, the NO_x emissions are around 0.5-2.3 g/GJ fuel product, which is low compared to the emissions during end use. SO_x emissions are in the range of 0.2-1.9 g/GJ fuel. NH_3 emissions are expected to be limited and are not mentioned in permits. No significant dust emissions are expected from the biofuel production itself. Some processes use closed transport systems to prevent the emission of dust.

Emissions reduction costs and performances, biofuel costs
Flue gas cleaning for medium scale biomass applications
For all NEC pollutants, mature and effective emission reduction techniques are found to be available. Technologies, performance and costs have been identified/estimated for wood combustion, digestion and bio-oil/fat-fired engines. However, all cost data, both investment and operational cost data, show broad ranges due to differences in primary combustion processes, process conditions, size of equipment, amount of pollutants to be removed, and other aspects of importance. For some emission reduction measures, information in the public literature is scarce. More precise data can only be determined for a specific installation with specific process conditions. It appeared not possible to obtain a clear relation between costs and performance of a specific emission reduction technique due to lack of available information. No generalized conclusions could be drawn concerning the additional costs for retrofit compared to newly build emission reduction techniques. As retrofit costs are determined strongly by the existing set-up of

a plant and the possibilities of fitting in a new emission reduction technology in the existing plant, no general cost factor should be used.

Flue gas cleaning for wood stoves
There are several technologies available to reduce air pollutant emissions (dust and VOC) from stoves such as electronic precipitators, catalysts or using approved stoves in stead of unapproved.

The PM_{10} cost effectiveness for installing approved stoves instead of unapproved stoves seems most advantegeous and is around 30-50 euro per kilogram of reduced PM_{10} emission depending on the assumed wood use. Other benefits of better stoves are that they also reduce the emission of CO, NMVOC and other products of incomplete burning. The PM_{10} cost effectiveness of electrostatic precipitators in new stoves is much higher, at least 200 Euro per kilogram PM_{10} emission prevented and this device does not reduce other pollutants. Cost of installing electrostatic precipitators in existing stoves is more expensive due to high labour costs associated with the integration of the device within the current configuration.

Biofuels production costs
With regard to the production costs of biofuels that are of interest for the Netherlands, no more than rough estimates or indicative data could be provided at this stage. There is a relatively large uncertainty with regard to current and future production costs. This is because (Dutch) data on actual operation and maintenance or feedstock costs of biofuel plants is scarce or incomplete due to the confidential nature of these data. The costs of biofuels are expected to increase which is related to an assumed increased demand for food. The roughly estimated production costs (excluding transport, taxes and profits) of the biofuels may be summarised as follows:

- Production costs of biodiesel range from € 0.30-0.58/l in 2010 to € 0.41-0.76/l in 2020.
- Production costs of bio-methanol range from € 0.22-0.30/l in 2010 to € 0.37-0.45/l in 2020.
- Production costs of bio-ethanol range from € 0.27-0.37/l in 2010 to € 0.47-0.57/l in 2020.

Estimation air pollutant emissions from stationary installations using biomass in the Netherlands
In this study, the effects on air pollutant emissions of the use of biomass in small- to large- scale stationary applications has been estimated based on new population and emission factor estimates. The estimation is an update of the estimation as performed in the integration phase of BOLK I [Hammingh et al, 2008]. It should be noted that the uncertainty in the presented numbers (population and emission factors) is large and therefore only give an order of magnitude estimation.

Table 1.7 Biomass use in stationary applications and air pollutant emissions in 2020

Scenario		Biomass use in 2020	NO_X	SO_x	NH_3	Dust	NMVOC
		[PJ/a]	[kton/a]	[kton/a]	[kton/a]	[kton/a]	[kton/a]
Estimated emission level in 2007		*71*	*5.3*	*0.5*	*0.1*	*2.2*	*10*
BOLK Phase 1	Reference Projections 2007	215	18	1.7	0.7	1.2	0.5
BOLK Phase 2	Updated Reference Projections 2009	80	3.5	0.3	0.1	1.2	6
	Scenario 'Low'	224	10	1.8	0.6	1.4	9
	Scenario 'High'	252	11	1.9	0.6	2.5	13

The following observations have been made. The updated Reference Projection 2009, which is the most important baseline projection of the Netherlands, does not include any co-firing in large scale power plants in 2020, due to the current absence of SDE subsidies. The previous reference emission projections of 2007 and the two scenarios Low and High of this study do include a certain amount of co-firing. The more detailed analysis (Chapter 5) in this report shows that the co-firing is one the main reasons why the total emissions from biomass use for the latter scenarios are higher, especially for NO_x, SO_x and NH_3 (originating from the de-NOx installations (SCR)). The total NH_3 emissions from this source are still low compared to emissions from agricultural activities.

Compared to the previous emissions estimates in BOLK-1, the total estimated NO_x emissions in this study are significantly lower in the low and high scenarios: 18 vs. 10-11 kton/a. The main explaination for this is that the applied NO_x emission factor for medium-scale installations (category 'combustion other' in the previous phase) in this study been significantly decreased compared to the previously used value. In BOLK-1, a maximum emission factor of 1020 g/GJ was assumed compared to the currently expected emission limit values for 2020 of 130 g/GJ for bio-oil/fat-fired engines and 40 g/GJ for solid biomass-fired installations. These values are based on the new emission legislation BEMS.

Mainly due to a significant increase of the applied NMVOC emission factor for small- and medium solid biomass-fired installations, the total expected NMVOC emissions has increased significantly from 0.5 to 6-13 kton/a.

This report shows that the contribution of wood stoves to the overall emissions from biomass stationairy sources is more than proportional in all scenarios especially for dust and NMVOC. The high emission factors for dust and NMOVC are the result of the absence of flue gas cleaning and less optimized combustion conditions in these wood stoves. This also explains the main difference between the scenarios High and Low as the fuel input for wood stoves doubles from 8 to 16 PJ/a between these two scenarios.

Discussion
Basic statistical data with sufficient detail and correlating relevant data (NEC emissions coupled with size, fuel (composition), flue gas cleaning measures, efficiency) is not found to be available for the studied categories. No statistical investigations or measurements could be performed in this study: results presented are based on available data and public literature and estimations.

Estimations of future contributions of specific bio-energy applications and medium-scale CHP is strongly dependend of subsidies and/or future obligations as these technologies are 1) currently not competative compared to large scale fossil applications and 2) future policies on subsidies or obligations are currently unknown/uncertain as well as 3) dependent on technological and market developments (*e.g.* second generation biofuels).

Actual emission factors can be very site specific and depend of a large number of factors (such as technology, fuel, permit, scale, emission-reducing measures). As such, often there is not a single identifiable emission factor for a certain technology, but there will be a range of emission factors, sometimes limited by a legal emission limit.

The above observations should be kept in mind when using the results of this study. Especially when assessing the environmental effects of the use of a specific technology if estimated populations (with a high uncertainty) are multiplied by an estimated emission factor (with a high uncertainty). The numbers presented in this study should therefore used with care, but can give a first indication of expected effects.

Recommendations
From this study, the following recommendations are proposed:

- To have a more detailed insight in the correlation between installation and emissions, e.g. within existing structures at CBS/Emissieregistratie, it is recommended to improve the registration/availability and coupling of relevant data. Current studies are often based on generic assumptions on populations and associated specific (international) emission factors.
- To have a more detailed insight in the cost for gas cleaning, an extensive collaboration and/or consultation with several flue gas cleaning equipment manufacturers would be recommended. Aspects hare are the relation between removal technology, size, initial/end concentration, new/retrofit, process conditions on one hand and the associated investment and operating costs on the other hand. Even then, a large spead in data can be expected, and the result will be time dependent.
- Improve the data on biomass storage and transshipment by performing specific emission measurements on this activity.
- Improve the data on NMVOC for the Dutch situation by measuring this component for a number of specific, representative installations.
- Improve the data on biofuel production emissions by further extending the studied permits and obtain actuel emission data (if possible/available) from biofuel producers.
- It should be noted that although it would be desirable to have access to these data, the cost of obtaining them (and maintaining them) will be substantial.

1. Introduction

1.1 Background

In the first phase of BOLK (Beleidsondersteunend Onderzoeksprogramma Luchtkwaliteit en Klimaat) a first screening was presented on the NEC emissions (the pollutants NO_x, SO_x, dust, NMVOC, NH_3) of the use biomass in stationary applications [ECN, 2008a]. This study deepens and widens the knowledge obtained in the previous phase of the BOLK program.

1.2 Problem definition and objectives

After integration the BOLK projects by ECN and PBL, it was concluded that information on specific subjects was missing or required further study to obtain a good insight in the consequences of using biomass in stationary applications. As it is expected that the use of biomass and medium-scale fossil fired CHP will increase the coming years due to climate policies, additional information has been collected in the following workprograms (WP), focused on the situation in the Netherlands:

WP1 Estimation of the population of biomass stationary applications now and in 2020, as well as medium-scale fossil fired installations;

WP2 Estimation of NEC emission factors of biofuel production, medium-scale biomass installations, fossil CHP, and small-scale wood stoves as well as the storage and transshipment of biomass;

WP3 Estimation of the costs of flue gas cleaning for medium and small scale biomass applications and biofuel production.

The information generated in this study is primairily intended to serve as input for a model assessing the relations between climate polity and air quality by the Energy Research Centre of the Netherlands (ECN)/Policy Studies and the Netherlands Environmental Assessment Agency (PBL) during the integration phase of BOLK II.

1.3 Approach

The data presented in this study are based on literature study, internet sources and a number of limited contacts with relevant companies/authorities. No emission measurements and extensive market consultations/modelling/statistical enquiries were performed nor were foreseen in this limited study. This should be kept in mind when using the results of this study, especially when assessing the environmental effects of the use of a certain technology if estimated populations (with a high uncertainty) are multiplied by an estimated emission factor (with a high uncertainty). The numbers presented in this study should therefore used with care, but can give a first indication of expected effects.

The total project duration was around 650 hours. The following authors contributed to this study:

- A.R. Boersma (ECN BKM[1]): emissions of medium-scale biomass/fossil-fired installations and biomass storage/transshipment and overall project management;
- J. van Doorn (Kodok): costs of flue gas cleaning for medium-scale biomass installations;

[1] BKM = Biomass Coal and Environmental Research

- D.C. Heslinga, B. Jansen and H.J.G. Kok (TNO): population, emissions and cost of flue gas cleaning for wood stoves;
- P. Lako (ECN Policy Studies): populations of biomass stationairy applications, medium-scale fossil CHP and biofuel production costs and populations;
- R. van der Linden (ECN BKM): emissions of biofuel production.

1.4 Reading guide

The structure of this report is as follows:

Chapter 2 decribes the results of the population studies (current and estimated future activities). In Chapter 3, the focus is on the emission factors of the examined technologies and processes, while in Chapter 4 cost and performance data is presented on emission reduction measures and biofuel production. The overall emission effects of using biomass in stationairy applications (impact analysis) are illustrated in Chapter 5. Chapter 6 gives the conclusions of this project. The recommendations are finally presented in Chapter 7.

2. Populations

2.1 Current status and perspectives of biomass co-firing, medium-scale biomass conversion and medium-scale cogeneration

2.1.1 Introduction

This section presents the current status (existing population) of medium-scale cogeneration plants (upto several tens of MW_{th}), taking into account autonomous growth and (if applicable) policy induced growth - as well as different types of biomass conversion plants in the Netherlands. The main questions addressed are a) what the current status and the perspectives are of biomass conversion plants in the Netherlands. to what extent cogeneration based on gas engines has captured the market and what the perspectives are of this type of CHP (combined heat and power), and

The current status and the medium-term (2020) perspectives of cogeneration based on gas-fired gas engines and biomass conversion plants is important in view of policies with regard to emission reduction of greenhouse gases (notably CO_2) and other airborne pollutants, like NEC components. Most technologies considered are aimed at energy conservation (cogeneration based on gas engines), reduction of greenhouse gases (biomass conversion) or both.

2.1.2 Approach

The research includes a review of specific energy and other statistics of the Netherlands, literature research, and interviews with a number of key players in the field of biomass conversion. No (extensive) modelling was performed. The presented future populations are based on ‘what-if’ scenarios. In the current timeframe (2009), there are a lot of developments in cogeneration and biomass conversion. Most of them have been reported in this study. However, some initiatives or developments may have been omitted since information was not yet complete and/or publicly available. Also, information may be subject to changes, such as postponement of envisioned biomass conversion projects and the availability of subsidies. The global economic recession may cause cancelling of bio-energy projects or a slowdown of growth in categories under consideration to a larger extent than anticipated. The indicated future populations contain therefore a large uncertainty.

The following sections describe:

- Co-firing in coal-fired power stations (Section 2.1.3)
- Medium-scale biomass combustion and anaerobic digestion plants with CHP (Section 2.1.4)
- Cogeneration based on gas-fired gas engines and gas turbines (Section 2.1.5)

The categories above are chosen due to the fact that they play a major role in the Schoon en Zuinig program/SDE subsidy. These three sections are then summarised in Section 2.3.1 and compared to the ‘Updated Dutch Reference Projections 2008-2020’ [Daniels and Van der Maas, 2009]

2.1.3 Co-firing in coal-fired power stations

This section reviews the current status and perspectives of co-firing of biomass in existing and future coal-fired power plants. Existing coal-fired power plants in the Netherlands have a generating capacity of approximately 4,200 MW_e. Table 2.1 shows data of biomass co-firing in existing plants and data of coal-fired plants under construction or firmly planned. In 2006, approximately 800 kilotonnes (kt) of biomass were co-fired, mainly based on direct co-firing and to a small extent based on gasification with co-firing of the produced gas in the boiler. The Amer power station (Geertruidenberg) has a substantial potential for additional co-firing. Gelderland-13 (Nijmegen) has a permitted level of co-firing of 400 kt/a, equivalent to 25% fuel substitution or 150 MW_e. If co-firing would be stretched to the permitted levels, approximately 2,800 kt/a of biomass could be used in 2013, equivalent to 25% coal substitution or 1,000 MW_e - 2.8 times the average of 2007-2008 (Figure 2.1).

Accordingly, CO_2 emissions could be reduced by 5.9 Mt/a CO_2 in 2013 compared to 2.1 Mt/a CO_2 on average in the timeframe 2007-2008, based on an average generating efficiency of coal-fired power plants of 38.5%, and a generic emission factor of 93 kg CO_2 per GJ of coal. Modifications to increase co-firing will take four years or more. Therefore, additional co-firing of biomass (to the tune of 1,800 kt/a) in existing coal-fired plants could result in additional emission reduction of approximately 3.8 Mt/a CO_2 in 2013.

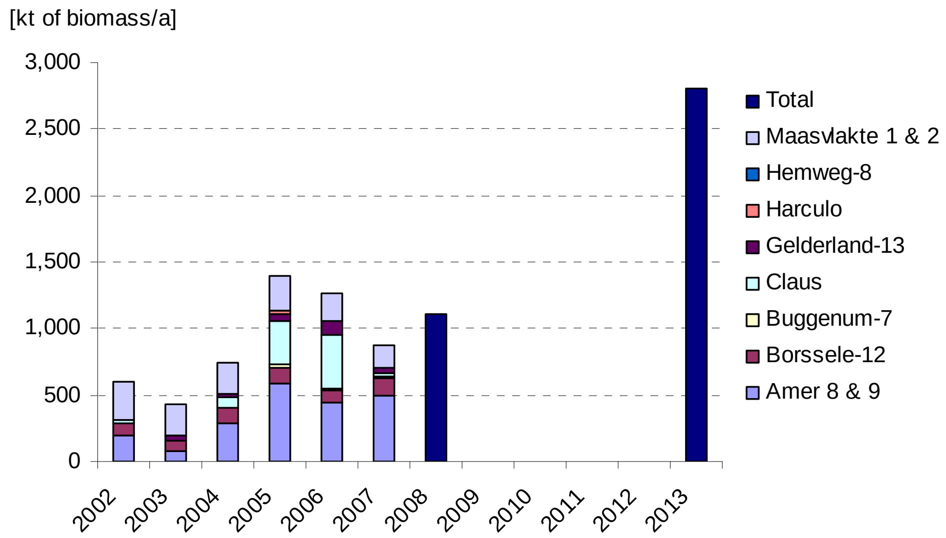


Figure 2.1 Potential of co-firing of biomass in Dutch coal-fired power plants

Note: Total co-firing of biomass of 2,800 kt/a in 2013 (or 2014) only refers to coal-fired power plants. From 2008 onwards, only co-firing in coal-fired power plants is considered (see the paragraph below Figure 1.2).

Sources: SenterNovem, 2008 and 2009; Electrabel 2008; NUON, 2006; CBS, 2008-2009.

A number of coal-fired power plants - four pulverised coal-fired units and one IGCC (Integrated Gasification Combined Cycle plant, starting as a gas-fired combined cycle plant) of NUON (Magnum project) - with a total capacity of approx. 4,500 MW_e are under construction or firmly planned (see Table 2.1).

This figure of 4,500 MW_e for new coal-fired capacity is largely in agreement with the capacity assumed in the 'Updated Dutch Reference Projections 2008-2020' (Daniels and Van der Maas, 2009). The only difference is that the NUON power plant in the Eemshaven is considered as an IGCC in the present study and as a combined cycle natural gas plant (which is indeed the initial stage) by Daniëls and Van der Maas.

New coal-fired power plants have a higher maximum electrical generating efficiencies (46%) than existing ones (40-43%), based on the lower heating value (LHV) of coal. If we assume that 25% of the coal would be substituted by biomass, this could result in an emission reduction of approximately 5.9 Mt of CO_2 per year based on an average generating efficiency of 44%, and a generic emission factor of 93 kg CO_2 per GJ of coal. New coal-fired units compete to some extent with existing ones. Therefore, the aforementioned CO_2 emissions reduction potentials - 5.9 Mt of CO_2/a based on existing coal-fired power plants and also 5.9 Mt of CO_2/a based on new coal-fired plants - are not quite independent, and may not be simply added up. With regard to co-firing in other power plants than coal-fired power plants, see the paragraph below Figure 2.2.

If co-firing in existing coal-fired plants would be stretched to the limits permitted, and biomass is gradually phased-in in new coal-fired power plants (partly at the expense of existing plants), the amount of biomass used and biomass-based power generated could evolve as shown in Figure 2.2. In 2020, biomass co-firing could amount to:

- 4,460 kt/a biomass.
- 10,500 GWh/a.
- CO_2 emission reduction to the tune of 7.0 Mt CO_2/a.

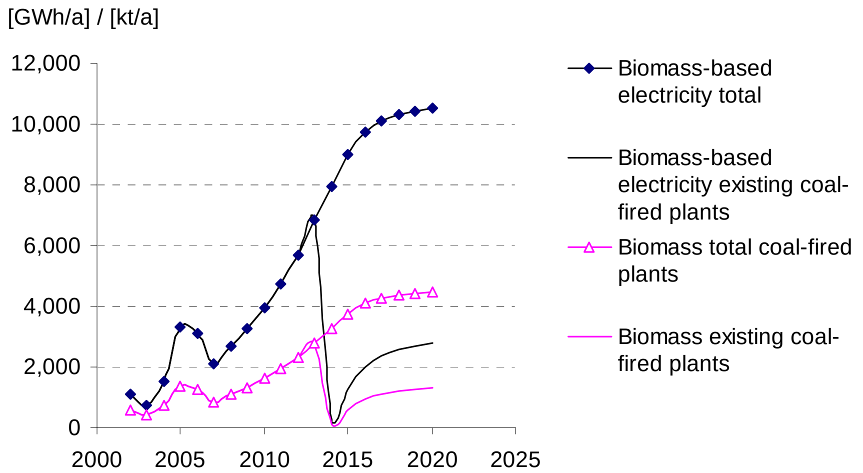


Figure 2.2 Potential of co-firing of biomass in existing and new coal-fired power plants

Note: The curves present the results of co-firing of biomass aggregated for all coal-fired plants or for existing coal-fired plants. In 2014, it is assumed that biomass is shifted to new coal-fired power plants as these plants have higher generating efficiencies (up to 46% net efficiency, 44% on average during a year) than existing plants (up to 40-43% net efficiency, 38.5% on average). Around 2013, five new coal-fired power plants (one of which initially operated as a gas-fired combined cycle power plant) will enter service, which combined may produce 28.5 TWh per year, about 15% more than all existing coal-fired power plants. Therefore, existing coal-fired power plants will shift more and more to medium load (capacity factor 50% or less instead of approximately 70% today). After 2014, incremental co-firing may be realised in existing coal-fired plants. Growth of co-firing may be limited by the possibility of closing import contracts for biomass.

References: Novem, 2004; SenterNovem 2005a, 2005b, 2007a, and 2008; CBS, 2008-2009.

The expansion of biomass co-firing as exhibited in Figure 2.2 has several restrictions, namely the time needed for modifications for increased co-firing at existing coal-fired power plants, the period of time needed for construction and commissioning of new coal-fired power plants, the need to secure long-term import contracts for biomass and permitting.

It is noteworthy, that co-firing of biomass in existing or new coal-fired power plants is not assumed to be implemented in the 'Updated Dutch Reference Projections 2008-2020' (Daniels and Van der Maas, 2009), as there is currently (September 2009) no subsidy available for this category in the SDE (Stimulering Duurzame Energieproductie), assuming no co-firing obligation. In the present study, however, this constraint is neglected as the potential is indicated irrespective of availability of subsidy.

Table 2.1 Overview co-firing of biomass in coal-fired power plants, existing or under construction/planned

Coal-fired power plant	Start of operation	Net capacity		Net efficiency	Co-firing capacity permitted	Co-firing capacity permitted	Co-firing (2007)
		[MW_e]	[MW_{th}]		[MW_e]	[kt/a]	[kt/a]
Existing							
Amer-8	1981	645	250	40		} 1,200	} 497
Amer-9	1994	600	350	43			
Gelderland-13	1982	602	PM	40.0		400	43
Maasvlakte-1	1989	520		40		} 288	} 174
Maasvlakte-2	1988	520		40			
Borssele-12	1988	406		40		600	123
Hemweg-8	1995	630	-	43		40	-
Buggenum-7 [a]	1993	253		43		330	25
Subtotal		**4,176**			**~ 1,000**	**2,858**	**862**
Under construction/planned							
Maasvlakte-3	2012?	1,055		46			
Electrabel Maasvlakte	2013?	700		46			
RWE Eemshaven-1	2012?	780		46			
RWE Eemshaven-2	2012?	780		46			
NUON Eemshaven	2013?	1,200					
Subtotal		**4,515**					

a Buggenum-7 is also used to be named the 'Willem-Alexander' power plant.

References: SenterNovem, 2008 and 2009; Electrabel 2008 (Gelderland-13); NUON, 2006 (Buggenum-7); KEMA 2006 and 2007 (Maasvlakte-3); IBR 2009 (Electrabel Maasvlakte).

2.1.4 Medium-scale biomass combustion and anaerobic digestion plants with CHP

In 2006 and 2007, five small (stand-alone, no co-firing in a coal/gas-fired power plant) biomass combustion plants of around 1 MW_e and 37 anaerobic digestion plants were commissioned, with a total capacity of 32 MW_e (See Table 2.2).

Figure 2.3 shows the cumulative capacity of this type of biomass plants. The combined capacity was approximately 47 MW_e (including Essent's 25 MW_e wood-fired power plant at Cuijk) in 2003, and 94 MW_e in 2007. In 2008, four biomass-fuelled power plants of HVC Alkmaar, Twence Hengelo, AVR Rozenburg (22 MW_e), and DEP Moerdijk (based on chicken litter) were put in operation or ready for commissioning with a combined capacity of 112 MW_e. Also in 2008, the capacity of anaerobic digestion plants increased to 95 MW_e [SenterNovem, 2009]. Therefore, by the end of 2008 the medium-scale biomass-based capacity was at around 260 MW_e.

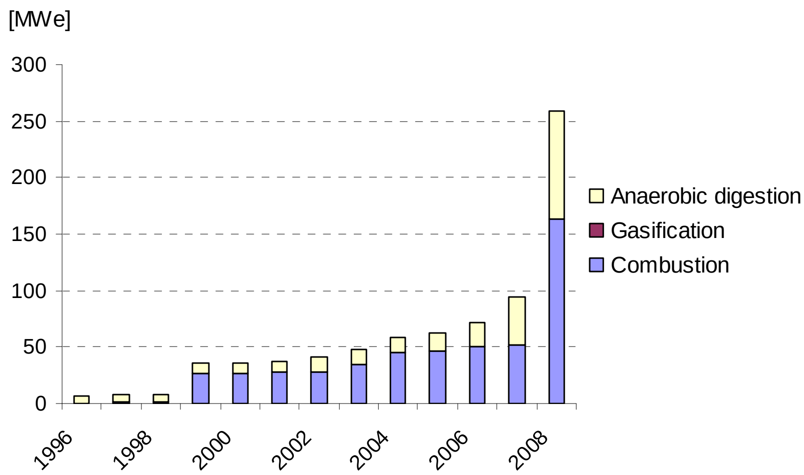


Figure 2.3 Cumulative capacity small-case biomass combustion and anaerobic digestion

Note: Only one small-scale gasification plant with a gas engine has been realised until this date.

Sources: Novem, 2004; SenterNovem 2005a, 2005b, 2006, 2007a, 2007b, 2008, and 2009.

For the period until 2020, two 'what-if' scenarios for medium-scale biomass-based installations are considered:

1. Expansion of biomass combustion or gasification by 10 MW_e per year, and expansion of anaerobic digestion plants by 20 MW_e per year (scenario 'low'), which is considered as a lower bound.
2. Expansion of biomass combustion or gasification by 15 MW_e per year, and of anaerobic digestion plants by 30 MW_e per year (scenario 'high'), which is considered as an upper bound.

These scenarios are based on rather rough estimates of additional capacity of biomass plants based on indigenous biomass, the potential for anaerobic digestion and co-digestion at farms in the Netherlands, and saturation effects from co-firing of biomass in coal-fired power plants and medium-scale biomass installations.

Table 2.2 Known medium-scale biomass conversion plants commissioned in 2006-2007

Site	Start of operation	Project description	Capacity [MW_e]
Combustion			
Berlikum	2006	Wood combustion	0.50
Berlikum	2006	Wood combustion	1.00
Delfgauw	2006	Bio-oil for peak shaving	
Sittard	2006	Bio-power based on ORC	1.20
Goor	2006	Residual wood combustion	1.60
Beetgum	2007	A-wood combustion	1.00
Anaerobic digestion			
Biddinghuizen 1	2006	Manure and agricultural residues	0.33
Donderen	2006	Manure and biocrops	0.68
Esbeek	2006	Manure, roadside grass, etc.	0.60
Gaasterland	2006	Manure & agricultural res.	0.19
Goutum	2006	Idem	0.03
Hooghalen	2006	Idem	0.30
Kraanswijk/Groenlo	2006	Idem	0.19
Leeuwarden	2006	Idem	0.19
Lelystad	2006	Idem	0.28
Nieuweroord	2006	Idem	1.60
Oosterwolde	2006	Idem	0.34
Putten	2006	Idem	0.35
Tietjerkstradeel 1	2006	Idem	0.19
Ysselsteyn 1	2006	Idem	0.69
Aldeboarn	2007	Idem	0.40
Baarlo	2007	Idem	0.84
Biddinghuizen 2	2007	Idem	0.65
Egchel	2007	Idem	0.54
Feerwerd	2007	Idem	0.36
Giethoorn	2007	Idem	0.84
Grubbenvorst	2007	Idem	0.54
Heeswijk-Dinther	2007	Idem	1.00
Kielwindeweer	2007	Idem	1.70
Marknesse	2007	Idem	1.40
Mussel	2007	Idem	0.69
Onstwedde	2007	Idem	0.54
Oude Zeug	2007	Idem	0.90
Tweede Exloërmond	2007	Idem	N/A
Tietjerkstradeel 2	2007	Idem	0.19
Veendam	2007	Idem	1.90
Vlagtwedde	2007	Idem	0.53
Vredepeel	2007	Idem	0.54
Warmenhuizen	2007	Idem	0.72
Well	2007	Idem	1.00
Wilbertsoord	2007	Idem	3.20
Winsum	2007	Idem	0.53
Ysselsteyn 2	2007	Idem	2.12
Cumulative 2006-2007			**~ 32.4**

Sources: SenterNovem, 2007a; SenterNovem, 2008.

Recently, the Minister of Economic Affairs published data of biomass-based capacity in the framework of the SDE. Until May 6th 2009, a total capacity of 184 MW_e had been submitted for subsidy in the SDE, whereas the budget for 2009 only allowed 43-55 MW_e of new capacity [Ministry of Economic Affairs, 2009]. This recent information has not been explicitly included in the two scenarios described above. The aforementioned range of 20 to 30 MW_e per year seems to be representative, considering limits to the amount of biomass that is available in the Netherlands and competition for biomass from, e.g.z biofuel production.

Figure 2.4 shows the capacity of combustion and anaerobic digestion plants from 2000 to 2020 for scenario 'Low', and Figure 2.5 shows the capacity for scenario 'High'.

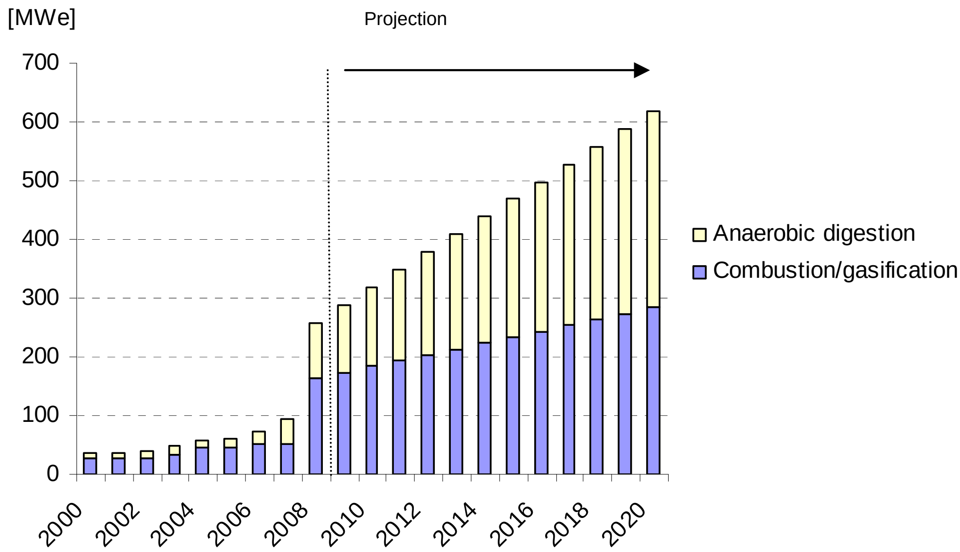


Figure 2.4 Electric capacity biomass combustion and anaerobic digestion 2000-2020, scenario 'Low'

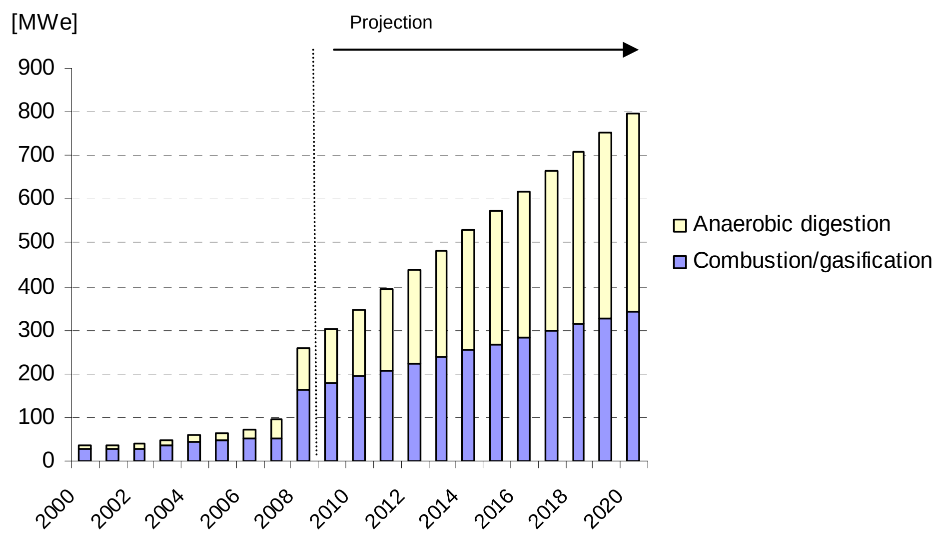


Figure 2.5 Electric capacity biomass combustion & anaerobic digestion 2000-2020, scenario 'High'

The capacity of medium-scale biomass installations may be increased in these 'what-if' scenarios from 258 MW_e in 2008 to 320-350 MW_e in 2010 and 620-800 MW_e in 2020. In the 'Actualisation of the Reference Projections, the capacity of medium-scale biomass installations is estimated at 254 MW_e in 2020, as a subsidy in the SDE was not available at the time of drafting of that study (September 2009). In this study, it is assumed that sufficient subsidy for biomass CHP plant is available. SDE tariffs for biomass installations can differ for technologies and scales[2].

Diesel engines based on (vegetable) bio- oil
Kroon and Wetzels (2008) analysed the status and prospects of diesel engines for power or CHP, based on bio-oil (vegetable oil). They assume that the total capacity could be increased from 10 MW_e to 110 MW_e in 2020. The total fuel use (bio-oil) in 2020 could amount to 5.5 PJ, or 0.1% of the primary energy demand projected for 2020.

2.1.5 Cogeneration based on gas-fired gas engines, gas turbines, etc

This section presents the status of medium-scale cogeneration based on gas-fired gas engines for CHP as well as gas turbines or oil-fired diesel engines for power generation or CHP with a capacity of less than 50 MW_{th} (based on the amount of fuel used) - gas turbines that are part of industrial complexes with a total capacity exceeding 50 MW_{th} are excluded. First, the current status of gas engines for CHP (based on natural gas) is covered, after that the status of gas turbines with a capacity of less than 50 MW_{th}.

In the period 1998-2004, the capacity of gas engines for CHP was almost stable (Figure 2.6). After that, it increased from about 2,000 MW_e in 2004 to 3,500 MW_e in 2007. Most of the additional capacity was realised in agriculture and horticulture (greenhouses). According to (Blanken, 2008), this increase of CHP based on gas engines was *inter alia* related to liberalisation of the energy markets.

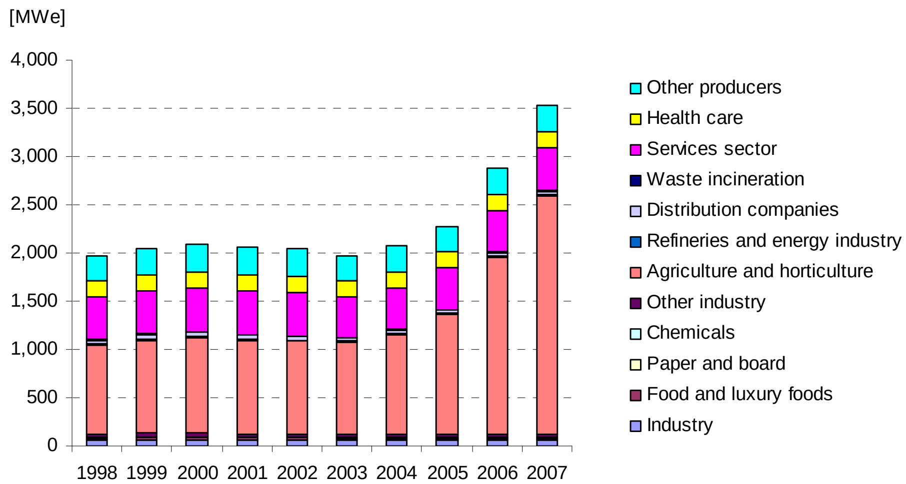


Figure 2.6 Generating capacity of gas engines used for CHP
Source: CBS statistics.

In that timeframe, the power generated by gas engine CHP plants remained almost flat (approximately 25 PJ_e) from 1998 to 2004, after that it increased to 40 PJ_e in 2007 (Figure 2.7).

---

[2] For biomass combustion plants, in 2009 the SDE tariff is 19.1 ct/kWh for a capacity < 10 MW_e and 11.7 ct/kWh for 10-50 MW_e; for anaerobic digestion based on manure, in 2009 the SDE tariff is 15.8 ct/kWh, and for anaerobic digestion based on co-digestion 19.2 ct/kWh; for co-firing in coal-fired power plants no subsidy is available.

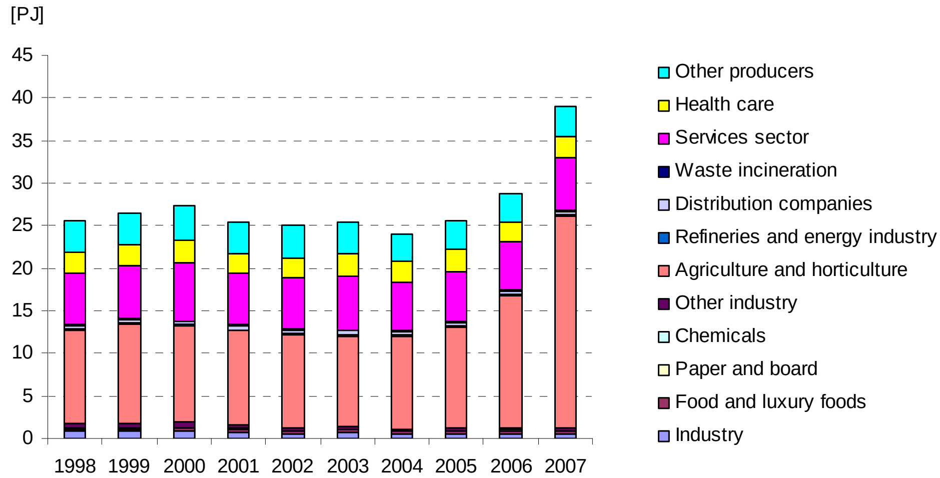


Figure 2.7 Power generation of gas engines used for CHP
Source: CBS statistics.

Figure 2.8 presents the heat generated by gas engine CHP plans in the same period of time. For 2007-2020, two distinctive 'what-if' scenarios for CHP based on gas engines are considered:

1. Expansion of CHP based on gas engines by 75 MW_e per year (scenario 'low'); and
2. Expansion by 150 MW_e per year (scenario 'high'); this scenario is comparable with the realisation in the period 1998-2007.

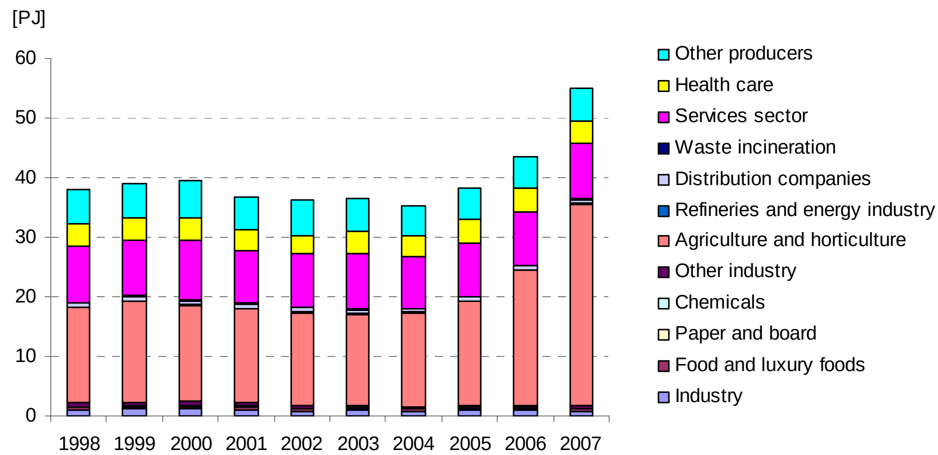


Figure 2.8 Heat production of gas engines used for CHP
Source: CBS statistics

These scenarios are explained and compared with other recent publications in the following. In 2008, a few publications provide indications about the potential of medium-scale CHP, notably from COGEN. These publications indicate that small-scale CHP could be increased to 6,000 MW_e in 2020 (Blanken, 2008; Davidse, 2008). Kroon and Wetzels (2008) give an estimate for CHP based on gas engines of 3,560 MW_e in 2010 and 2020, of which 3,000 MW_e in the horticulture sector, and a variant with continued growth ending up at 3,500 MW_e in horticulture and total 4,060 MW_e in 2020. The above-mentioned scenarios for CHP based on (gas-fired) gas engines are shown in Figure 2.9. Modest growth (scenario 'low') would mean 4,500 MW_e in 2020, and a higher growth (scenario 'high') 5,500 MW_e. Scenario 'low' is roughly equal to the high growth variant of Kroon and Wetzels (2008). Daniëls and Van der Maas (2009) put CHP based on gas engines at 3,700 MW_e in 2020, of which 3,300 MW in agriculture and horticulture.

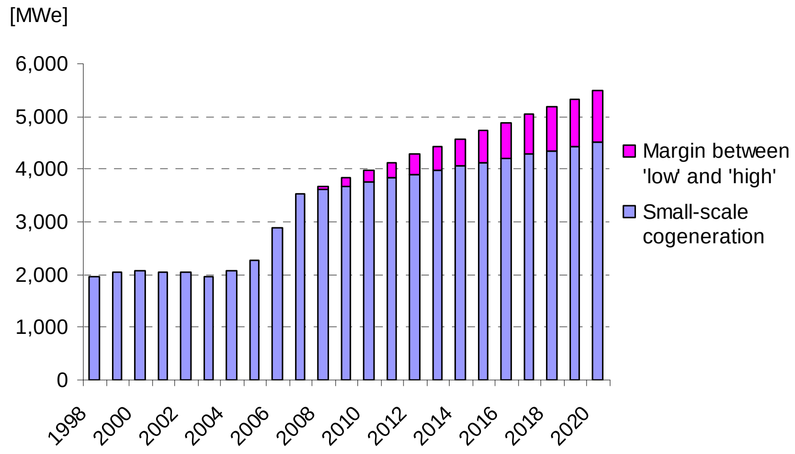


Figure 2.9 Electric capacity small-scale cogeneration (gas engines) in the Netherlands

Kroon and Wetzels (2008) made an investigation of the current and future status of relatively small gas turbines for power generation or CHP in the Netherlands, which have a (total) fuel-based capacity of less than 50 MW_{th}. This capacity refers to the so-called BEES-B limit. Gas turbines that are part of a larger complex with, e.g., boilers the fuel-based capacity of which exceeds the aforementioned capacity limit are excluded.

The current capacity of gas turbines within the BEES-B limit is 34.3 MW_e. The authors have analysed the effect of increasing use of such gas turbines, assuming a capacity of 60 MW_e, which is concomitant with a fuel consumption (mainly natural gas) of 3.5 PJ per year. With regard to future expansion (in excess of the current capacity of 34.3 MW_e), it is possible that small-scale power plants - gas engine or gas turbine plants - will be built based on marginal onshore gas fields (e.g., to be developed by the NAM).

2.2 Residential stoves

2.2.1 Introduction

Within the BOLK study an inventory has been made to explore the emissions caused by woodstoves and open fire places used by private persons and the possible technological measures to reduce the emissions of those woodstoves and open fire places. Senternovem has information and distinguishes household woodstoves (capacity $<18kW_{th}$) and industrial woodstoves (capacity $>18kW_{th}$). In household woodstoves around 2.5 times more wood is burned as is burned in industrial woodstoves. Because the emission of industrial woodstoves has already been put to limits, setting emission limits for household woodstoves can significant contribute to the required emission reduction.

2.2.2 Current population

For residential heating a distinction can be made between main heating devices and atmosphere heating devices. In the Netherlands residential heating is mostly done by natural gas combustion devices. Also a growing number of houses are coupled to central heating systems or city heating systems. Therefore, residential heating by wood stoves as main heating is rare in the Netherlands. For atmosphere heating a lot of wood fired devices are used. It concerns mainly open fire places, inset stoves and freestanding stoves. Since 2006, all inset and freestanding stoves purchased in the Netherlands have to be in compliance with the European standards EN 13240 and EN 13229. These standards set minimum levels to the efficiency of wood fired stoves. Stoves with closed doors are required to have efficiencies higher than 70% and are called approved stoves.

Open fire places
Open fire places can not be approved because they only have an efficiency of about 10%. In winter efficiency can be negative because a substantial amount of warm air from the room is used for combustion and leaves the house by the chimney. This warm room air has to be replaced by cold outside air. The amount of open wood fire places in the Netherlands is reducing strongly and a lot of people switch over to natural gas fired stoves for atmosphere heating. Many of local authorities have a discouragement strategy for open fire places, mainly because of odour nuisance in the neighborhood. This can e.g. be accomplished by prohibiting installing of a stack channel in build new houses.

Inset wood burning stoves
Inset wood burning stoves are constructed in metal. Efficiencies are much higher than for open fire places because combustion air is regulated to realize optimal combustion. The average efficiency of inset stoves in the Netherlands is about 55%. The newest generation of approved inset stoves has efficiencies of more than 70%.

Freestanding wood burning
Freestanding wood burning stoves also have regulated combustion air to increase energy efficiency. Freestanding stoves have efficiencies of about 75% because they have heat emitting surfaces all around the stove. Most freestanding stoves are constructed in metal. There are also other types like soapstone stoves or stove with ceramic heat resistant tiles at the outside. These types can have efficiencies of 85% to 90%. Most freestanding stoves are made of metal and the average efficiency of this kind of stove can be taken as 75%.

The numbers of residential open fires and stoves are given in Table 2.3 for different reference years. The numbers are retrieved from [Koppejan, 2008] and checked with [Hulskotte, 1999] for the year 1996. No statistical monitoring of stoves have been performed since 2003.

Table 2.3 Amount of residential open fires and stoves in the Netherlands for different years and their efficiency [The Dutch emission inventory, 2009]

	Efficiency	**Numbers in 1996**	**Numbers in 2002**	**Numbers in 2008**
Open fire places	10%	370,000	320,000	260,000
Inset stove, approved	60%	0	50,000	75,000
Inset stove, unapproved	50%	325,000	275,000	230,000
Freestanding stove, approved	75%	55,000	120,000	160,000
Freestanding stove, unapproved	60%	110,000	90,000	70,000
Total		**860,000**	**855,000**	**795,000**

From this table it can be concluded that the total number of residential open fire places and stoves for wood combustion shows a decline during recent years. The total number is reduced by about 7% during last 6 years compared to a reduction of less than 1 % during the six years before that period. This is the result of a large reduction in the number of the very inefficient open fire places and the unapproved inset and freestanding stoves and an increase in approved inset and freestanding stoves.

Within the last years no new information is acquired on the number of woodstoves in the Netherlands. As far as known new data is up coming in 2010, the centre for statistics in the Netherlands CBS is currently busy (November 2009) processing the data.

2.2.3 Expected population in 2020

On the bases of Table 2.3 the numbers of appliances in two extrapolations have been made for the expected numbers of appliances up to 2020. For this extrapolation the trends in the period between 2002 and 2008 are extrapolated to the year 2020. The period before 2002 is not included in the extrapolation because this was the starting period in which the EN testing standards have been developed and approved stoves were introduced resulting in start up behavior.

The first scenario, Scenario High, is based on an extrapolation up to 2020 of the increasing or decreasing trend for each separate stove type in the 2002-2008 period. The summed total number of stoves in Scenario High for the year 2020 is then 828,000.

However, according to Table 2.3 the total number of stoves has been reduced in the period between 2002 and 2008 with 1.2% per year. Using this trend for the low scenario, results in an expected total number of 687,000 stoves in the year 2020. Subsequently, this total number of stoves is distributed over the different stove types using the 2020-ratios of the Scenario High.

Table 2.4 Expected amount of residential open fires and stoves for the year 2020 Scenario Low

	Numbers in 2002	Numbers in 2008	Change 2002-2008	Expected in 2020
Open fire places	320,000	260,000		142,000 *)
Inset stove, approved	50,000	75,000		140,000 *)
Inset stove, unapproved	275,000	230,000		134,000 *)
Freestanding stove, approved	120,000	160,000		236,000 *)
Freestanding stove, unapproved	90,000	70,000		35,000 *)
Total	**855,000**	**795,000**	**-1.2%/year**	**687,000**

*) total number based of general trend and deviation based on trend in total number of stoves in Scenario High.

Table 2.5 Expected amount of residential open fires and stoves for the year 2020 Scenario High

	Numbers in 2002	Numbers in 2008	Change 2002-2008	Expected in 2020
Open fire places	320,000	260,000	-3.4%/year	172,000
Inset stove, approved	50,000	75,000	7.0%/year	169,000
Inset stove, unapproved	275,000	230,000	-2.9%/year	161,000
Freestanding stove, approved	120,000	160,000	4.9%/year	284,000
Freestanding stove, unapproved	90,000	70,000	-4.1%/year	42,000
Total	**855,000**	**795,000**	**0.34%/year *)**	**828,000**

*) after summation of the trends from the individual types of stoves

From the tables above is is clear that the number of approved stoves increases while the number of unapproved stoves decreases, but slower. Also the number of open fire places decreases. Furthermore it must be noticed that total numbers of stoves in Scenario 1 is 17% smaller than in Scenario High.

2.3 Current wood and waste use and emissions

The Dutch emission inventory has data according the burning of wood and waste in woodstoves until the year 2003, after 2003 the data has been kept constant over time. The data on wood and waste consumption is presented in Table 2.6 and Figure 2.10 till Figure 2.12.

The first thing to be noticed is that the approved inset stoves have no data prior to 2000: the Dutch emission inventory has implemented this class since 1999. Furthermore, the global trend shows an increase in fuel use for the approved stoves and a decrease for unapproved stoves and open fire places.

The trend shows an overall decrease in fuel consumption. This matches the trend in the number of stoves till the data is kept constant over time.

Table 2.6 Wood and waste consumption per stove type in kilo tonnes (TJ) per year 1990-2007

Fuel type	Year	Inset stoves approved		Inset stoves unapproved		Open fire places		Freestanding stoves approved		Freestanding stoves unapproved	
Waste	1990			2.92	(85.6)	2.08	(60.9)	1.12	(32.8)	2.24	(65.6)
	1995			3.69	(108.1)	2.11	(61.8)	1.10	(32.2)	2.21	(64.8)
	2000	0.60	(17.6)	3.22	(94.3)	1.78	(52.2)	1.74	(51.0)	2.65	(77.6)
	2005	0.66	(19.3)	2.85	(83.5)	1.68	(49.2)	2.13	(62.4)	2.21	64.8)
	2007	0.66	(19.3)	2.85	(83.)	1.68	(49.2)	2.13	(62.4)	2.21	(64.8)
Wood	1990			259	(4015)	184	(2852)	99	(1535)	198	(3069)
	1995			255	(3953)	146	(2263)	76	(1178)	152	(2356)
	2000	38	(589)	203	(3147)	112	(1736)	109	(1690)	167	(2589)
	2005	42	(651)	179	(2775)	106	(1643)	134	(2077)	139	(2155)
	2007	42	(651)	179	(2775)	106	(1643)	134	(2077)	139	(2155)

Figure 2.10Fuel use in stoves in TJ per year 1990-2007

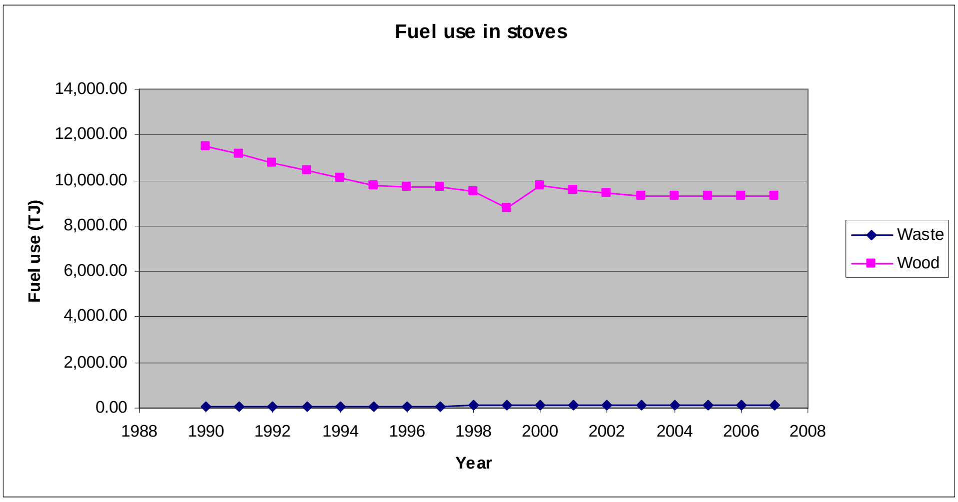


Figure 2.11Wood consumption in stoves in kilo tonnes per year 1990-2007

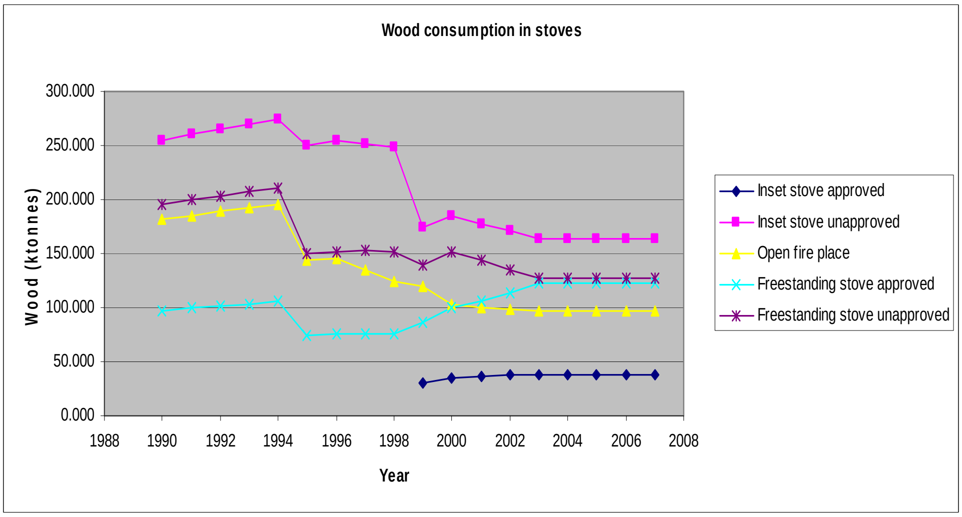
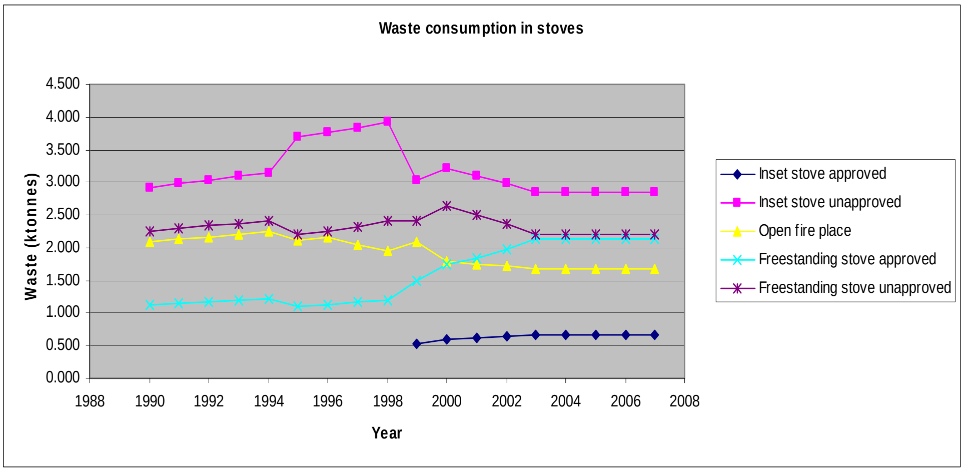


Figure 2.12Waste consumption in stoves in kilo tonnes per year 1990-2007



In Figure 2.11 and Figure 2.12 trends are shown in wood use and waste use. Two significant (methodological) changes have been implemented in these data series. In 1995 a correction in heating value accompanied by a compensating change in fuel use was introduced. This change had no consequence for the total energy use in the stoves. In 1999 new data on inset stoves (approved) were introduced. This was partly compensated by decreasing the numbers of open fire places and unapproved inset stoves.

Within the last years no new information has been acquired on the amount of fuel used for stoves in the Netherlands. As far as known new data will be presented in 2010, the Centre for Statistics (CBS) in the Netherlands is busy processing the data. Since the emissions are based on the amount of fuel consumed, the uncertainty of the presented emission is at least as big as the uncertainty in the amount of fuel consumed.

In Table 2.7 data is presented calculated by the Dutch emission inventory (for methodology, Hulskotte, 1999). The compounds presented are those of the NEC directive accompanied by CO_2 and particulate matter. Within the Dutch emission inventory there is no data for ammonia emission caused by woodstoves. The year 2007 is the last year for which definite data are available.

Table 2.7 Fuel consuption and emissions of woodstoves and open fire places in tonnes per year 1990-2007

Fuel	Year	Fuel use (TJ)	Dust (PM_{10})	Dust ($PM_{2,5}$)	CO_2	NMVOC	NO_x	SO_2
Waste	1990	87.79	193	116	9,622	32	17	17
	1995	95.67	207	124	10,485	34	18	18
	2000	104.9	237	142	11,499	36	20	20
	2005	100.1	220	132	10,971	34	19	19
	2007	100.1	220	132	10,971	34	19	19
Wood	1990	11,476	1,980	1,876	1,257,777	9,763	1,317	148
	1995	9,742	1,698	1,609	1,067,670	8,252	1,122	126
	2000	9,766	1,613	1,528	1,070,343	7,576	1,077	126
	2005	9,316	1,486	1,408	1,021,001	7,005	1,028	120
	2007	9,316	1,486	1,408	1,021,001	7,005	1,.028	120

Most recent data in the Dutch Emission Register about the actual amount of wood fired in stoves are from the year 2003. The data for the year 2003 have been processed in 2005 to obtain a definite data set. The newest data set is expected in 2010. Because of missing information for more recent years the amount of wood fired has not been updated in the Dutch Emission Register for the years 2005 en 2007. According to information of the Dutch Ministry of

Housing, Spatial Planning and the Environment the use of stoves and open fire places has increased during recent years and this will have lead to increased use of wood.

2.3.1 Summary

Co-firing of biomass in coal-fired power stations

If co-firing would be stretched to the permitted levels, approximately 2,800 kt/a of biomass could be used in existing coal-fired power plants in 2013, equivalent to 25% coal substitution or 1,000 MW_e - 2.8 times the average of 2007-2008. Accordingly, CO_2 emissions could be reduced by 5.9 Mt CO_2 in 2013 compared to 2.1 Mt CO_2 on average in 2007-2008. Additional co-firing of biomass (1,800 kt/a) in existing coal-fired plants may result in additional emission reduction of approximately 3.8 Mt/a CO_2 in 2013.

A number of coal-fired power stations - four pulverised coal-fired units and one IGCC (starting as a gas-fired combined cycle plant) of NUON - with a combined capacity of 4,515 MW_e are under construction or in planning. New coal-fired power plants have slightly higher generating efficiencies (maximum net efficiency 46%, average efficiency during a year 44%) than existing ones (maximum net efficiency 40-43%, average efficiency during a year 38.5%). If we assume that 25% of the coal would be substituted by biomass, this could result in an emission reduction of approximately 5.9 Mt CO_2 based on an average generating efficiency of 44%. New coal-fired units compete to some extent with existing ones. Therefore, the aforementioned CO_2 emissions reduction potentials - 5.9 Mt CO_2/a based on existing coal-fired power plants and also 5.9 Mt CO_2/a based on new coal-fired plants - are not quite independent, and may not be simply added up.

If co-firing in existing coal-fired plants would be stretched to the limits permitted, and biomass is gradually phased-in in new coal-fired power plants, the amount of biomass used and biomass-based power generated could evolve as follows: in 2020, biomass co-firing could amount to:

- 4,460 kt/a biomass.
- 10,500 GWh/a.
- CO_2 emission reduction of 7.0 Mt CO_2/a.

Medium-scale biomass combustion and anaerobic digestion plants with CHP

The total medium-scale biomass-based capacity is 94 MW_e in 2007 and 258 MW_e by the end of 2008. For the period to 2020, two different 'what-if' scenarios are considered:

1. Expansion of biomass combustion or gasification by 10 MW_e per year, and expansion of anaerobic digestion plants by 20 MW_e per year (scenario 'low').
2. Expansion of biomass combustion or gasification by 15 MW_e per year, and of anaerobic digestion plants by 30 MW_e per year (scenario 'high').

The distribution among biomass-fired installations and installations based on anaerobic digestion is uncertain. Nevertheless, it seems that the total capacity of small-scale biomass combustion and anaerobic digestion may increase to 470-570 MW_e in 2015 and 620-800 MW_e in 2020.

There are various constraints with regard to biomass-based capacities and power generation:

- New co-firing of biomass in coal-fired power plants is currently not eligible for subsidy in the SDE.
- In particular for medium-scale biomass plants it cannot be taken for granted that the installations remain in operation after the end of the period of subsidy (SDE tariff).

Table 2-3 presents a summary with regard to co-firing of biomass in coal-fired power and small- and medium-scale biomass installations. The ‘Updated Dutch Reference Projections 2008-2020’ of Daniëls and van der Maas (2009) result in a total fraction of 4.7% renewable energy (not only biomass) in the primary energy use in 2020. Table 2-3 shows that the amount of biomass in coal-fired power plants in 2020 (89 PJ in the present study), in the categories ‘Biomass combustion thermal/CHP/power’ (49-66 PJ), and in ‘Total anaerobic digestion’ (36.6-49.7 PJ) is much higher than in the updated Reference Projections. The difference ranges from 144 PJ (‘low’) to 173 PJ (‘high’) in 2020. This implies that the total fraction renewable energy could be 8-9% in 2020 instead of the aforementioned 4.7%. The gap between the renewable obligation for the Netherlands in the EU and the renewable fraction (not only biomass) in the updated Reference Projections is 9% (14% minus 4.7%), whereas it is a 5-6% in case of the present study. All of these figures need to be treated with care, as they are not based on detailed modeling but on a one-to-one comparison of the present study and the updated Reference Projections.

The different categories in Table 3.1 and used in this study are explained by comparison with categories used in the Updated Reference Scenarios of Daniëls and van der Maas (2009) in Table 3.2.

Table 3.2 Comparison table of categories of biomass or residue combustion/conversion Updated Reference Scenarios vs. current study

Category ‘Updated Reference Scenarios (in Dutch)	Category current study	Remarks
Biomassa bijstook		
Biomassa meestook (kolencentrale)	Co-firing coal-fired power	Only one category the in present study
	Co-firing gas-fired power	Co-firing in gas-fired power plants not deemed economically feasible
(Subtotal)	*Total co-firing*	
Overig biomassa verbranding		
Biomassaverbranding thermisch	Biomass combustion thermal (heat)	concerns small scale instalallations mainly in households
	of which wood combustion in households	
Biomassa grootschalig	Large-scale biomass combustion CHP/power	hundreds of MWth input
Biomassa kleinschalig	Medium-scale biomass combustion CHP/power	several tens of MWth input, e.g. Cuijk installation
Biomassaverbranding WKK	Bio-oil for power or CHP	PPO/animal fat installations
	Total biomass combustion thermal/CHP/power	
Biomassa vergisting		
Afvalwaterzuivering		
Rioolwaterzuivering		
(Subtotal)	Biogas from AWZI/RWZI	
Mestvergisting	Agricultural biogas plants	
GFT-vergisting	Other biogas installations	
Stortgas	Biogas from waste tips	
	Total anaerobic digestion	

Table 2.8 Summary of results

Category	Fuel use 2004 and 2007			Reference Scenario 2020 (Daniëls and Van der Maas, 2009)		Scenario Low 2020 (present study)		Scenario High 2020 (present study)	
	2004 [PJ]	2007 [PJ]	2007 [%]	[PJ]	[%][a]	[PJ]	[%][a]	[PJ]	[%][a]
Co-firing coal-fired power plants[b]	8.2	15.4	0.5	0	0	89	2.3	89	2.3
Co-firing gas-fired power plants	5.9	0.3	,<0.1	0	0	-		-	
Total Biomass combustion thermal/CHP/power [c], of which:	16.3	18.9	0.5	18.7 [d]	0.5	49	1.3	66	1.5
- Biomass combustion thermal (heat)	*11.3*	*11.9*	*0.3*	*8.1*	*0.2*	*8* [e]	*0.2* [e]	*16* [e]	*0.4* [e]
of which wood combustion in households	*9.3*	*9.3*	*0.3*	*7.5*	*0.2*	*8*	*0.2*	*16*	*0.4*
-Medium-scale biomass combustion CHP/power [c]	*5.0*	*7.1*	*0.2*	*10.6* [d]	*0.3*	*42*	*1.1*	*51*	*1.3*
-Large-scale biomass combustion CHP/power	*0*	*0*	*0*	*0*		*0*		*0*	
Total anaerobic digestion, of which:	5.3	7.3	0.2	12.4 [d]	0.3	37	0.9	50	1.3
-Biogas from waste tips	*2.0*	*1.9*	*<0.1*	*0.2*	*<0.1*				
-Biogas from AWZI/RWZI [f]	*2.0*	*2.0*	*<0.1*	*8.3* [d]	*0.2*				
-Agricultural biogas plants	*0*	*1.9*	*<0.1*	*2.4* [d]	*<0.1*				
-Other biogas installations	*1.2*	*1.5*	*<0.1*	*1.6* [d]	*<0.1*				
Bio-oil for power or CHP, of which:	P.M.	0.5	<0.1	0 [d]	0	5.5	0.1	5.5	0.1
-Based on PPO [f]	*Negl.*					*P.M.*		*P.M.*	
-Based on animal fats [g]	*Negl.*					*P.M.*		*P.M.*	
-Based on palm oil	*0*					*P.M.* [h]		*P.M.* [h]	
Co-firing cement factory [i]	1.7	N/A	0	0		0		0	
Waste-to-power	26.1 [j]	27.8 [j]	0.8	48 (=48%*101.6 [k])	1.2	41 [j]	1.0	41 [j]	1.0

a Percentage renewable energy of the projected primary energy demand of 3,942 PJ in 2020 in the reference scenario of Daniëls and van der Maas (2009).
b Based on a generating efficiency of 38% for existing coal-fired plants and 46% for new coal-fired capacity, and co-firing of 3,750 kt/a biomass in 2020.
c CHP is assumed to be based on a electric conversion efficiency of 30%.
d As the MEP subsidy for biomass CHP expires after a numbers of years, and the SDE tariff for biomass CHP (combustion or anaerobic digestion) proved to be insufficient in 2008 to trigger new capacity, Daniels and van der Maas (2009) assume that a limited capacity (e.g., based on sewage sludge, or biomass combustion) is in operation in 2020.
e In the present study, it is assumed that in 2020 biomass is solely used in the industry for power and heat (CHP) and no longer partially for thermal applications (heat only).
f Afval Water Zuivering Installatie c.q. Riool Water Zuivering Installatie.
g PPO = Pure Plant Oil. A few projects are based on PPO or animal fat, among which a CHP plant based on bio-oil for heating for a swimming pool in Ermelo (Vliet, 2009).
h Currently, there are no incentives (SDE) for power generation based on palm oil. Therefore, it is assumed that power generation based on palm oil will not be implemented.
i Based on (Wilde et al, 2006). According to (Stam and Erbrink, 2008), ENCI in Maastricht would terminate their industrial activities (cement production) in 2010.
j 48% of municipal solid waste (waste-to-power) is renewable (biogenic). Data for 2004, 2007 and 2020 - projection based on (SenterNovem, 2009) - refer to biogenic MSW.
k The figure of 101.6 PJ ('Reference scenario') named 'Vuilverbranding' refers total MSW, in contrast to the 48% biogenic fraction in '2004', '2007', and 'present study'.
Sources: Vliet, 2009; SenterNovem, 2009; Wilde et al, 2006; Stam and Erbrink, 2008

Cogeneration based on gas engines (gas-fired) and medium-scale gas turbines (< 50 MW_{th})
In the period 1998-2004, the installed capacity of *gas engines* for CHP was almost flat. After that, it increased from about 2,000 MW_e in 2004 to 3,500 MW_e in 2007. Most of the additional capacity was realised in agriculture and horticulture (greenhouses). This increase of CHP based on gas engines was *inter alia* related to liberalisation of the energy markets. For 2007-2020, two distinctive 'what-if' scenarios for CHP based on gas engines are considered:

1. Expansion of CHP based on gas engines by 75 MW_e per year (scenario 'low').
2. Expansion by 150 MW_e per year (scenario 'high'); this scenario is comparable with the realisation in the period 1998-2007.

Taking into account the associated uncertainty, the perspectives of CHP based on gas engines are as follows. The more modest growth of cogeneration based on gas engines would end up at 4,500 MW_e, and the higher growth at 5,500 MW_e in 2020. According to COGEN, the small-scale cogeneration capacity could even be 6,000 MW_e in 2020.

Kroon and Wetzels (2008) made an investigation of the current and future status of relatively small gas turbines for power generation or CHP in the Netherlands, which have a (total) fuel-based capacity of less than 50 MW_{th}. The current capacity of gas turbines within the BEES-B limit is 34.3 MW_e. The authors have analysed the effect of increasing use of such gas turbines, assuming a capacity of 60 MW_e, which is concomitant with a fuel consumption (mainly natural gas) of 3.5 PJ per year.

The tables below summarise capacity and fuel consumption ('low' and 'high' respectively) of gas-fired CHP (gas engines or, gas turbines) compared with (Daniëls and van der Maas, 2009).

Table 2.9 Summary of expected capacity of medium-scale gas-fired CHP [MW_e]

Present study	**2005**	**2007**	**2010**	**2015**	**2020**
Gas engines					
Agriculture & horticulture	1,240	2,465			
Other	1,040	1,069			
sub-total	2,280	3,534		4,150-4,750	4,500-
Based on gas turbines (<50 MW_{th})	34.3	34.3	40	50	60
Total	**2,314**	**3,568**	**3,790-4,040**	**4,200-4,800**	**4,560-5,560**
Daniëls and van der Maas (2009)	**2005**	**2007**	**2010**	**2015**	**2020**
Gas engines					
Agriculture & horticulture	1,240	2,465			3,263
Other	1,040	1,069			441
Sub-total	2,280	3,534			3,704
Based on gas turbines (<50 MW_{th})	34.3	34.3	40	50	60
Total	**2,314**	**3,568**			**3,764**

Table 2.10 Summary of expected fuel consumption of medium-scale gas-fired CHP [PJ/a]

Present study	2005	2007	2010	2015	2020
Gas engines	59	97	102-108	112-128	123-150
Agriculture & horticulture	32	68			
Other	27	29			
Based on gas turbines (<50 MW_{th})	3.1	3.1	3.7	4.6	5.5
Total	**62**	**100**	**106-112**	**117-133**	**129-156**
Daniëls and van der Maas (2009)					
Gas engines					102
Agriculture & horticulture	32	68			
Other	27	29			
Based on gas turbines (<50 MW_{th})	3.1	3.1	3.7	4.6	5.5
Total	**62**	**100**			**107**

2.4 Biofuel production

2.4.1 Introduction

This section provides an overview of biofuel plants and investment cost in the Netherlands[3]. A main consideration in production of biofuels, is that the EU requires that members attain specific fractions of biofuels in transport fuels to, e.g., 4% in 2010, and 10% in 2020 - within boundary conditions such as 1st and 2nd generation biofuels, e.g., based on ligno-cellulosic biomass. Another important consideration, closely related to the aforementioned one, is that the EU does neither prescribe which biofuels should be developed (currently available or advanced biofuels) nor where biofuel plants are to be built. As country-specific incentives are hardly available or still have to be developed, it is not easy to give an accurate estimate of the potential of biofuel production within the boundaries of a specific country, e.g., the Netherlands. Some studies, among which (Platform Groene Grondstoffen, 2006) project ambitious high fractions of biomass in the primary energy consumption of the Netherlands in 2020 and 2030 (up to 30%), but these have not been considered as guiding for the present study.

There have been several plans to produce biofuels in the Netherlands that have not come to fruition. Some parties did not meet the technological and financial requirements to invest in production of biofuels. Some plans have been stalled because the prospects in terms of revenues or costs of feedstock were too uncertain (taking into account the apparent lack of financial incentives from governments). Finally, some technologies are still in an early stage of development. For instance, no plans exist to build biodiesel plants based on the Fischer-Tropsch synthesis technology. This technology is in the stage of early (medium-scale) demonstration in Germany. In this timeframe, there is no clear perspective for biodiesel based on Fischer-Tropsch synthesis.

Section 2.4.2 presents data on the production of biodiesel, and Section 2.4.3 information on bio-methanol and bio-ethanol production. A summary is presented in Section 2.4.4.

2.4.2 Biodiesel

Table 2.11 presents an overview of biodiesel plants. Ten biodiesel projects have been realised or are in the stage of construction or planning. These projects have different capacities and use different feedstocks. The five smallest projects are based on rape oil and frying fats and oils:

3 For operational costs is referred to Section 4.3.

- Sunoil Biodiesel bv, Emmen, 72,000 t biodiesel per year, since 2006.
- Biodiesel Kampen bv, Kampen, 55,000 t biodiesel per year, since 2006.
- Biovalue bv, Eemshaven, 80,000 t biodiesel per year, since 2007.
- Ecoson, Son, 4,500 t biodiesel per year, since 2007.
- BioDsl, Breda, 9,000 t biodiesel per year, since 2008.

Six relatively large biodiesel plants have been realised or are under construction:

- J&S Bio Energy, Amsterdam, 200,000 t biodiesel per year (summer 2008?).
- Rosendaal Energy bv, Sluiskil, 250,000 t biodiesel per year (September 2008)[4].
- CleanerG bv, Zwijndrecht, 200,000 t biodiesel per year (2008).
- Biopetrol Industries AG, Rotterdam, 400,000 t biodiesel per year (end of 2008).
- Greenmills, Amsterdam, 100,000 t biodiesel per year (2010?).
- 'B2G' (Neste Oil en IOI Group), Rotterdam, 800,000 t biodiesel per year (2011).

J&S Bio Energy uses rape oil, Canola, and soy oil as feedstock, and 'B2G' (Neste Oil en IOI Group) palm and rape oil, and animal fats. The relatively high investment cost of the 'B2G' plant of Neste Oil and IOI Group can be explained by the production process applied which is based on hydro-treating with hydrogen imported from a refinery. The 'B2G' plant doesn't produce glycerol as a by-product.

Table 2.11 Overview biodiesel plants in the Netherlands

Company	**Site**	**Commissioned**	**Feedstocks**	**Capacity**			
				Biodiesel	**Glycerine**	**Acid-free fats**	**Investment**
				[kt/a]	**[kt/a]**	**[kt/a]**	**[M€]**
Sunoil Biodiesel bv	Emmen	October 2006	Rape oil, vegetable oil, and animal fats	72			
Biodiesel Kampen bv	Kampen	2006	Frying fats and oils	55			
Biovalue bv	Eemshaven	September 2007	Rape oil	66 [a]			
Ecoson, VION Food	Son	December 2007	Animal fats, C3 fats (50 kt /a)	4.4	(0.44)	44	10
J&S Bio Energy	Amsterdam	Summer 2008	Rape, Canola, and soy oil	200			42.5
Rosendaal Energy bv	Sluiskil	September 2008	Vegetable and animal fats	250			60
BioDsl bv	Breda	October 2008	Frying fats	~ 9			
CleanerG bv	Zwijndrecht	2008		200			
Biopetrol Ind.	Rotterdam	End of 2008	Rape and soy oil	400	60		80-116 [b]
Greenmills	Amsterdam	2010?	Used frying fats and animal fats	100			78
'B2G'	Rotterdam	2011	Palm & rape oil, etc	800			670
Total				**2,156**			**940-976**

a By-products: 100,000 t rape cake and 600 t fertiliser per year.
b Lurgi puts the investment for a plant of 200,000 t biodiesel/year at 58 M€, and Biopetrol Industries AG that of two plants with a combined capacity of 600,000 t biodiesel/year at € 90 million net (after subsidies).
Sources: De Nie and Blom, 2008; NHR, 2008; Thamsiriroj, 2007; Neeft, 2009; Buck, 2009; Sunoil, 2006; Biodiesel Kampen, 2009; Biovalue, 2007; Ecoson, 2009; Host, 2009; J&S, 2007; Rosendaal, 2008; BioDsl, 2009; Biopetrol, 2006; Lurgi, 2006; Neste Oil, 2008.

4 At the end of July 2009, the court of Middelburg declared Rosendaal Energy bv bankrupt. This is no exception in Europe. It may be caused by export of subsidised biodiesel from the USA to Europe, either directly or via Canada. Also, the price of imported palm or soy oil may have been too high in order to compete with conventional diesel.

2.4.3 Bio-methanol and bio-ethanol

One bio-methanol plant (BioMCN I) is in operation, and three bio-ethanol plants - Abengoa (corn, grain), N2 Energie bv (waste) and Nedalco bv Sas van Gent (sugar beet) - are under construction or planned (Nedalco II, 75% sugar beet, 25% residue food industry), see Table 2.12.

Table 2.14 gives a comparison of investment costs of bio-ethanol plants - under construction or planned - in the Netherlands with 2nd generation bio-ethanol plants or biorefineries[5] in the USA. Figure 2.13 presents the investment costs of 2nd generation bio-ethanol plants and biochemical or thermo-chemical biorefineries in the USA, supplemented with data of N2 Energie and Nedalco II. A problem with the estimated investment costs of Nedalco II is that this planned bio-ethanol plant is 75% based on sugar beet (1st generation) and 25% based on residues of the food industry (cellulose-ethanol, 2nd generation). The footnote below Figure 2.13 indicates which part of the investment cost of Nedalco II is attributed to 2nd generation bio-ethanol. The investment costs of 2nd generation bio-ethanol plants in Figure 2-10 are presented in US$ instead of €, as most of the data refer to such plants in the USA.

Vogt et al (2009) indicate that bio-methanol is a prospective biofuel. Table 2.13 compares the BioMCN plant at Delfzijl based on glycerine (a by-product of biodiesel) - capacity 200 kt/a in 2009, and 800 kt/a in 2011 - with plants based on wood (Hagfors, Sweden, planned) or 'black liquor'[6]. Realised (BioMCN I) and proposed plants based on wood or black liquor have capacities of 100-500 MW_{th} (input). The investment cost based on wood is higher than based on glycerine or black liquor. BioMCN uses two gas-based methanol plants from the 1970s (Stork, 2008). Bio-methanol based on 'black liquor' has representative investment costs.

Figure 2.14 presents the investments costs of bio-methanol production based on wood, black liquor, and glycerine as a function of the capacity (in mln l per year), as well as (estimated) investment costs of BioMCN for two capacities, viz. 200 kt/a (April 2009) and 800 kt/a (planned 2011). It is noted that BioMCN makes use of two methanol plants based on natural gas commissioned about 30 years ago, the investment costs of which have been neglected as the methanol plants have already been depreciated.

5 A biochemical or thermo-chemical biorefinery produces energy, chemicals, and/or food and feed.

6 Black liquor is a pulp-rich slurry obtained as by-product of the Kraft pulping operation used for paper production.

Table 2.12 Bio-ethanol and bio-methanol plants in the Netherlands

Bio-ethanol plants	**Site**	**Start**	**Feedstocks**	**Capacity Bio-ethanol [mln l/a]**	**Capacity DDGS [a] [kt/a]**	**Investment [M€]**
Abengoa	Rotterdam	2009	Corn and grain	480	325	500
N2 Energie	Hardenberg	2010	Waste	33.5		60
Nedalco I	Sas van Gent	2010?	Sugar beet	60		
Nedalco II [b]	Sas van Gent	2012?	Idem + residues food industry	200		175
Total				**773.5**	**325**	**735**
Bio-methanol plant	**Site**	**Start**	**Feedstock**	**Capacity Bio-methanol [kt/a]**		**Investment [M€]**
BioMCN I	Delfzijl	2009	Glycerine (~ 250 kt/a)	200		70 [c]

a DDGS = Dried Distillers Grain with Solubles.
b A '2nd generation' bio-ethanol plant of 200 mln l/a would require an investment of € 150-200 million.
c A BioMCN share of more than 50% has been sold for € 36 mln (BioMCN, 2009). If capacity would be expanded to 800 kt/a, the investment cost could be € 178 mln, based on € 70 mln for phase 1 and € 36 mln for expansion by 200 kt/a. Energy Valley (2008) puts the investment cost for 800 kt/a at € 100 mln or more.
Sources: Flach, 2006; IFP, 2007; Neeft, 2009; Buck, 2009; Abengoa, 2008; N2 Energie, 2007; Cosun, 2007; Utilities, 2007; BioMCN, 2009; Energy Valley, 2008.

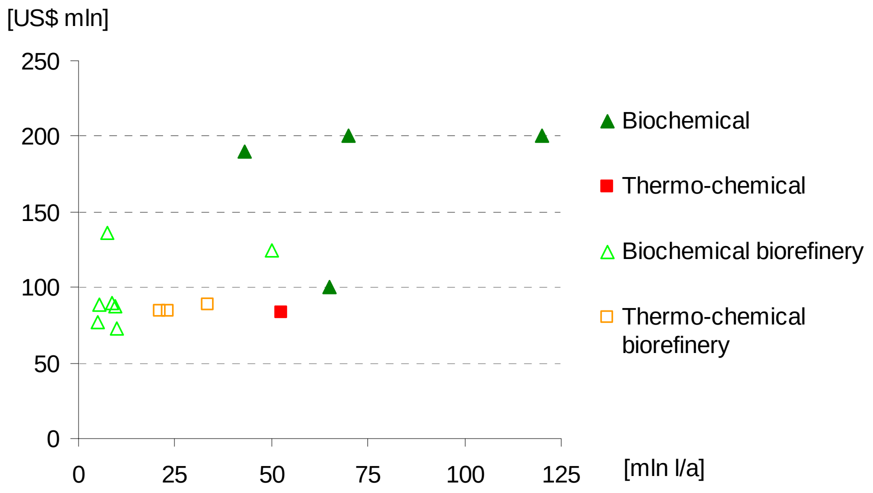


Figure 2.13 Investment cost (2nd generation) bio-ethanol plants as a function of capacity

Note: The investment costs refer to 2nd generation bio-ethanol plants and biorefineries in the USA, the 2nd stage of the Nedalco plant (considered as a biochemical biorefinery) at Sas van Gent, and the bio-ethanol plant of N2 Energie bv at Hardenberg (considered as thermo-chemical biorefinery). In case of Nedalco II, it was assumed that 75% of the feed is based on sugar beet. For first generation bio-ethanol, investment costs are assumed to be 0.6 €/l·a. The investment attributed to '2nd generation bio-ethanol' is therefore US$ 125 mln.
Sources: Ahring, 2007; IEA/OECD, 2008; Abengoa, 2008; N2 Energie, 2007; Cosun, 2007; Utilities, 2007.

Table 2.13 Bio-methanol based on glycerine, wood (Hagfors, Sweden) or 'black liquor'

Plant	Site	Feedstock	Capacity		Investment		
			MW input	Mln l/a	Absolute	Per ton MeOH/a	Per l MeOH/a
			[MW]	[Ml/a]	[M€]	[€/t·a]	[€/l·a]
BioMCN I	Delfzijl, NL	Glycerine	250	253	70	350	0.27
VärmlandsMetanol AB	Hagfors, Sweden	Wood	100	116	208	2,270	1.79
Black liquor gasification		Black liquor, 3,400 tDS/d	490	575	335	730	0.58

Sources: Gillberg, 2009; Nykomb Synergetics, 2003; Ekbom, 2005; Olah et al, 2006; BioMCN, 2009; Energy Valley, 2008.

In the 'Updated Dutch Reference Projections 2008-2020' of (Daniëls and Van der Maas, 2009), reference is made of a study (Bersch, 2008) on biofuel plants in the Netherlands (built, under construction, or planned). However, not all of the indicated plants will be realised. The biodiesel, bio-ethanol, and bio-methanol plants considered here, represent a total fuel production that is equivalent to approximately 108 PJ/a. This is approximately 2.8% of the primary energy demand projected for 2020, and approximately 16% of the primary energy use of transport in 2020.

Table 2.14 Comparison capacities and investments (2nd generation) bio-ethanol plants in the Netherlands and United States

Plant	Site	Feedstocks	Capacity	Investment cost	
			10^6 l/a	Absolute	Per l/a
			[Ml/a]	[M€]	[€/l·a]
Abengoa	Rotterdam	Corn and grain	480	500	1.0
N2 Energie bv	Hardenberg	200,000 t waste	33.5	60	1.8
Nedalco II	Sas van Gent	Sugar beet and residues of food industry	200 (75%/25%)	175 (51%/49%)	0.9
Biochemical			**[Ml/a]**	**[M$]**	**[$/l·a]**
Abengoa Bioenergy LLC	Colwich, Kansas	Corn cobs, corn stover, switchgrass	43	190	4.4
Bluefire Ethanol	Corona, Californië	Municipal solid waste	65	100	1.5
Iogen Biorefinery Partners LLC	Shelley, Ohio	Wheat straw, barley straw, corn straw, switchgrass	70	200	2.9
Poet Energy	Emmetsburg, Indiana	Corn cobs, corn stover	120	200	1.7
Thermo-chemical			**[Ml/a]**	**[M$]**	**[$/l·a]**
ALICO Inc.	LaBelle, Florida	Citrus wastes	52.6	83	1.6
Range Fuels	Soperton, Georgia	Wood chips, wood waste	151.3 [a]	225	1.5
Biochemical biorefienry			**[Ml/a]**	**[M$]**	**[$/l·a]**
Ecofin LLC	Washington County, Kentucky	Corn cobs	4.9	77	16
ICM	St. Joseph, Montana	Switchgrass, forage sorghum, corn stover	5.7	86	15
Lignol Innovations	Commerce City, Colorado	Woody biomass, agricultural residues	9.5	88	9.3
Mascoma	Monroe, Tennessee	Switchgrass and hardwoods	7.6	136	18
Pacific Ethanol	Boardman, Oregon	Wheat straw, stover, poplar residuals	10.2	73	7.2
RSE Pulp	Old Town, Maine	Wood chips (mixed hardwood)	8.3	90	11
Verenium Corp.	Jennings, Louisiana	Bagasse, energy crops, agricultural and wood residues	5.3	92	17
Thermo-chemical biorefinery			**[Ml/a]**	**[M$]**	**[$/l·a]**
Flambeau LLC	Park Falls, Wisconsin	Forest harvest residues	22.7	84	3.7
NewPage	Wisconsin Rapids	Wood process residues	20.8	84	4.0

a By-product: 34 mln l of bio-methanol per year.
Sources: Ahring, 2007; IEA/OECD, 2008; Abengoa, 2008; N2 Energie, 2007; Cosun, 2007; Utilities, 2007.

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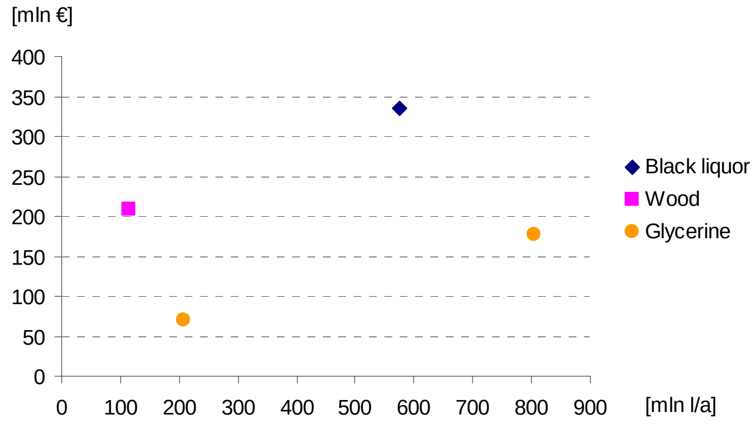

Figure 2.14Investment cost of bio-methanol production as a function of capacity
Sources: Gillberg, 2009; Nykomb Synergetics, 2003; BioMCN, 2009; Energy Valley, 2008.

2.4.4 Summary

At this date (2009), about ten biodiesel plants are in operation, under construction or planned with a total capacity of approximately 2 Mt of diesel per year, and with a total investment of the order of magnitude of M€ 1,000. About half of these biodiesel plants are based on rape oil and frying fats and oils. Their capacity ranges from 2,000 to 8,000 t biodiesel per year. Another five biodiesel plants use rape, Canola, and soy oil, or palm and rape oil, and animal fats as feedstock. Their capacity ranges from 100,000 to 800,000 t biodiesel per year. In the latter category, the biodiesel plant with a capacity of 800,000 t biodiesel per year has an investment cost of M€ 670.

Also, two to three bio-ethanol plants are under construction or planned, with capacities from 33.5 to 480 million l/a. Feedstocks used are corn and grain, or waste (2nd generation bio-ethanol). Another biofuel plant is based on glycerine, with a capacity of 200,000 t bio-methanol per year (making use of two existing methanol production plants). Its capacity may be increased to 800,000 t bio-methanol per year. Table 2.15 summarises the capacity of biofuel plants in the Netherlands, from 2008 (existing) to 2012 (including plants under construction or planned).

In 'Updated Dutch Reference Projections 2008-2020' (Daniëls and Van der Maas, 2009), reference is made of a study (Bersch, 2008) on biofuel plants in the Netherlands (built, under construction, or planned). However, not all of the plants will be realised. The biodiesel, bio-ethanol, and bio-methanol plants considered here represent a total fuel production that is equivalent to approximately 108 PJ/a. This is approximately 2.8% of the primary energy demand projected for 2020, and equal to approx. 16% of the primary energy use in transport.

Table 2.15 Summary of (projected) capacity of biofuel production in the Netherlands

[kt/a]	2006	2007	2008	2009	2010	2011	2012
Biodiesel	127	197	1,256	1,256	1,356	2,156	2,156
Bio-ethanol				384	459	459	619
Bio-methanol				200	200	200	800
Fischer-Tropsch biodiesel [a)]				N/A	N/A	N/A	N/A
[PJ/a]	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Biodiesel	4.7	7.3	46.8	46.8	50.6	80.4	80.4
Bio-ethanol				10.3	12.3	12.3	12.3
Bio-methanol				4.0	4.0	4.0	15.9
Fischer-Tropsch biodiesel [a)]				N/A	N/A	N/A	N/A

a No concrete plans with regard to biodiesel production based on Fischer-Tropsch synthesis are available.

3. Emission factors

3.1 Introduction

Estimates of emission factors of stationary biomass applications have been determined during the first phase of BOLK [Boersma, 2008]. Often international literature was used for the estimation. In this second phase, emissions factors of the following technologies/applications have been further detailed, when possible, for the Dutch situation:

- Medium-scale biomass applications and medium-scale fossil CHP (as stimulated by the SDE subsidy), mainly gas engines (Section 3.2)
- Wood stoves (Section 3.3)
- Biofuel production (Section 3.4)
- Biomass transshipment and storage (Section 3.4)

3.2 Medium-scale[7] biomass-fired installations and fossil-fired CHP

3.2.1 Introduction

Unlike the CO_2 emissions where emission rates are linked to almost solely the fuel properties, the non-CO_2 emission factors are mostly influenced by various parameters that are specific to each country, and also to the specific conditions of each combustion equipment or plant [EMEP, 2009]:

- The fuel characteristics;
- The type of technology;
- The combustion, operating and maintenance conditions;
- The size and the age, and
- The emission control policy.

Preferebly, these correlating data are registered and monitored. However, statistical data with the correlations between emissions and size for the Dutch situation could not be retrieved during this study and is indicated not to be available for the relevant catagories in this study [Guis, 2009; Peek, 2009; Elzinga, 2009]. To obtain these data, an extensive and detailed statistical project to obtain the correlation between type of installation, fuel, size, age and gas cleaning (with or without SCR, and operation of this SCR) would be required, which is beyond the scope of this study.

Furthermore, the population and associated emission of gas engines is not individually registered by the CBS [Zwart, 2009; Kroon, 2009] nor via the Emissieregistratie system. For medium-scale installations in statistical studies for the CBS and PBL, national emissions for medium-scale installations are based on overall emission factors for specific activities, and are not based on an emission factor on installation level and often based on international databases or estimations [Guis, 2009; Peek; 2009]. Therefore, the data presented in this study is based on previous public reports and relevant emission limits.

For some components, an emission level even has not been set (and are thus not measured) as they are considered not important. When possible, Dutch literature and sources were used. However, when the relevant emissions factor could not be retrieved from these sources, international litarature has been consulted.

[7] Medium scale here does not include co-firing or large-scale installations up to several hundreds of MWth and domestic/industrial woodstoves

The introduction of BEMS (see next section) will imply that current emission factors are not representative for the year 2020. Therefore, for 2020, BEMS emissions limits for NO_x, SO_x and dust are assumed, unless it is expected that the emission is lower. NMVOC and NH_3 are not regulated in the BEMS, an estimate is done based on literature or existing emission limits.

3.2.2 New Dutch emission limits 2020 for medium-scale installations: BEMS

For most medium-scale CHP, the relevant emissions limits are given by NeR and BEES B[8] and result in different emission limits, depending, amongst others, on the permitting date and size of the installation, and type of fuel. Recently more strict emissions limits are proposed in new regulations: BEMS (Besluit Emissie-eisen Middelgrote Stookinstallaties) [VROM, 2009], which is currently under review. The new regulations will imply that emission limits are harmonized (large vs. small scale and independent of permitting date) and will have a nivilating effect. The total amount of installations under BEES-B is currently around 10,000 in the Netherlands [Kroon, 2009]. The BEMS will be applicable for all boilers, gas/diesel engines and turbines, with a thermal capacity of more than 1 MW_{th} and upper limit of 50 MW_{th}, not falling under BEES-A.. On July 15th 2009, a reaction was published by Minister Cramer of the Dutch ministry of Housing, Spatial Planning and the Environment on questions raised on the first BEMS proposal. This resulted in some adaptions in the proposal [VROM, 2009]. These adaptations are incorporated in this study.

The new BEMS is formulated according to Best Available Technologies (BAT). Emission limits in this new legislation are dependent of the technology and fuel that is fired. The emissions limits for NO_x and dust of the BEMS will be valid for all installations (new and existing) with a transition period of eight years after introduction of the new legislation (planned introduction date January 2010). New installations have to comply directly from this date. This new legislation results in comparable emissions limits for new as well as older installations, in contrast to the existing situations where a broad range of emission limits could be found. As older installations can face relatively expensive (retrofit) costs for additional gascleaning, the introduction of the BEMS can results in shut-down of unfeasible installations under the new requirements. After three years, there will be an evaluation whether or not the emission limits in BEMS should be sharpened.

3.2.3 Technology selection and emission factors

The following biomass- and fossil-fired technologies have been selected for this study and are based on the expectation that they will have significant contribution to the population:

Biomass-fired technology selection

Medium-scale application of biomass is foreseen to play a more and more important role. The most important technologies in the medium scale are (bio)gas fired gas engines and bio-oil fired engines, together with industrial solid biomass combustion (mostly woody materials) for heat and/or power.

Fossil-fired technology selection

For the medium-scale fossil-fired (CHP) installations, only natural gas fired engines, gasturbines and gas fired boilers are expected to be relevant and are therefore considered in this study. Of the BEES B installations, they represent the vast majority of the fuel input [Kroon, 2009]. Emission factors are estimated for these technologies. Although there are some oil-fired and coal-fired installations, their contribution is very limited and decreasing. Currently no new installations of these types are built due to bad image and problems with permits [Kroon, 2008]. Therefore, no specific search to emission factors of these types of installations has been performed in this study.

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[8] For an extensive overview of relevant emission regulations is referred to the previous BOLK report. BEES A is applicable for larger installations or installations at larger sites (province as permitting authority).

For these technologies, the NEC emission factors (expressed in g/GJ fuel input) are estimated. The several relevant NEC components are:

NO_x

NO_x is formed during combustion of all fuels. Relevant is the change of NO_x emission limits during the last decades. To determine the appropriate emission factor for an installation fired on a specific fuel, one has to have insight in the population in terms of date of permit, size and possible later modification. In this study the previously estimated NOx emission factors for the actualization of BEES B [Kroon, 2008; Kroon, 2009a] are used for the current emissions factor, assuming that they are representative for the whole population. For 2020, the BEMS limits are used.

SO_x

SO_x emissions have a direct relation to the sulphur present in the fuel. Natural gas has (almost) no sulphur present, while for biomass woody feedstocks usually contain only limited amounts of sulphur compared to coal. Therefor not the BEMS emission limit values are used for an estimation of the emission factor, but values found in literature.

Dust

Dust is mainly emitted by combustion of solid and liquid fuels. The emission of this component will strongly depend of the ash content of the fuel that is fired and the abatement technogy that is applied. For these fuels, the BEMS emission limit has been used for 2020. No limits on dust are set in the new BEMS for gas-fired installations, therefore literature values are used. The fraction PM2.5 is estimated by using standard fractions of PM10 [Visschedijk, 2007].

NMVOC

NMVOC[9] is a product of incomplete combustion and is a result of an incomplete combustion. They are directly influenced by usage patterns, technology type and size, age/vintage, maintenance and operation of technology. It should be noted that the emission rates can vary by several orders of magnitude as a function of the operating and maintenance conditions, particularly in the case of older or smaller equipment. While the mobile sources are the most significant sources of NMVOCs, the small residential combustion devices, particularly those using biomass, are also important [Amous, publication year unknown]. The contribution of these component that is energy related reported to be very limited (<10%) compared to other sources [Daniels, 2005]. In general, NMVOC emissions are not emitted in large quantities in gas-fired installations, most hydrocarbon emissions are methane. For (bio)gas engines it is possible that the NMVOC emissions will rise when the settings of the engine will be changes to reach lower NO_x levels. With solid biomass combustion, uncomplete combustion can result in NMVOC emissions. For bio-oil-fired engines, it is assumed that the C_xH_y limit is equal to the NMVOC emission (based on permits for diesel engines on palm oil), resulting in a worst-case estimate.

In general, NMVOC emissions tend to decrease as the capacity of the combustion installation increases, due to the use of advanced techniques, which are typically characteriserd by improved combustion efficiency [EMEP, 2009]. There are no emission limits in the Netherlands for combustion installations on this pollutant for the relevant technologies. Therefore, literature values have been used for the emission factor. However, especially for NMVOC data, hardly any Dutch data was retrieved. Foreign sources have been used for estimating this component.

[9] NMVOC are non-methane volatile organic species and are to be distinguished from methane (CH_4), a strong greenhouse gas. Especially when firing gas containing methane on piston engines, methane can present in the flue gas directly after the engine, due to methane slip

NH_3

NH_3 emissions are not a direct consequence of combustion, but of a incomplete reaction of ammonia with NO_x in the de-NOx for flue gas cleaning. Therefore, the only NH_3 emission is related to de-NOx installations (SCR or SNCR). If these technologies are applied, a common emission limit is 5 mg ammonia/Nm^3 of flue gas (without oxycat) [Infomil, 2009]. The total contribution of NH_3 to the total emissions of the studied sources is expected to be relatively low. Main contributors are agricultural activities and domestic (95% of total) [Van Dril, 2005].

For current and future emission factors is assumed that no SCR is installed (or required) in gasfired boilers and gasturbines, resulting in an emission factor of zero. For gas engines, it is assumed that currently 50% of the installated capacity has an SCR, mostly in horticulture with an additional oxycat in which the ammonia is deeply removed (est. 95%) with a final emission of around 0.3-0.4 mg/Nm^3. For this application, the SCR is not always operational during operation of the gas engine (depending on the demand for CO_2 fertilisation) [Kroon, 2009a]. For the current total gas engine population (in PJ) is assumed that 45% has an SCR (NH_3 emissions) (and is always operational) and 55% has no SCR (no NH_3 emissions) [Kroon, 2009a]. NH_3 emissions from gas engines on natural gas with SCR are reported to be around 0.10-0.15 g/GJ [Olthuis, 2007], this would result in an emission factor of approx 0.05-0.07 g/GJ.

Table 3.1 indicates the estimated current and future emission factors of the medium scale biomass conversion installations.

Table 3.1 Estimated NEC emission factors medium-scale biomass installations, 'max' indicates an emission limit, bold = used value for impact analysis Chapter 5

Type of installation	Period	NO_x [g/GJ]	SO_x [g/GJ]	Dust/ PM10 [g/GJ]	PM2.5 estimate [fraction of PM 10]	NMVOC [g/GJ]	NH_3 [g/GJ]
Solid biomass boiler	2008/2009	67 [a] 100[k] max 70-**130** [d]	**10** (range 6-40) [g] 5[j] 0-2 (Installation Cuijk)[j]	**5** [a]	0.79 [f]	3.3-48 [g] **60** [g] 100 [i] (for Belgium, GAINS data)	-without DeNOx: 0 -with denox: **1.7** g/GJ [d] (Installation Cuijk)
	2020	max **35** [b] or 40 [k]	**10** (range 6-40) [a] max 68 [b]	max **1.7** [b]	0.79 [f]	**60**, assumed to be the same as in 2009	**1.7** (SCR assumtion)
Bio-oil/fat in dieselengine	2008/2009	30-150[n] max **130**[e] max 400-1200 (diesel)[d]	0[a], 1-22 [n] max **9** [e]	25[a] 2-4[n] max 13-**17** [e]	N/A	100 [h] **31** (CxHy) [e]	max **4.4** [e]
	2020	max **130** [b]	**9** [e] max 69-70 [c]	max **17** [c]	N/A	**31**, assumed to be the same as in 2009, worst case	max **4.4** [c], SCR assumption
Biogas in gas engines	2008/2009	max 140 (new)-800 (old)[a] 175-**195**[p]	0.5[a] **2** [l] 10 [m]	**0.5**[a] 2 [l]	*1 (estimate based on natural gas) [f]	4-14 [g] **14** [j]	-without De-NOx: **0** -with SCR 0.10-0.15 g/GJ (natural gas) [o]
	2020	max. **30** (intention VROM for three years after introduction BEMS, until then: 100 [c]	**2** [l] max approx 70 [b] .	No limit, **0.5** assumed	*1 (estimate based on natural gas) [f]	**14**, assumed to be the same as in 2009	All SCR assumed: **0.15**

References: a) Daniels, 2008; b) VROM, 2008; c) VROM, 2009; d) Kroon, 2008; e) BIOX, 2007; f) Visschedijk, 2007; g) EMEP, 2009; h) NERI, 2007; i) De Groot, 2008; j) De Wilde, 2006; k) Kroon, 2009a; l) Guis, 2006; m) Gijssen, 2001; n) Toom, 2009; o) Olthuis, 2007 p) Engelen

The following remarks on the technologies can be made:

Solid biomass boilers
Solid biomass boilers are mainly fuelled by wood (residues), like chips/shaving or (clean) residues. The first BEMS draft proposes 35 g/GJ based on SCR [VROM, 2009]. However, there were objections from industry that this limit cannot be reached as SCR has not been proven for smaller scale installations. It was therefore proposed that the emission limit should be based on SNCR applications (and clean wood combustion), but no limit specific is given in the official correspondence [VROM, 2009a]. 40 g/GJ is assumed here [Kroon, 2009a] but on the long term it might be possible to reach the limit of 35 g/GJ. The expected SO_x emissions are relatively low, as the sulphur content of biomass is generally low. NH_3 emissions can be expected if a DeNOX has been installed. NMVOC emissions are relatively high compared to other sources described in this study.

Bio-oil in diesel engines
There are a limited number of diesel engines running on animal fat known in e.g. Ermelo and Eindhoven to heat swimming pools. NO_x and NMVOC emissions, same as with diesel engines, are expected to be relatively high compared to other souces, while SO_x is in the medium range for biomass fuels. PPO is currently not known to be fired in the Netherlands. Permits voor diesel engines running on palmoil stearine for the installations for the company BIOX indicated some emission limits [Groningen, 2006; Groningen; 2007].

Bio-gas in gas engines
The application of bio-gas in gas engines is mainly at waste disposal sites, manure (co)digestion and sewage water treatment plants. Main growth is taking place for manure digestion. The most significant emissions are NO_x emissions. Reported measured values in 2009 for NOx emissions from biogas-fired gas engines (measurements on three as engines in the power range of 360-1400 kWe(design)) without SCR are in the range of 175-195 g/GJ [Engelen, 2009]. In Europe about ten biogas engines are indicated to be equipped with SCR and experiences are said to be promising [VROM, 2009]. However long term experiences are not available. Therefore, in the BEMS draft the intention is to have a limit for 30 g/GJ on the long term [VROM, 2009]., however if these emisson limits can achieved still has to be demonstrated.

Gas engines on biogas will meet the requirements of SO_2 as H_2S needs to be removed before to meet the specifications of the gas engine. SO_2 was therefore not regulated for (bio)gas engines [Handrijking Mestvergisting]. Dust emissions are low due to the wet process conditions.

The estimated NEC emission factors are given in Table 3.2:

Most relevant emission for fossil fuels is indicated to be the contribution of NO_x [Peek, 2009], which is estimated in several studies [Kroon, 2003; Vissedijk, 2007].

Natural gas in gas engines
Natural gas (and biogas) are relatively clean fuels. They produce relatively low amounts of CO_2/MJ and dust. NO_x emission are low compared to a diesel engine. Reduction of emissions is possible by using a threeway catalyst comparable to a car engine or (the most popular) by operating the engine on a lean mixture. By using a large excess of air, the combustion temperature is lowered and thus the formation of NO_x. The relation between excess air and formation of different pollutant is illustrated in Figure 3.1. When the excess air is increasing the amount of NMHC/NMVOC is increasing. In green house application, the flue gases of gas engines can be used to enrich the air with CO_2 for fertilization. For this application, it is necessary that the flue gases are extremely clean. Normally, a de-NOx is applied and CO and NMHC/NMVOC are removed by an oxycat.

Table 3.2 Estimated NEC emission factors medium-scale fossil-fired installations, ('max' indicates an emission limit)

Type of installation	Period	NO_x [g/GJ]	SO_x [g/GJ]	Dust/PM10 [g/GJ]	PM2.5 estimate [fraction of PM 10]	NMVOC [g/GJ]	NH_3 [g/GJ]
Gas engine	2008/2009	av. 16 (greenhouses, with SCR on)[k)] 166-333 (greenhouses with SCR off)[k)] 174 greenhouses [e)] 200 other [e)]	0.22 [a)]	0.15 [a)] 0.19 [g)]	*1 [e)]	117 [b)] (no oxycat) +/- 0 (with oxycat) 46 (incl 5% gas oil) [c)]	approx 0.10-15 with SCR[j)] 0 without SCR [j)] Average: 0.05-0.07
	2020	>2,5 MW_th: max 30 [f)] <2,5 MW_{th}: max 30 (intention VROM after three years, until then: 80. [f)]	0.22 [a)] max 67 [f)]	No limit, 0.15 assumed	*1 [e)]	117 (no oxycat > worst case)	0.15, assuming SCR
Gas turbine	2008/2009	58 [h)]	0.22 [a)]	0.15 [a)]	*1 [e)]	1.4 [b)]	0 (assumed no SCR needed)
	2020	max 40 [f)]	max 67 [f)] 0.22 [a)]	No limit, 0.15 assumed	*1 [e)]	1.4, assumed to be the same as in 2009	0 (assumed no SCR needed)
Gas fired boiler	2009	40 [h)]	0.22 [a)]	0.15 [a)]	*1 [e)]	1-4 [b)] 1-3 [c)]	0 (assumed no SCR needed)
	2020	max 20 [f)]	max 67 [f)] 0.22 [a)]	No limit, 0.15 assumed [a)]	*1 [e)]	4, assumed to be the same as in 2009	0 (assumed no SCR needed)

References: a) Guis, 2006; b) NERI, 2007; c) EMEP, 2009; d) Kroon, 2008; e) Visschedijk, 2007; f) VROM, 2008; g) De Wilde, 2006; h) Kroon, 2009; i) Kroon, 2008a; j) Olthuis, 2007 k) Engelen, 2009

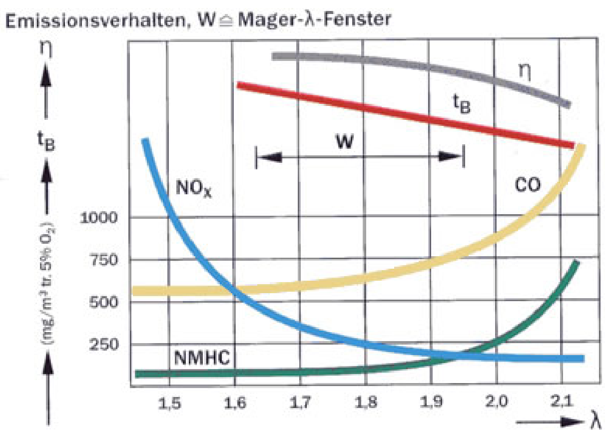

Figure 3.1 Relation gas engine emissions versus lambda (or λ) with no flue gas cleaning. The x-asis shows the air excess ratio lambda. NMHC = non methane hydrocarbons [Energietech, 2009]

Within three years, the intention in BEMS is to have the same NO_x limits for bio- and natural gas-fired engines with a capacity smaller than 2.5 MW_{th}, and for installations that are larger then 2.5 MW_{th}. This will imply the application of an SCR technology for NO_x reduction for all gas engines

The average NO_x emission factor of gas engines has been strongly reduced the last decades. Current emission factors for a large number of gas engines in green houses are reported to be 20 g/GJ due to the use of SCR, necessary to make CO_2 fertilisation for crops possible [Daniëls, 2008].

70% of all gas engines placed after 2003 in greenhouses have an SCR installed and this significantly decreases the overall emission factor. The average emission factor for gas engines in this sector is currently reported to be 60 g/GJ [Kroon, 2008], which is substantially lower than the reported overall average, see Table 3.3. Recently measured average NO_x emissions for gas-fired gas engines *with* CHP in green house horticulture with SCR on are indicated to be 16 g/GJ, substantially lower than the proposed BEMS emission limit of 30 g/GJ [Engelen, 2009].

Table 3.3 Estimated emission factors NOx gas engines [TNO, 2007; Kroon, 2005] in g NO_x/GJ fuel

	2000	2005	2010
Gas engine on natural or residue gas	260	217	174
Gas engines greenhouses	259	200	142

NMVOC emissions can be specifically high for gas engines without SCR/oxycat[10], based on Danish data. It is reported in literature that this is especially the case for lean-burn gas engines [NERI, 2007], at least in Denmark. This effect is also indicated in Figure 3.1. However, if an oxycat is used to make the flue gas suitable for greenhouse fertilisation used the emissions of NMVOC can be strongly reduced and almost no NMVOC will be present in the flue gas [Energietech, 2009].

Without SCR, no NH_3 emissions are expected. Reported emission factors with SCR are around 0.11 g/GJ voor natural gas fired gas engines [Olthuis, 2007].

Natural gas in gas turbines
Small-scale gas turbines are fired on natural gas and the specifications for turbines are very strict. NO_x emissions are low, as well as SO_x, dust and NMVOC. An SCR is not necessary and therefore NH_3 emissions are assumed to be negligible [Kroon, 2009].

Natural gas in gas-fired boilers
Gas-fired boilers are mainly used for steam/heat generation and not for CHP. The emissons of gas fired boilers are mainly NO_x, which is so low that an SCR is normally not required [Kroon, 2009]. As for gas-fired boilers, the emissions of dust and SO_x are very low, as well as for NMVOC.

3.3 Emission factors from residential wood stoves

In scenario study [Koppejan, 2008] the emission factors presented in Table 3.4 are used, but no direct reference is given. Within the Dutch Emission Inventory the emission factors presented in Table 3.5 are used. Furthermore, net heating values (LHV) of 15.5 $MJ/kg_{wet\ basis}$ for wood and 29.3 $MJ/kg_{wet\ basis}$ for waste[11] are used in the Dutch Emission Inventory. It must be noted that the heating value of waste is very dependent on the type of waste burned.

The largest variation in heating value for wood arises with the moisture content. Freshly cut wood has a moisture content of around 50%, where well dried fire wood has a moisture content of 20% or less. Burning dry wood results in a more efficient combustion and cleaner flue gases. The moisture content is not mentioned in the consulted literature on the emission factors. Within the Dutch emission inventory no emission factor for ammonia is known.

[10] Oxycat = oxidator catalyst. It should be noted that most CxHy emissions of a gasengine are methane emissions. These emissions are not affected by an oxycat.
[11] The value of 29.3 $MJ/kg_{wet\ basis}$ is high as a first estimate within the emission inventory. This value has not been used in this study to estimate total emissions as the emissions of waste combustion on small-scale are relatively low compared to wood combustion. The actual heating values are lower.

To convert emission factors in both tables below from g/kg fuel to g/GJ, the factors can be multiplied by 34.1 for waste and 64.5 for wood. This multiplication is based on the assumed net heating values as used in the Dutch emission inventory. It should be noted that per fuel the factors can vary based on the fuels composition.

Table 3.4 Emission factors (g/kg fuel) used in a scenario study on woodstoves [Koppejan, 2008]

Compounds	**Open fire place**	**Freestanding / Inset stoves**		
		unapproved	**approved**	**DIN*plus***
CO	50.00	100.00	60.00	15
TSP	7.00	3.00	0.50	0.77
PAH	0.05	0.09	0.058	0.01
NO_X	2.06	2.06	2.06	2.06
C_XH_Y	7.50	15.00	2.00	1.24
NH3	No data	No data	No data	No data

Table 3.5 Emission factors used by the Dutch emission inventory [www.emissieregistratie.nl]

Fuel	**Compound**	**Unit**	**Approved stoves**	**Unapproved stoves**	**Open fire places**
Waste	CO_2	kg/GJ	109.6[a]	109.6 [a]	109.6 [a]
	NMVOC	g/kg	3 [b]	5 [c]	5 [c]
	NO_x	g/kg	2 [c]	2 [c]	2 [c]
	PM_{10}	g/kg	20 [b]	40 [c]	11 [c]
	$PM_{2,5}$	g/kg	12 [b]	24 [c]	6.6 [c]
	SO_2	g/kg	2 [d]	2 [d]	2 [d]
	NH3		No data	No data	No data
Wood	CO_2	kg/GJ	109.6 [a]	109.6 [a]	109.6
	NMVOC	g/kg	6 [e]	12 [e]	20 [c]
	NO_x	g/kg	2 [c]	2 [c]	1.2 [g]
	PM_{10}	g/kg	1.5 [f]	3 [f]	2.5 [c]
	$PM_{2,5}$	g/kg	1.4 [f]	2.8 [f]	2.4 [c]
	SO_2	g/kg	0.2 [g]	0.2 [g]	0.2 [g]

References: a Vreuls,2006; b Schatting TNO; c Slob,1993; d van Dijck; e Veldt, 1995; f CEP-MEIP 200; g EPA,1996b et al., 1993

In both sets of emission factors the values are within the same range. However not all data are the simular, for example the emission factors of TSP (Table 3.4) and PM_{10} (Table 3.5) do not show the same trend. For TSP the open fire places displays the highest emission factor where for PM_{10} the unapproved stoves displays the highest emission factor.

3.4 Biofuel production

3.4.1 Introduction

In this section, information is presented on the NEC emissions that originate from biodiesel, bio-ethanol, bio-methanol and Fischer-Tropsch plants in the Netherlands. Please note that additional information regarding the chain (including cultivation of crops and transportation and distribution) can be found in the ECOFYS report BOLK II, by Michèle Koper, Maarten van den Berg and Carlo Hamelinck (2009). Several regulations exist for different types and scales of processes. A number of regulations are relevant for permitting:

- Bees-A [Overheid, 2009]
- BREF Grote Stookinstallaties (BREF Large combustion plants) [Infomil, 2009]
- BREF Op- en overslag goederen (BREF Storage and transshipment) [Infomil, 2009]
- BREF Monitoring [Infomil, 2009]

- BREF Koelsystemen [Infomil, 2009]
- NeR (Nederlandse emissie richtlijn) [Infomil, 2009]
- MER [Commissie MER, 2009]
- Wet milieubeheer [Overheid, 2009]

3.4.2 Approach

The information on the emission of NEC pollutants was derived from permits of the individual processes. It was observed that the available permits do not necessarily follow the existing national regulations (they can be both more or less strict). In addition, permits for similar types of biofuel installations can differ. It was chosen to list the permits of the relevant industry. When no source was indicated, ECN in-house data are used. None of the installations in this study had to carry out a detailed Environmental Impact Assessment (EIA) [12].

It is not straightforward to express the emissions in g/ton product or g/GJ, due to the often present interactions with other industries or companies with respect to e.g. utilities. Furthermore, it must be kept in mind that some processes produce more than one product besides biofuels. All emissions in this study are allocated to the biofuel as primary product and expressed in g/GJ of the biofuel product, using the lower heating value (LHV) of the products.

Only the emissions of the biofuel production location itself are taken into consideration. Therefore, the emissions from e.g. feedstock production, transportation, residue treatment (e.g. waste water) are not included in this report. Finally, some of the processes have a single permit for the production process and the combustion plants, while others have two separate permits, or even obtain all heat and power from a different company altogether. Appendix C gives a detailed overview of the emissions and processes and emission prevention measures.

3.4.3 Biofuel processes

Below, the individual processes and associated emissions are described. Currently several biodiesel industries in the Netherlands exist, and two installations were selected for this study. Only three bio-ethanol factories currently exist in the Netherlands, and the largest and the smallest are chosen here. Only one bio-methanol process exists in the Netherlands, and no industrial Fischer Tropsch installation exists (or is planned) in the Netherlands. There is one Fischer Tropsch plant on biomass in Germany (Choren Industries GmbH) which is currently demonstrated at pilot scale.

The individual companies of which the permit was obtained and used in this chapter are listed below in Table 3.6. The measures taken to reduce the emissions in each installation are listed in. Appendix C.

Table 3.6 Studied permits of biofuel processes in the Netherlands

Company	Product(s)
Heros Sluiskil BV (Rosendaal Energy)	Biodiesel
Biopetrol Industries AG	Biodiesel
Abengoa Bioenergy Netherlands BV	Bio-ethanol
Koninklijke Nedalco BV	Bio-ethanol
BioMCN	Bio-methanol

3.4.3.1 Bio-ethanol: 1st and 2nd generation

Bio-ethanol factories are divided into two categories: 1st and 2nd generation bio-ethanol. First generation factories produce ethanol from sugars while the second generation first converts the lignocellulosic feedstock into sugars (and residues) in a pretreatment step, after which the sugars are converted to ethanol in a process that is nearly identical to the 1st generation process.

[12] Environmental Impact Assessment (EIA) in Dutch: Milieu Effect Rapportage (MER)

Therefore, it can be concluded that the only major difference between the two bio-ethanol processes is found in the pretreatment.

Bio-ethanol pretreatments
The 2nd generation bio-ethanol factories are still under investigation, and no commercial installation exists at this moment. Worldwide, research groups work on new pretreatments and continuously improve the processes. Below, a non-exhaustive list is given with pretreatments and their possible emissions. All pretreatments need heat, and will therefore require a combustion/steam plant.

Table 3.7 Pretreatments and possible emissions

Pretreatment	Possible emission
Organic acid	VOC (organic acid)
Organosolv	VOC (solvent, e.g. ethanol)
Mild-acid	No emissions expected
Ammonia fibre explosion	Ammonia
Kraft pulping (or related technology)	SO_2
Steam explosion	No emissions experted

VOC = Volatile Organic Compounds

In addition, the 2nd generation bio-ethanol plants are often envisaged to be part of a so-called biorefinery. This is a larger process that used a certain biomass as feedstock and produces more than one product. Just like 2nd generation bio-ethanol factories, the biorefineries are still being investigated and a wide variety of (future) biorefineries exist.

Ethanol process
Ethanol is produced in a fermentor that emits CO_2. This CO_2 stream contains some ethanol, fusel oil and tert-butyl-ether. Ethanol is the largest VOC in this flow, and most of it is recovered in an ethanol scrubber for economic reasons, but small amounts are emitted. The other sections in the factory require heat, which generates combustion-related emissions.

It should be noted that the Abengoa factory does not emit any CO_2 and therefore no VOC. Instead, it compresses and sells the CO_2.

3.4.3.2 Biodiesel

Biodiesel is made from vegetable oil and an alcohol (usually methanol) which react and produce biodiesel and glycerol. Both the products have negligible vapour pressure and will not cause any relevant emissions. The only chemical that can cause VOC emissions is methanol, which can leak during transshipment and storage. The process itself does not produce any emission. The combustion facility will create all emissions related to combustion.

Two permits were investigated, differing significantly in types of described equipment and permitted emissions. The biodiesel factory of Heros Sluiskil BV obtains the utilities from another installation. This installation has a separate permit, but is owned by the same company (Heros Sluiskil BV). Biopetrol Industries AG has an (unspecified type of) off-gas cleaner, which is not found in the Heros Sluiskil BV process. In addition, Biopetrol Industries AG produces bio-gas which is combusted causing emissions related to combustion, including SO_2. Emission limits for the bio-gas production and combustion are mentioned in the same permit as the biodiesel production.

3.4.3.3 Bio-methanol

There exists only one bio-methanol production facility in the Netherlands, namely the BioMCN installation. BioMCN has two separate processes: one using natural gas, the other using using glycerol (and also natural gas), to produce methanol. The permit does not allow to clearly distinguish between the bio-methanol produced from glycerol and methanol from natural gas.

The process consists of three sections: the reformer, synthesis and distillation. The glycerol is first pretreated (purified), after which it is vapourized and fed to the reactor. In the reformer, the glycerol is converted to CO and H_2 (and CO_2) which are used in the synthesis. The reformer requires heat from a combustion installation. The synthesis section converts the gases into methanol, which is subsequently purified in the distillation section. The BioMCN plant has six flares on the terrain.

Glycerol/natural gas ratio
The permit leaves room for interpretation of the ratio of glycerol/natural gas:

- Page 6 states that "in this application the glycerol is used only in MeOH-I (one of the two separate processses of BioMCN) for the production of bio-methanol".
- Page 19 states the SO_2 emissions for MeOH-I for 100% natural gas consumption and for 50%/50% natural gas / glycerol consumption.

These two statements are presented here to show that at best, BioMCN produces 25% bio-methanol, but it can also switch to 100% natural gas (thus producing fossil methanol).

3.4.3.4 Fischer Tropsch diesel

The Fischer Tropsch process first produces, like the BioMCN process, synthesis gas (CO and H_2). Theoretically, any fuel can be used to produce synthesis gas. The synthesis gas is produced in a gasifier (when liquid and solid fuels are used) and in a reformer (when natural gas is used, like in the BioMCN process). However the emissions of the gasification step are expected to be very low.

The synthesis of fuels will proceed under similar conditions as the BioMCN process, although the products are different. This is an exothermic process, meaning that it produces heat, and does not require any heat input. It is not expected that any emissions originate from the FT synthesis itself. The products are subsequently purified in a series of separations.

Quantitative data are feedstock, process and company dependent. Because no commercial installation exists in the Netherlands (or worldwide), no data could be presented in this report. A pilot scale factory exists in Germany (Choren Industries GmbH). However, emission data have been requested but not received during the duration of this project.

The most likely emissions, apart from those previously mentioned, are VOC from storage and leaks. Off-gas can be combusted, and can cause emissions as well.

3.4.4 Results

The emission factors of the several biofuel production processes are given in Table 3.8 The emissions for the various types of processes vary widely. This can be attributed to the variation in types of processes and also the type of permit (with or without combustion plant). The indicated emissions allocated to the biofuel product. Due to the complexity of biofuel plants (often multiple (wet) input and multiple output), this study gives a first indication of expected emissions.
With respect to the expected NEC emissions: NMVOC emissions will arise mainly from the biofuel production/storage itself and are in the range of a maximum of 0.26-1.4 g/GJ fuel . Especially NO_x and SO_x emissions will arise from the required heat and power utilities for the biofuel production process, although SO_x emissions are expected to be very low when natural gas is used for firing. Per GJ product, the NO_x emissions are around 0.5-2.3 g/GJ fuel product, which is low compared to the emissions during end use. SO_x emissions are in the range of 0.2-1.9 g/GJ fuel. NH_3 emissions are expected to be limited and are not mentioned in permits. No significant dust emissions are expected from the biofuel production itself. Some processes use closed transport systems to prevent the emission of dust (see: Appendix C).

Table 3.8 NEC emission factors for biofuel production

Product	Company	NO_x	SO_x	VOS	Dust	NH_3
Biodiesel	Heros Sluiskil BV (Rosendaal Energy) [Gedeputeerde staten van Zeeland, 2007b]	Permit does not state max. allowable emissions. Separate permit for combustion plant (biomass plant)				
Biodiesel + glycerol	Biopetrol Industries AG [Gedeputeerde staten van Zuid-Holland, 2006]	2.26 g/GJ biodiesel 1.99 g/GJ product (total incl. glycerol) (*)	0.52 g/GJ biodiesel 0.46 g/GJ product (total incl. glycerol)	<0.26 g/GJ *biodiesel* <0.23 g/GJ product (total (incl. glycerol)	(***)	(***)
Bio-ethanol	Abengoa Bioenergy Netherlands BV [Gedeputeerde staten van Zuid-Holland, 2007]	0.49 g/GJ ethanol (**)	(***)	CO_2 containing VOC is compressed and sold. Other: not possible to express in an amount per ton product	(***)	(***)
Bio-ethanol	Nedalco [Gedeputeerde staten van Zeeland, 2006]	(***)	(***)	0.26 g/GJ ethanol	(***)	(***)
(Bio)methanol	BioMCN [Gedeputeerde staten der Provincie Groningen, 2008]	Reformer power (MW) is unknown.	Reformer 1, 100% natural gas: 0.21 g/GJ Reformer 1, 50% natural gas, 50% glycerol: 0.28 g/GJ Reformer 2, 100% natural gas, 1.7 g/GJ	1.4 g VOS / GJ methanol based on glycerol as feedstock (above values: assuming a 25-75 consumption of methane / glycerol, and assuming that all VOC originate in the glycerol-process) 2 g methanol /GJ methanol (transshipment) 8.9 g methane / GJ methanol based on methane as feedstock	(***)	(***)

(*) Calculated max. values: permits states 70 mg/m^3 leads to 30 ton/year, but the calculated value is 36 ton/jaar (+1.7 ton/year for the oil heaters = 38 ton/ year)
(**) Copied from the permit
(***) Permit does not state max. allowable emissions

3.5 Biomass storage and transshipment

3.5.1 Introduction

If biomass will be used on a large scale in the Netherlands, import of biomass will be necessary to ensure that sufficient biomass will be available for energy conversion, as local availability is limited. In that case, large scale biomass storage and transshipment facilities will be required, most probably in port areas like Rotterdam and Amsterdam. Bulk transshipment of e.g. coal, ore and agribulk is reported to be a significant source of dust emissions [Klimont, 2002]. For coal, it is reported that emissions for the coal storage and transhipmemt can even be larger than from stack emissions [De Wilde, 2005]. Information on the possible dust emissions of biomass storage and transshipment are currently lacking. This section decribes the available/accessable knowledge on the emissions of this activity.

3.5.2 Approach

To retrieve dust emission factors for biomass transshipment and storage, a literature search has been performed. Quantitative data and data on emission factors of diffuse sources in general are very limited [VITO, 2006].

Furthermore, several Dutch companies and authorities have been contacted for information on emission factor data [Voerman, 2009; Mieoch, 2009; Vrins, 2009; EMO, 2009, EBS, 2009; Essent, 2009; Kriegsman, 2009; Westraten, 2009; Henderickx, 2009; Schott, 2009; Kok, 2009; Van de Ende, 2009] and the lack of availabiliy of reliable (public) measurement data on this subject was confirmed. However, sources indicate that measurement data and estimations are available, but are confidential [Beers, 2009; Ostermeijer, 2009]. These data were not available for this study.

3.5.3 Results

Storage requirements

Relevant for expected dust emissions of biomass storage and transshipment are is the way of storing biomass: open or closed. Biomass is available in a wide variety. The conditions to store biomass can vary accordingly. Table 3.9 gives the requirements to store biomass. From this table can be observed that for wood chips it is preferred to have a stored coverage to prevent self-heating and decay of the material. However, in this overview wood pellets are missing. It is required to store wood pellets dry, as they will fall apart when moisturized.

From several contacts with power producers is concluded that they prefer to have covered storages to have controlled storage conditions, to prevent wetting and product detoriation. Larger installaties have usually a covered storage (e.g. the wood-fired combustion plants in Cuijk and Lelystad) while coal-fired power plants have silo's and covered transshipment for their wood pellets for co-firing. Wood chips are reported to be transported by closed container and stored in a covered storage [Westraten, 2009]. It is also indicated that as a result of the closed storage and transport systems, they do not consider dust emissions as a significant problem.

Estimation emission factors

(Diffuse) emissions of bulk transshipment and storage activities are strongly dependend on a number of parameters: particle size distribution, density, moisture content, duration of the storage and tendency for particles to agglomerate, mechanical strength, nature of the manipulation, storage facilities and meteriological conditions (drought and wind speed). The average dust emission factor can therefore very significantly from location to location. Emissions of dust are prevented by applying several precautions, required for dust sensitive materials, like closed transport systems and the wetting by sprays. These are extensively described in the NeR [Infomil, 2009].

Table 3.9 Overview storage recommendations for biomass feedstocks [based on: FNR, 2002]

Fuel type	Moisture content [wt%$_{wet\ basis}$]	Storability	Storage requirements	Risks and recommendations
Wood (massive), fresh, not debarked	50-55	Limited	Open air	Beetles and fungus infestation
Wood (massive), reduced in size and debarked, fresh	50-55	Dries during storage	Open air	Fungus infestation
Wood chunks, reduced in size, around 10 cm, without fine particles fraction	<45	Good storability in heaps, even better in closed storages	Open air	Fungus infestation and risk of self-heating if moisture content > 25%
Wood chips (small) with larger fine particles fraction	<25	Good	Covered storage	Fungus infestation, loss of heating value, self heating
Bark	<50	Limited	Open air or covered storage	Loss of heating value, loss of structure, self heating, silage effluent
Straw	<15	Good	Open air only with coverage of in covered storage	Fungus, dust infestation
Whole plants	<12	Good	Open air with coverage of in covered storage	Fungus infestation, dust, mouses, rotting
Thinnings	<14	Good	Open air with coverage or in covered storage	Fungus infestation, rotting, dust

Table 3.10 Dusting classes NeR

	Class	
Not drift sensitive	S5	
	Not wettable[1)]	**Wettable**
Highly drift sensitive	S1	S2
Moderately drift sensitive	S3	S4

[1)] Class S1 and S3 may only be stored in closed spaces

The NeR [Infomil, 2009] specifies five different classes for drift sensitive materials, see Table 3.10. As the form and properties of biomass feedstocks can vary considerably, there is not one applicable dusting class for biomass. For each material wind tunnel tests can be performed to determine its appropriate class. Biomass fuels are not a specifically indicated in the classification list of drift sensitive materials within the NeR (4.6), see Appendix A. It is indicated that for most wood chips and wood pellets S5 (not drift sensitive) is the most appropriate, but wood pellets can also be classified in different classes, depending on the kind/quality of pellet and kind of erosion [Van de Ende, 2009]. For wood pellets is indicated that the first fraction that is flown away is class S1 and the course fraction is class S3. In a specific permit, the required emissions reduction measures are based on class S3 [Zeeland, 2008].

To calculate the total emissions, specific dust measurements can be performed or - if not available - based on specific emission factors correlated to its class according to the Netherlands Technical Agreement NTA 8029 ‘Bepaling en registratie van industriële fijnstof emissies’ [NEN, 2008]. The DCMR Environmental Protection Agency Rijnmond (the environmental authority of the Port of Rotterdam region), indicates that biomass feedstocks commenly are classified as class S3 and class S5 and that dust formation is not considered as very problematic [Voerman, 2009]. This agency has no data nor measurements available on biomass transshipment and storage activities and recommends to use standard indicative emission factors according to the NeR dusting classes, as a first estimate.

Indicative numbers for emission factors for bulk storage and handling and other agrobulk activities are given in Table 3.11 and based on data from the Database Fijn Stof [FO industrie, 2009]. The quality of the emission data is indicated as low. A distinction can be made by emissions from manipulation (reception, transshipment, transport means etc) and fugitive emissions. The fugitive emissions are strongly dependent of the atmospheric condications like precipitation and wind [NEN, 2008].

For the emission factor for bulk transshipment, the indicated emission factor is expressed without conveyer belts (direct transportation, e.g. with a grab) including the transport from transport means (e.g. ship/truck/train) to storage and from storage to transport means. When (open) conveyer belts are used, the emission factor should be *multiplied* by two. Biomass is often transhipped with a closed grab of with a closed pneumatic system to prevent dust emissions and wetting. If no storage is included (direct transport to another means of transport), the emission factor should be *divided* by two [Mulder, 1987]. The numbers presented in this table are based on emissions without abatement. However, it is indicated that PM10 emission reductions can be achieved by 70% upto 90-95% when the appropiate measurements are taken [Beers, 2009]. A factor 20 reduction is reported when using a dust removal system for a grain bunker [Mulder, 1987]. The number presented in the table below therefore present a worst case if no abatement is indicated.

As reliable data on the emissions from biomass storage and transshipment is absent, an order of magnitude estimation is done in the following sections for wood pellets and wood chips.

Emission factors for wood pellets
Assuming class S3 (wood pellets) for biomass feedstocks, 10 g/ton or respectively of PM10 emissions can be expected as an upper level with direct transport for manipulations activities, with intermediate storage, according to the typical values indicated in the tabel above. This corresponds to a value of 0.59 g PM10 per GJ handled material (17 GJ/ton_{wet}), assuming no emissions during storage and no abatement.

For wood pellets, emission data of a coal-fired power plant have been used for this study. It concerns the transshipment and storage in silos of wood pellets, with closed transportation systems and filters to remove dust. The estimated overall emission factor is 0.40 g/ton material handled and stored. In a worst case scenario (doubled emissions), the dust emissions would be 0.80 g/ton pellets, or 0.047 g/GJ.

Wood chips are reported to be designated as weakly drift sensitive [Winiwarter, 2007; Van de Ende] or not drift sensitive (Class S5) [Voerman, 2009]. In the first reference, emissions for the production of wood chips for the local industrial use in the board and paperindustry are given. An emission factor for TSP is indicated to be in the range of 28-32 g/t wood chips for emissions of a conveyer belt (from chipper to heap) and the removal of the material from the bottom of the heap to a silo (low drop height, no dust abatement). Assuming a fraction of PM10 of 10% of the TSP, this would correspond to 2.8-3.2 g/ton wood chips handled or 0.23-0.26 g/GJ diffuse emissions (assuming 12 GJ/ton_{wet} wood chips).

In case an NeR dusting class S5 material is assumed, according to the table above the emission factor for manipulation is given as 0.5 g PM10/ton with direct transport (e.g. grab) and intermediate storage without abatement. This would correspond to 0.04g/GJ for wood chips, excluding storage emissions.

From permits in the USA, a dust emission factor for wood chips could be retrieved. For a specific permit, values are given of an emission factor of 45 g/ton for PM and 21g/ton for PM10 for reception and storage of dry wood [Kingsford, 2008] and is considered in the permit as a conservative estimate. This would correspond to 3 g/GJ for PM and 1.6 g PM10/GJ, significantly higher than the indicated emission factors in Table 3.11.
Based on the presented data, estimates of emission factors can range orders of magnitude. For comparison, the emission limit for dust in the BEMS proposal is around 1.7 g/GJ. Even for coal

or other bulk commodities, large variations can be found in reported emission factors, see also Appendix B.

Table 3.11 Emission factors of bulk handling and storage [FO Industrie, 2009]

Industry	First criteria	Dusting Class	Abatement	TSP [g/ton]	PM10 [g/ton]	PM2.5 [g/ton]	Quality Rating
Standard emission factors NeR dusting classes							
Bulk storage and handling	diffuse emissions due to manipulation	S1		1000	200	N/A	low
		S2	moisterized	100	10	N/A	low
		S2	not moisterized	1000	200	N/A	low
		S3		100	10	N/A	low
		S4	moisterized	10	0.5	N/A	low
		S4	not moisterized	100	10	N/A	low
		S5		10	0.5	N/A	low

Industry	First criteria	Second criteria	Abatement	TSP [g/ton]	PM10 [g/ton]	PM2.5 [g/ton]	Quality Rating
Bulk storage and handling							
Coal and minerals	diffuse emissions	manipulation activities			3	N/A	low
Iron ore	diffuse emissions	manipulation activities			2	N/A	low
Agribulk	diffuse emissions	manipulation activities			24	N/A	low
Xoal and minerals	diffuse emissions	open storage			1 ton/ha/yr	N/A	low
Iron ore	diffuse emissions	open storage			1 ton/ha/yr	N/A	low
Animal and vegetable products from the food and beverages sector							
Manipulation Agricultural bulk goods (Grains Derivatives, Tapioca)				24	N/A	N/A	low
Grain Elevator (silo)	grain receiving	Straight Truck	No abatement	90	30	5	low
Grain Elevator (silo)	grain receiving	Hopper Truck	No abatement	18	3.9	0.65	low
Grain Elevator (silo)	grain receiving	Railcar	No abatement	16	3.9	0.65	low
Grain Elevator (silo)	grain receiving	Barge - Continuous Barge Unloader	No abatement	15	3.7	1	low
Grain Elevator (silo)	grain receiving	Marine Leg	No abatement	75	19	2.5	low
Grain Elevator (silo)	grain receiving	Ships	No abatement	75	19	2.5	low
Grain Elevator (silo)	headhouse and grain Handling		No abatement	31	17	2.9	low
Grain Elevator (silo)	storage Bin		No abatement	13	3.2	0.55	low
Grain Elevator (silo)	grain Shipping	Truck (Unspecified)	No abatement	43	1.5	0.25	low
Grain Elevator (silo)	grain Shipping	Railcar	No abatement	14	1.1	0.19	low
Grain Elevator (silo)	grain Shipping	Barge	No abatement	8	2	0.28	low
Grain Elevator (silo)	Grain Shipping	Ship	No abatement	24	6	1.1	low
Grain Processing Facilities, Animal feed mills	Grain receiving		No abatement	8.5	1.3	N/A	low
Grain Processing Facilities, Animal feed mills	Feed Shipping		No abatement	1.7	N/A	N/A	low
Almond Processing	Unloading			300	N/A	N/A	low
Soybean Milling	Receiving		No abatement	75	N/A	N/A	low
Coffee Roasting Operations	Green Coffee Bean Screening, Handling and Storage System		Filter	27	N/A	N/A	low

Estimation emissions[13]

On the long term the storage and transshipment of biomass are indicated to be respectively 13-20 Mton/a [Schonewille, 2009] and 6 Mton/a for the harbour of Amsterdam [Gorris, 2009]. The expected main biomass stream is wood pellets, but some wood chips can be imported as well, depending on the economic conditions. However, it is also indicated that torrefaction pellets can be of importance in the future, which maybe stored outside. However, as this material is not commerciallty available yet and its dusting behaviour is yet unknown. For a worst case scenario, 20 Mton per annum of imported biomass has been assumed, see Table 3.12.

Assuming that biomass will be imported as wood pellets with closed systems (transport and storage), a first order of magnitude estimation for 2020 is around 0.016-0.020 kton/a of dust emissions with an imported volume of 20 Mton/a. This represents around 1.6-2.0% of the total emissions from bulk storage and transshipment and 0.04-0.05% of the national dust emissions in 2008.

When wood chips are assumed, based on S5 emission factor of the NeR (the other emission factors seem to be an overestimate for the Dutch situation with required dust preventing measures according to the NeR, also compared to the emission factors reported for grain with a large fraction of dust in Table 3.11), the estimate of the emissions is around 0.01 kton/a (= 1% of current the bulk storage and transshipment emissions and 0.03% of the total emissions), without any abatement.

The current total dust emissions of transshipment and storage activities is reported to be around 1 kton/a [Daniels, 2008]. Total dust emissions for the Netherlands in 2008 are given in Table 3.13 and are 37 kton [Natuur en Milieu Compendium, 2009]. Therefore, the contribution of this possible source of dust appears to be not very large. However, it is possible that locally the dust concentration can be increased due to biomass transshipment and storage activities. The uncertainty in these numbers is assessed to be large, due to lack of reliable data.

Table 3.12 First order estimation emissions biomass storage and transshipment 2020 (20 Mton/a)

Feedstock	Emission factor		Based on reference	PM10 emissions
	g/ton	g/GJ		kton/a
Wood pellet	10	0.59	based on NeR S3 emission factor (see Table 3.11)	0.200
	1 (= 10% * 10)	0.06	based on NeR S3 with 90% reduction by use of abatement	0.020
	0.8	0.05	Anonimous dutch power plant, with filters	0.016
Wood chips	0.5	0.04	based on NeR S5 emission factor (see Table 3.11)	0.010
	0.05 (=10% * 0.5)	0.004	based on NeR S5 EF, with 90% reduction by use of abatement	0.001
	3.2	0.25	Winiwarter	0.064
	21	1.62	Kingsford	0.420

[13] It should be noted that biomass dust from biomass handling and transhipment is for most part biodegradable in contrast to e.g. coal dust and most other sources (e.g. combustion) of dust.

Table 3.13 Dust emissions per sector in the Netherlands 1990-2008, in kton/a [Natuur en Milieu Compendium, 2009]

Year	1990	1995	2000	2005	2007	2008
Agriculture	9.0	9.1	9.8	8.8	9.2	9.5
Industry, Energy and Refineries	38	22	13	11	11	10
Tranport	21	17	14	12	12	12
Households	4.4	3.9	3.8	3.3	3.4	3.3
Trading, services and construction	2.8	2.4	2.5	2.2	2.3 [a)]	2.4
PM10 total	**75**	**55**	**44**	**38**	**37**	**37**

a) includes storage and transshipment dust emissions of 1 kton/yr [Daniels, 2008]

4. Reduction technologies: costs and performance data

4.1 Costs and performance data of removal of NEC components in flue gas for medium-scale biomass installations

4.1.1 Introduction

One of the recommendations from the BOLK I report [ECN, 2008a] is to perform an update of the cost and performance data of the most relevant emission reduction techniques applied for flue gas cleaning. The results of this update (part of WP 3 of the BOLK II project) are described in this chapter.

The flue gas composition before gas cleaning is determined by the concentration of contaminants in the fuel and process conditions. Part of these contaminants will be captured in the ash and thus will not appear as SO_2 or NO_x in the flue gas of a combustion installation. The amount of dust in the raw flue gas depends mainly on the physical characteristics (ash content) of the fuel and the process conditions. A complicating factor for NO_x is the formation of thermal NOx due the oxidation of N_2 at high combustion temperatures. Although the flue gas composition has a complex relation with fuel characteristics and process conditions, some general remarks can be made.

In Table 4.1 the fuel composition of coal (coal mix used in the Netherlands), wood (average of a large number of analyses) and natural gas are shown. The concentrations are expressed in g/GJ_{LHV} (amount per energy unit). By expressing these values per energy unit, the different fuels can be compared directly. The given typical values should be considered as an indication due to variation in composition of all mentioned fuels.

Table 4.1 Some typical fuel compositions expressed in g per GJ_{LHV} fuel

Components/Fuel	Coal	Natural gas[a]	Wood	Biogas
N	554	0.09 (as NH_3)	186	< 0.1
S	270	1.4	32	27
Cl	11	1.6	29	< 0.1

[a] maximum values

From this table it can be seen that the replacement of coal by wood (without flue gas cleaning measures) might lead to lower concentrations of NO_x (fuel NO_x) and SO_2 whereas the concentration of HCl might be higher, all depending however on the process conditions. Replacement of natural gas can lead to higher SO_2 concentrations in the flue gas.

A vast number of techniques are available for the reduction of the emission of dust, NO_x, NH_3, SO_2 and NMVOC of stationary bio-energy plants. The emission reduction measures described in this report are focused on application for three types of stationery bio-energy plants (excluding small-scale applications, like wood stoves):

- combustion of wood;
- combustion of vegetable or animal fats/oil in a diesel engine;
- anaerobic digestion plants with a biogas powered gas engine.

For each type of these bio-energy plants, different technologies have been developed and are being applied commercially. A specific combustion or digestion technology will have specific emission levels for each of the NEC pollutants depending on the reactor design and process conditions. Furthermore, the emission levels are influenced by the capacity of the plant and the type (particle size, moisture content, ash content, quality of the wood, bio-oil or biogas) of the applied fuel.

Compared to coal-fired power plants, bio-energy plants have a much lower capacity. Nevertheless, a number of emission reduction technologies used in coal-fired power plants is also suitable for bio-energy plants, such as DeNOx (SNCR) and dedusting techniques (bag house filter or ESP) (see Table 4.4 for an indication of the capacity range for the different emission reduction techniques).

The scale of the technologies can vary between very small (domestic scale, several kW_{th}) up to large plants (>100 MW_{th}). Bio-energy plants can be applied for the production of heat only or for the simultaneous production of heat and power. This all results in broad bandwidths for the concentration of pollutants in the raw, untreated flue gas and for the required performance and accompanying costs of the emission reduction measures. In order to focus this study, for each bio-energy plant a characteristic scale and application is selected and briefly described. For this characteristic scale the costs for emission reduction measures are estimated.

For the emission reduction techniques, average and median investment and operational costs are given based on literature data. The bandwidth in costs is indicated as minimum and maximum costs related to the calorific value of the input. In general, it can be stated that for smaller capacities the costs of emission reduction will be higher. For smaller installations, the costs will shift towards the upper limit of the indicated bandwidth.

It should be noted that by expressing the costs as function of energy content of the input the overall efficiency of the conversion into useful energy (heat and/or power) is not taken into account. Compared to large coal and gas power plants for power production, the overall efficiency of small bio-energy plants for CHP or heat production can be up to twice as high. This efficiency advantage is not reflected in the presented cost data.

4.1.2 Bio-energy plants

In order to focus, this study a limited number of bio-energy plants were selected e.g. wood combustion, bio-oil combustion in a diesel engine and biogas (from anaerobic digestion) used for firing a gas engine.

4.1.2.1 Wood combustion

The applicability of techniques is often expressed as a range in flue gas flow in volume per time units. For a 50 MW_{th} wood combustion installation the (wet) flue gas flow is ca. 70,000 m^3/hr; this will be used as volume flow criteria for emission reduction measures. Investment costs for gas cleaning techniques are often reported in Euro per volume flow flue gas. In this report these values are recalculated into Euro per energy unit fuel. The following assumptions for wood combustion plants are used:

- Wood (fresh wood chips) fired combustion installation (fuel composition according to Phyllis ID-922; [Phyllis database])
- Moisture content is 40 wt%
- Calorific value is 10.7 GJ/ton as received (LHV)
- Air ratio of the combustion process is 1.3
- 8,000 operational hours per year
- Technical lifetime of the installation is 10 years

These assumptions result in the production of 4.1 m^3 wet flue gas per kg fuel (as received) or 0.4 m^3 flue gas per MJ fuel (as received, LHV base).

In Table 4.2 an overview of commercial wood combustion plants in the Netherlands is shown with the applied measures for emission reduction. As wood contains hardly any sulfur in general, no SO_2 removal techniques are applied, except in combination with chlorine removal for combustion of B-wood (demolition wood, with more strict emission limits compared to clean wood). NH_3 removal is in general not applied in wood combustion plants; only in combination with SCR/SNCR, the slip of NH_3 is sometimes reduced by emission reduction measures. The emission of NMVOC from wood combustion plants is prevented by choosing the right operational conditions (efficient combustion) and therefore no flue gas cleaning for NMVOC is applied.

Table 4.2 Wood combustion plants in operation in the Netherlands with applied emission reduction measures

Plant location	MW_{th}	Fuel[a]	Dust	NO_x	NH_3	SO_2	NMVOC
Cuijk	85	wood	ESP	SCR	-	-	-
Goor	9	B-wood (waste)	Cyclone, fabric filter			Injection adsorbents	-
Lier	4	B-wood (waste)					-
Lelystad	Ca. 10	wood	Multi-cyclone, ESP				-
Schijndel	7.5	wood	ESP		-	-	-
Berlikum	5.7						-
Alkmaar	75	B-wood (waste)	Cyclone, fabric filter	SNCR	Semi-wet	Semi-wet	-
Hengelo	80	B-wood (waste)	Cyclone, fabric filter	SCR		Injection adsorbents	-
Sittard	Ca. 10	wood	Multi-cyclone, ESP				-

[a] wood = untreated wood from forests, parks and/or saw mills, B-wood is waste demolition wood, with stricter emission limits
References: SenterNovem 2005c; Bioenergietwente; SenterNovem, 1999; Host, 2009; Ecofys, 2006; Aradis, 2008.

4.1.2.2 Anaerobic digestion

An inventory of anaerobic digestion installations equipped with gas engines in 2007 revealed that the largest contribution to the total energy supply by digestion plants with a gas engine lies in the capacity range of 300-400 kW_e (> 40% of the total installed capacity; see also section 2.1.4 of this report). The average gas engine capacity in this range is 345 kW_e [ECN, 2008b].

For this study, this average capacity is used to describe a characteristic anaerobic digestion plant. Assuming a biogas production of 20 m^3 biogas per ton manure input and 200 m^3 biogas per ton co-product (for instance mais silage), 50% manure (in weight) and 7,000 operational hours per year a 345 kW_e gas engine will consume 1,200,000 m^3 of biogas annually (assuming an electric efficiency of 37% [Walla, 2008]) . Thermal input in this case is 0.95 MWth in the form of biogas. This 'average' digestion plant will process 11,000 ton of manure and co-products annually. Combustion of this amount of biogas in a gas engine (lambda = 1.4) eventually produces approximately 1,500 m^3 flue gas per hour. For 1 MJ of biogas 0.44 m^3 of wet flue gas is produced. Costs of emission reduction techniques are calculated relative to the calorific input of the biogas.

In some cases prior to combustion in the gas engine, measures are taken to reduce the H_2S content of the biogas thereby reducing the emission of SO_2. Applied methods for H_2S reduction are the addition of air to the biogas or Fe-containing salts in the digester. By adding a small amount of air to the digester H_2S is dissociated into solid elemental sulfur which is removed from the installation together with the digestate. The application of in-process removal measures for H_2S the concentration of SO_2 in the off-gas of the gas engine is strongly reduced and in general no SO_2 reduction measures are necessary. The emission of NMVOC and NO_x in flue gas of the gas engine is counteracted by de-NOx and with in some cases an oxidation catalyst [Handreichung, 2004].

4.1.2.3 Bio-oil/fat combustion

Typical thermal capacities for bio-oil-fired installations are in the range of 0.1-10 MWth [references bio-oil combustion]. According to a product specification de-NO_x is performed by SCR (with urea injection) [Dortech, 2009].

For the calculation of the mass flow of flue gas from bio-oil combustion the following assumptions were made:

- The caloric value of the bio-oil is 37 MJ_{LHV}/kg)
- thermal capacity is
- 8,000 operational hours per year
- air factor is 3.5 (resulting in 15%vol O_2 in the flue gas)

The combustion of one kg of bio-oil (37 MJ_{LHV} /kg) produces 36.7 m^3 of flue gas (wet), which corresponds with 1.0 m^3 flue gas per MJ fuel input.

Table 4.3 Bio-oil (animal fat) fired installations in the Netherlands

Plant	$MW_{e/th}$	Dust	NO_x	NH_3	SO_2	NMVOC
Calluna,	600 kW_e		De-NOx			Oxy-catalyst
Ermelo	580 kW_{th}					
Zwembad Tongelreep Eindhoven	2 MW_e					
Philips Boerderij,	32 kW_e,	-	-			
Eindhoven	45 kW_{th}					

References: Ingenia, 2009; Dordtech, 2009; Unica, 2009

4.1.2.4 Selection of emission reduction techniques

The selection of emission reduction techniques is made based on the following criteria:

- Applicable in the capacity range up to around 50 MW_{th} input for stand-alone combustion installations and 1 MW_{th} (biogas input) for anaerobic digestion – gas engine plants
- Proven technology
- Used in existing bio-energy plants

Many emission reduction techniques for each individual pollutant are applied at commercial scale. Based on the above mentioned criteria a selection is made and the selected techniques are described. The removal efficiency, the range of scale for application and the costs for each technique are quantified based on information from literature.

Emission reduction techniques
In Table 4.4 the most commonly used emission reduction techniques for wood combustion, anaerobic digestion and bio-oil combustion are summarized. The technologies indicated in bold are further described in this report.

Depending on the conversion technique not all the NEC pollutants are emitted. In Table 4.5 an overview is given of the relevance of the pollutants per conversion technique.

Table 4.4 Emission reduction techniques for dust, NO_x, SO_2, NH_3 and NMVOC. W = wood combustion, A = anaerobic digestion, O = oil combustion. Bold = detailed in this study [VITO/Infomil, 2009]

Pollutant	Emission reduction technology	Capacity range [m^3/hr]	Conversion technique W	A	O	Remarks
Dust	**Cyclone**	100-100,000 (<100 kWth-70 MW_{th})	X			Not suitable for very small particles; Not suitable for low dust concentrations; Often used in combination with other dust removal system
	Fabric filter (Baghouse filter)	No limitations	X			Achievable: 10 mg /m^3; Often used in combination with limestone or active carbon injection
	ESP 1-stage	> 20,000 (> 15 MW_{th})	X			
	ESP 2-stage	< 100,000 (< 70 MW_{th})	X			
	Ceramic filter	2,000-500,000 (1-350 MW_{th})	X			Achievable: 1 mg/m^3
	Wet scrubber	< 200,000 (< 150 MW_{th})	X			Waste water production
	Rotating particle separator		X			
	Settling chamber	100-100,000 (< 100 kWth-70 MW_{th})	X			Low efficiency
NOx	**SNCR**	No limitations	X			
	SCR	< 1,000,000 (< 700 MW_{th})	X	X	X	NH_3 slip < 5 mg/Nm^3; Achievable: 50 mg NOx/Nm^3
	Flue gas recirculation	No limitations	X			
	Wet scrubber	< 2,000,000 (< 1,400 MW_{th})	X			Waste water production
SO_2	**Limestone injection**	10,000-300,000 (7-350 MW_{th})	X			In combination with dust removal; also removal of Cl (35-80%) and F (95%)
	Wet scrubber	50-500.000 (< 350 MW_{th})	X			Also can remove dust (> 50%), VOC (50-99%), NH_3 (> 99%), HCl and HF (99%)
NH_3	**Wet scrubber (acid)**	50-500,000 (< 350 MW_{th})		X		
	Bio-filter	No limitations		X		Also removal of NMVOC
	Active carbon injection			X		Also removal of H_2S and NMVOC
NMVOC	Active carbon injection	100-100,000 (<100 kWth-70 MW_{th})	X			
	Catalytic afterburner	1,000-30,000 (1-20 MW_{th})	X	X	X	
	Thermal afterburner	1,000-30,000 (1-20 MW_{th})	X	X	X	
	Bio-filter	No limitations		X		Also removal of NH_3

Table 4.5 Relevance of NEC emissions for the described bio-energy techniques. X= relevant, O is not or less relevant.

	NOx	SO_2	dust	NH_3	NMVOC
Wood combustion	X	O	X	X[a]	O
Anaerobic digestion	X	O	O	X[a]	O
Fat/oil combustion	X	O/X	X	X[a]	O/X?

[a] only if SCR of SNCR for DeNOx is used

4.1.3 Cost data

Large number of technical variations exists on each technique with specific advantages and disadvantages. Furthermore, depending on process conditions, presence of corrosive components in the flue gas, type of construction material, desired cleaning efficiency and combinations with other cleaning devices, the investment and operational costs can vary considerably. Therefore, ranges in costs and efficiencies will be used throughout this report. Based on these ranges the arithmetic average and median values will be derived (€/1000 m^3 flue gas, €/MWth and €/GJ input) which can serve as input for the calculation model as well as minimum and maximum values. For the calculation of the cost expressed in €/GJ input the amount of fuel used during the technical life (10 years) is used.

Biogas from anaerobic digestion
Due to the somewhat higher flue gas production per MJ fuel input and the lower number of operational hours the costs for emission reduction measures (expressed in €/MWth and €/GJ) in the flue gas of biogas combustion in a gas engine are a factor 1.3 higher in comparison with wood combustion.

Bio-oil combustion
The use of bio-oil in a diesel engine is performed with a high excess air factor leading to a high flue gas volume per MJ fuel input. Therefore, costs are a factor 2.5 higher in comparison with wood combustion.

The presented data should be multiplied by the above indicated factors.

4.1.4 Description of emission reduction techniques

The following sections describe the several emission reduction techniques for NEC pollutants, their performance and costs.

4.1.4.1 Dust removal

Biomass combustion causes particle emissions through the flue gas. A number of techniques is available to reduce the particle emissions to acceptable levels. The performance of these techniques is dependant on particle size distribution, particle load, average particle density and volume flow. In order to evaluate the performance, information on particle size distribution in the untreated flue gas of combustion installations is necessary.

The performance of dust removal techniques is dependant on the particle size. In Figure 4.1 a graph is shown in which the performance is expressed in percentage removal efficiency as a function of the particle size of the dust. From this figure, it can be seen that depending on the particle size and the desired removal efficiency the various techniques differ considerably. In general the removal efficiency for larger particles is higher.

Cyclone
A number of variations based on the cyclone principle exist. The most common applied variations are high performance, high through-put and multi-cyclones. For this study high performance cyclones, which combine a relatively high performance with low costs, are evaluated in more detail.

Cyclones use centrifugal force to remove particulate matter from a gas stream. Cyclone normally consists of a shell into which dusty gas is introduced through a tangential inlet. The dusty gas spins in a vortex that results in dust particles being centrifuged towards the walls and moving down towards the conical base of the cyclone.

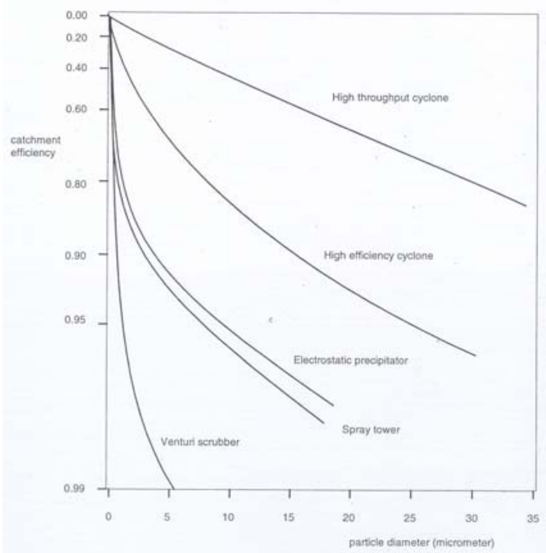

Figure 4.1 Typical dust removal efficiency versus particle size of cyclones, ESP, spray tower and venturi scrubber [van Loo, 2002]

The ‘dedusted’ gas in the middle of the cyclone moves up towards the outlet at the top. The collected dust must be removed from the cyclone without being picked up again (re-entrained). This is achieved by:

- discharging the dust into a separate hopper or silo,
- ensuring an adequate dust collection rate to avoid accumulation and reduce the potential for blocking the cyclone,
- using an air tight discharge device (such as a rotary valve) from the collection hopper.

In general, the performance of cyclone in terms of efficiency of removal increases with increasing particle size. In Figure 4.2 the efficiency is plotted versus the particle size for high efficiency and high through-put cyclones.

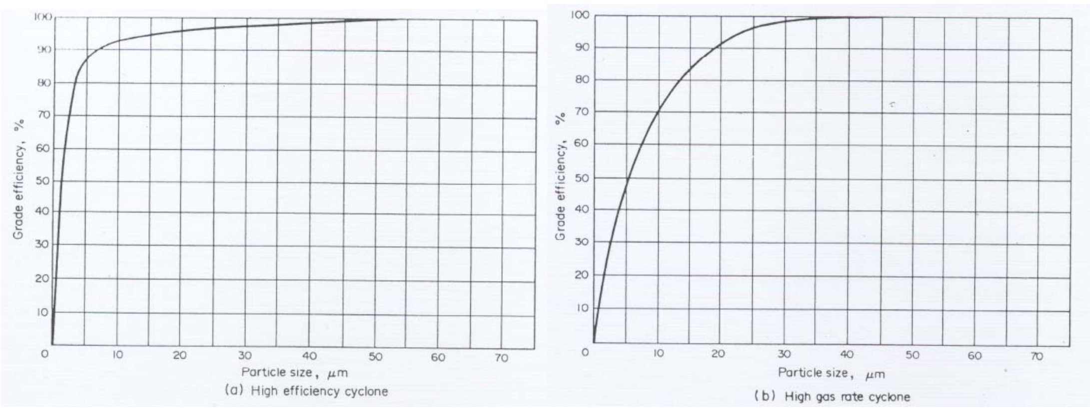

Figure 4.2 Dust removal efficiency of high efficiency and high through-put cyclones as a function of particle size [Coulson and Richardson, 1986].

The dust removal performance is of cyclones visualized in Figure 4.2. It is clear that high efficiencies are achieved for larger dust particles (>10 µm) for high efficiency cyclones. The removal efficiency for smaller particles shows a steep decrease. Cyclones can be applied for a wide range of capacities. The removal efficiency for different particles sizes is summarized in Table 4.6.

Table 4.6 Dust removal efficiencies of cyclones for different particle sizes

Type	PM	PM_{10}	$PM_{2.5}$	Reference
High efficiency cyclone	80-99%	60-95	20-70	[EPA]
High throughput cyclone	80-99%	10-40	0-10	[EPA]
	90% (> 10 μm) 99% (> 50 μm)	50% (6-10 μm)	5% (1 μm)	[VITO/Infomil 2009]

The working range of standard cyclones vary from 0.5 to 50 m^3/s (1,800 – 180,000 m^3/hr) [EPA cyclone]; 1-100,000 m^3/hr [VITO/Infomil 2009]. Special designed cyclones can be applied at smaller volume flows. The dust loading in the flue gas which can be processed by cyclones typically range from 2.3 to 230 gram per m^3. Special designed cyclones can be used at extreme high dust loadings (up to 16,000 g dust/m^3). The maximum operating temperature is determined by the used material. Applications up to temperatures of 540^{o}C have been reported.

The investment costs of cyclones are dependent on the operational conditions (temperature, presence of corrosive components in the flue gas) with corresponding material demands. In general for biomass combustion the operational conditions are quite mild, so relatively low cost materials can be used. Based on data from literature the investment cost are estimated at € 500-2,060 per 1000 m^3 flue gas. Power consumption varies between 0.2 – 0.5 kWh per 1000 m^3 flue gas. The operational costs are mainly costs for power. The costs for discharging of the dust are not included.

The economic data for cyclones are shown in Table 4.7. In the last column of the table the number of references on which the values are based is given.

Table 4.7 Investment costs, operational costs and power consumption of cyclones for wood combustion

	Unit	Average value	Median value	Min. value	Max. value	Number of refs.
Investment costs	€ per 1000 m^3/hr flue gas (wet)	1,300	1,200	500	2,100	8
	€/MWth input	1,700	1,600	670	2,800	8
	€/GJ input[a]	0.0059	0.0056	0.0023	0.0097	8
Operational costs	€/GJ input	0.058	0.023	0.008	0.26	6
Powerconsumption	kWh/GJ input	0.22	0.11	0.075	0.56	8

[a] calculation based on total fuel input during 10 yrs (technical life time) and 8,000 hrs/yr
References: Van Loo, 2002; VITO; VITO, 2003; EPA; VITO, 2009; VITO, 2004; VROM, 2008a

Fabric filter
In a fabric filter flue gas is passed through a tightly woven or felted fabric. Particles in the flue gas are collected on the surface by sieving. The dust cake on the surface can enhance the efficiency considerably by acting as a sieve itself. Fabric filter designs are in the form of sheets, cartridges or bags with a number of filter units housed together. The most important design parameter is the air-to-cloth ratio (ratio of the volumetric flow versus the cloth surface). The appropriate ratio depends on the particle loading of the flue gas, characteristics of the particles and the cleaning method. Pulse jet cleaning with air is often used as cleaning method.

Fabric filter systems are available as standard design or as specially designed units in low, medium or high capacity systems. Standard fabric filters are used for 0.1 to 50 m^3/s (360-180,000 m^3/hr) flows. For larger flows special designs fabric filters are being used. They can be used for flows as high as 1,800,000 m^3/hr [EPA Fabric Filter]; 300-1,800,000 m^3/hr [Infomil/VITO 2009]. The relative investment costs decrease with increasing capacity from 13,000 € per m^3/hr (< 1,000 m^3/hr) to less than 1,000-4,000 € per m^3/hr (> 100,000 m^3/hr) [BBT kenniscentrum, 2004].

Table 4.8 Dust removal efficiency of fabric filters for different particle sizes

Efficiency			Reference
97% (2 µm)	99-99,9% (4 µm)	99,99 % (9 µm)	Emis
99,95% (> 2,5 µm)			Vito/Infomil 2009

The working temperature is depending on the material used. For standard fabric filters the maximal working temperature is ca. 290 °C, whereas special applications are possible up to 800 °C with filters made of ceramic or metal fibers. Dust loading can vary from 1-25 g/m^3 (up to 230 g/m^3).

Table 4.9 Investment costs, operational costs and power consumption of fabric filters for wood combustion

	Unit	Average value	Median Value	Min. value	Max. value	Number of refs.
Investment costs	€ per 1000 m^3/hr flue gas (wet)	7,600	5,000	1,000	25,000	9
	€/MW$_{th}$ input	10,200	6,700	1,400	34,000	9
	€/GJ input[a]	0.035	0.024	0.0047	0.12	9
Operational costs	€/GJ input	0.17	0.075	0.0094	0.65	5
Power consumption	kWh/GJ input	0.49	0.26	0.075	1.9	4

[a] calculation based on total fuel input during 10 yrs (technical life time) and 8,000 hrs/yr
References: Infomil; VITO, BREF LCP

Electrostatic Precipitator (ESP)
Electrical force is used to move charged particles in a gaseous stream onto collector plates in an Electrostatic Precipitator. The particles are given an electric charge by electrodes with a high voltage (20,000-100,000 V). In dry ESP's the collected particles are mechanically removed from the collector plates by mechanical means (rapping) and fall into a hopper. In wet ESP''s the particles on the collector plates are washed off by means of a fluid.

In one-stage filters both ionization and collection of the particles takes place in one compartment. In two stage filters ionization and collection are divided spatially. The design of ESP's is based on the required surface area of the collector plates (expressed in m^2 surface area per m^3 gas flow per time unit) in combination with the desired particle removal efficiency. The type of dust particles, especially the resistivity of the particles, is also an important design parameter. Higher efficiencies required larger surface area of collector plates. The working ranges vary depending on the type of ESP and are summarized in Table 4.10. Typical effiencies are given in Table 4.11. The power consumption is 0.34-0.85 kWh per 1000 Nm^3/hr [BBT-kenniscentrum, 2004]; 1.2 kWh/actual m^3 [Schneider, 1975]. Typical gas velocities are 0.6-1.4 m/s [website Hamos].

Table 4.10 Working ranges ESP types

Type	Range [m^3/hr]
Dry ESP	
Pipe filter	1,800-2,000,000 [VITO/Infomil 2009]
Plate filter	360,000-2,000,000 [VITO/Infomil 2009]
	200,000-1,000,000 [EPA-ESP]
Wet ESP	
Pipe filter	1,800-900,000 [VITO/Infomil, 2009]
Plate filter	1,800- 180,000 [VITO/Infomil, 2009]

Table 4.11 Dust removal efficiency of ESP's for different particle sizes [VITO/Infomil 2009]

Particle size	1 µm	2 µm	5 µm
Dry ESP	> 97%	> 98%	> 99.9 %
Wet ESP	97-99%		

Table 4.12 Investment costs, operational costs and power consumption of ESP (1-stage) for wood combustion

	Unit	Average value	Median value	Min. value	Max. value	Number of refs.
Investment costs	€ per 1000 m^3/hr flue gas (wet)	17,300	13,200	2,100	30,000	7
	€/MW_{th} input	23,000	18,000	2,900	40,400	7
	€/GJ input[a]	0.081	0.062	0.010	0.14	7
Operational costs	€/GJ input	?[b]	?	?	?	0
Power consumption	kWh/GJ input	0.27	0.19	0.038	1.2	6

[a] calculation based on total fuel input during 10 yrs (technical life time) and 8,000 hrs/yr
[b] no information available on operational costs.
References: VITO; BREF LCP; Buckley; VITO, 2003; Infomil/VITO, 2009; EPA

4.1.4.2 De-NOX

The most commonly used techniques for NO_x (mixture of NO and NO_2) removal from flue gases are SNCR (Selective Non-Catalytic Reduction) and SCR (Selective Catalytic Reduction). NO_x is removed by injection of NH_3 or a urea solution. NH_3 and urea act as reducing agents for NO_x under formation of N_2. The actual chemical reactions of NO and NO_2 with the reducing agent NH_3 which takes place are:

$$4\ NH_3 + 4\ NO + O_2 \rightarrow 4\ N_2 + 6\ H_2O$$
$$8\ NH_3 + 6\ NO_2 \rightarrow 7\ N_2 + 12\ H_2O$$

Reactions with urea are:

$$2(NH_2)_2CO + 4\ NO + 2\ H_2O + O_2 \rightarrow 4\ N_2 + 6\ H_2O + 2\ CO_2$$
$$4(NH_2)_2CO + 6\ NO_2 + 4\ H_2O \rightarrow 7\ N_2 + 12\ H_2O + 4\ CO_2$$

SNCR

The reduction reaction takes place without catalyst at high temperature. The optimal temperature is between 930-980 ^oC (temperature range: 850-1100 ^oC). At lower temperatures the reaction rate is too slow, whereas at higher temperatures NH_3 is (partly) oxidized into NO. An important parameter is the molar ratio of NH_3 versus NO_x. Optimal ratios are between 1.5 and 2.5.

The NO_x removal efficiency is 30-90%, depending on operational conditions. SNCR is used at volume flows below 200,000 m^3/hr [VITO/Infomil, 2009]. The impact of capacity on the costs of De-NOx by SNCR and SCR is shown in table 3-7.

Table 4.13 Cost in €/kg NO_x removed decrease with increasing capacity [ECN, 2008a]

Capacity in MW_{th}	10	50	100	300	600
Cost in €/kg NO_x removed by SNCR	1.8	0.7	0.3	0.1	0.05
Cost in €/kg NO_x removed by SCR	32	10	3.0	1.2	0.7

SCR

In the presence of a catalyst NO and NO_2 react with NH_3 or urea. Operating temperatures are between 170-510^{o}C. Several types of catalysts are being used: base metal oxides (V, Mo, W), zeolites, iron oxides or activated carbon. The NO_x removal efficiency is 80-95%. The NH_3/NOx ratio is 0.8-1.0.

Table 4.14 Investment costs, operational costs and power consumption of NO_x reduction by SNCR and SCR for wood combustion

Investment costs	Unit	Average value	Median value	Min. value	Max. value	Number of refs.
SNCR						
Investment	€ per 1000 m^3/hr flue gas (wet)	5,900	6,300	1,700	10,400	6
	€/MW_{th} input	8,000	8,500	2,300	14,000	6
	€/GJ input[a]	0.028	0.030	0.0081	0.049	6
Operational costs	€/GJ input	0.080	0.060	0.012	0.17	3
Power consumption	kWh/GJ input	0.110	0.097	0.052	0.19	4
SCR						
Investment	€ per1000 m^3/hr flue gas (wet)	24,000	15,000	4,600	83,000	6
	€/MW_{th} input	32,000	20,500	6,200	110,000	6
	€/GJ input[a]	0.11	0.071	0.022	0.39	6
Operational costs	€/GJ input	0.52	0.31	0.13	1.3	4
Power consumption	kWh/GJ input	0.53	0.32	0.19	1.3	4

[a] calculation based on total fuel input during 10 yrs (technical life time) and 8,000 hrs/yr
References: EPA SCR; EPA SNCR

4.1.4.3 SO_2 Removal

Sulfur in the fuel is combusted into predominantly SO_2 (95%) and to a lesser extent SO_3. Part of the sulfur reacts with components in the ash. A large number of techniques are available for SO_2 removal divided in regenerative and non-regenerative processes. Both wet, dry and semi-wet processes can be applied. Two technologies for SO_2 removal are described: limestone injection and wet scrubbers.

Dry sorbent injection
Several adsorbents are used for SO_2 removal, such as CaO, $NaHCO_3$, $Ca(OH)_2$, $CaCO_3/MgCO_3$ (dolomite) and $CaCO_3$ (limestone). At the high temperature in the furnace the carbonates decompose under formation of CaO (lime). CaO reacts with SO_2 and forms (solid) calcium sulfite ($CaSO_3$) and calcium sulfate ($CaSO_4$), which is removed together with other particles by the dust removal unit. A surplus of Ca in relation with SO_2 is needed (molar ratio Ca/S: 1.5-7).

The SO_2 removal efficiency is 50-80%. Dry sorbent injection can be used for volume flows of 10,000–300,000 m^3/hr [VITO/Infomil, 2009].

Wet scrubbers
An aqueous suspension of finely ground limestone is injected into SO_2 containing flue gas. SO_2 dissolves in the slurry droplets, is adsorbed and removed with the liquid stream. After the scrubber the flue gas passes a demister to remove remaining droplets. Commonly used techniques are spray towers and packed towers. Operation temperature is 45-60°C. There was not sufficient data on the limestone injection to have a reliable estimate.

Table 4.15 Investment costs, operational costs and power consumption of SO_2 reduction by limestone injection and wet scrubber for wood combustion

Investment costs	Unit	Average value	Median value	Min. value	Max. value	Number of refs.
Wet scrubber						
Investment	€ per 1000 m^3/hr flue gas (wet)	11,000	7,300	2,500	25,000	6
	€/MWth input	15,1	9,8	3,4	33,7	6
	€/GJ input[a]	0.052	0.034	0.012	0.12	6
Operational costs	€/GJ input	?[b]	?	?	?	
Power consumption	kWh/GJ input	0.54	0.28	0.075	1.9	6
Limestone injection						
Investment	€ per 1000 m^3/hr flue gas (wet)	N/A				
	€/MWth input					
	€/GJ input					
Operational costs	€/GJ input					
Power consumption	kWh/GJ input					

[a] calculation based on total fuel input during 10 yrs (technical life time) and 8,000 hrs/yr
[b] no information available
References: CCTH; Infomil; BREF LCP; Infomil/VITO 2009; EPA FGD.

4.1.4.4 NH_3 Removal

In combustion processes no NH_3 is formed and, in case NH_3 is present in the fuel (*e.g.* biogas) it will be oxidized into NO_x. In some cases NH_3 is used as additives for NOx reduction. Small amounts of NH_3 can pass the SCR unit and end up in the flue gas (ammonia slip). Therefore, in some exceptional cases additional NH_3 removal is applied.

Wet scrubber
For removal of NH_3 an acid solution is used, such as sulphuric or nitric acid solutions. The removal efficiency can be as high as 99% for NH_3.

Table 4.16 Economic values investment costs NH_3 reduction by wet scrubber

Investment costs	Unit	Average value	Median value	Min. value	Max. value	Number of refs.
Investment	€ per 1000 m^3/hr flue gas (wet)	11,000	7,300	2,500	25,000	6
	€/MW_{th} input	15,000	9,800	3,400	34,000	6
	€/GJ input[a]	0.052	0.034	0.012	0.12	6
Operational costs	€/GJ input	?[b]	?	?	?	
Power consumption	kWh/GJ input	0.55	0.28	0.075	1.9	6

[a] calculation based on total fuel input during 10 yrs (technical life time) and 8,000 hrs/yr
[b] no information available
References: Infomil; BREF LCP; Infomil/VITO, 2009; EPA NH3

4.1.4.5 NMVOC Removal

Techniques for NMVOC removal are bio-filters and catalytic afterburners.

Catalytic oxidation afterburner
The incoming gas is directed through a catalyst. By using a catalyst the operational temperature (300-500 ^oC) can be kept lower in comparison with non-catalytic afterburners without loss of efficiency. The activity of the catalyst can be negatively influenced by some components (poisoning). Removal efficiency of NMVOC, depending on operational conditions, ranges from 95-99%.

Bio-filter
Bio-filters exist of a bed of wood chips or other biologic material. The gas is flowing through the bed and pollutants are absorbed. Organic components are decomposed by micro-organisms in the bed. The use of micro-organisms limits the operational conditions with respect to temperature, allowable concentrations of pollutants, residence time and pH.

The bed is moisturized with water to prevent dehydrating. Bio-filters are applied for NMVOC removal but also for odour removal. Flows are between 100 and 100,000 m^3/hr and operating temperature is either 15-38 ^oC or 50-60 ^oC (thermophylic conditions). In general, a neutral pH is optimal for bio-filters [EPA Bioreactors, 2003; BBT Kenniscentrum, 2004]. The relation between investment costs, including equipment and installation (factor 1.85) and flow can be estimated by the formula: $I = (45.424 * flow^{0.808}) * 1.85$ [BBT Kenniscentrum, 2004] flow in m^3/hr.

Claimed removal efficiencies for VOC's are 70-95% for bio-filters and up to 99% for catalytic afterburners [VITO/Infomil, 2009].

Table 4.17 Economic values investment costs NMVOC removal by catalytic afterburner and bio-filter

	Unit	Average value	Median value	Min. value	Max. value	Number of refs.
Catalytic afterburner						
Investment	€ per 1000 m^3/hr flue gas (wet)	45,000	45,000	10,000	80,000	2
	€/MW_{th} input	61,000	61,000	13,000	110,000	2
	€/GJ input[a]	0.21	0.21	0.047	0.38	2
Operational costs	€/GJ input	0.53	0.53	0.12	0.94	2
Power consumption	kWh/GJ input	0.56	0.56	0.38	0.75	2
Bio-filter						
Investment	€ per 1000 m^3/hr flue gas (wet)	11,000	11,000	8,000	14,000	2
	€/MW_{th} input	15,000	15,000	11,000	19,000	2
	€/GJ input[a]	0.052	0.02	0.040	0.066	2
Operational costs	€/GJ input	N/A[b]	N/A	N/A	N/A	
Power consumption	kWh/GJ input	N/A[b]	N/A	N/A	N/A	

[a] calculation based on total fuel input during 10 yrs (technical life time) and 8,000 hrs/yr
[b] no information available
References: Infomil; EPA Bio reactors, 2003

From the cost data tables for the technologies investigated above, it can be seen that the bandwidth in found costs are large. This is due to a number of factors such as variation in materials used, equipment size and whether the costs mentioned in literature includes installation costs etc. as well. In general, this is not indicated in literature.

Concerning the scale of the installation and thus the corresponding scale of the emission reduction techniques no exact correlation between costs and scale was found. Only more empirical relations are often used such as the Williams' 0.6 rule:

Williams' 0.6 rule: $I / I_o = (Q / Q_o)^{0.6}$

With:

I = investment cost equipment (for other capacity)
I_o = investment costs of reference equipment (at reference capacity)

Q = capacity of equipment for other capacity
Q_o = capacity of reference equipment

For specific types of equipment, exponents can be found in literature varying between 0 and 0.9.

No general relation between investment costs of equipment for new plants and retrofit cases were found. This might be due to the fact that retrofit cases are very site specific and there can differ substantially for each individual case.

4.2 Technology and costs of emission reduction for wood stoves

4.2.1 Introduction

In the Netherlands most stoves and fire places dispose of their flue gases by natural draught through chimneys on the top of the roof. If reduction technologies are installed in the chimney, the flue gases have to overcome this extra pressure drop. Some emission reduction devices have a very low pressure drop, that they hardly influence the natural draught. Other flue gas cleaning facilities have higher pressure drops, resulting in the need of a flue gas ventilator to blow the flue gas out of the chimney. In this section three types of emission reduction technologies are mentioned; an electrostatic precipitator, a catalyst and improved stoves. Examples of reduction technologies can be found in Cercl Air, IZES gmbH (2008) and Sattler (2007).

4.2.2 Electrostatic precipitators for stoves

An electrostatic precipitator (ESP) only reduces emissions of particulate matter. The technology is based on charging the particles by high voltage (around 20 kV), after which the particles are drawn to the earth electrode and precipitate on it. When the layer of precipitated particles reaches a certain thickness, the layer must be removed by cleaning the device. A disadvantage of this reduction technique is the formation of ozone, which is emitted into the air with the rest of the flue gases. For household stoves some types of electrostatic precipitators are available:

Rüeggfilter Zumikron
A pipe form shaped electrostatic precipitator (brand Rüeggfilter Zumikron) for stoves smaller then 40 kW. The electrostatic precipitator is installed in chimney pipe and can be build into pipes with a diameter of 150 till 300 mm. The temperature of the flue gases passing the electrostatic precipitator might not excite the 400^{o}C. The reduction efficiency for particulate matter is 60-90% and the precipitator should be cleaned two till four times a year (for the cleaning an opening of 30 cm*30 cm is needed). The concentration of particular matter leaving the chimney is less then 30 mg/m^3. The power consumption is 12 W at 230 V and the precipitator costs around EUR 1,200.

TRION Kaminfilter
A 1 m - 1,5 m long pipe form shaped electrostatic precipitator (brand TRION Kaminfilter) for stoves smaller then 35 kW is available with a reduction efficiency up to 90% for particulate matter. The precipitator is installed in the flue gas exhaust and should be removed from the chimney for cleaning. The energy consumption is 20 W and the precipitator costs EUR 1,500 till EUR 2,000 (excl. labor cost for installing).

Spartherm Airbox
A two stage electrostatic precipitator (brand Spartherm Airbox) which is placed on the stove. The reduction efficiency for particulate matter is 65% with an energy consumption of 20 W. Cleaning should take place after 100 hours usage by using a brush and a vacuum cleaner. This precipitator should cost EUR 1,400 (excl. labor cost for installing).

The cost effectiveness of electrostatic precipitators is calculated in Section 4.2.5.

4.2.3 Catalysts

The following catalysts are known:

MoreCat

The MoreCat Catalyst should be build into the chimney. The catalytic material is placed on a carrying construction and mounted in a metal ring. It is said that this catalyst reduces odour with 75% and removes 50% of the particulate matter. In the catalyst soot is burned at temperatures exciding the 250^{o}C leaving non combustible fly ash. The ring can easily be removed from the chimney to clean the fly ashes that remained in the catalyst. When starting up the stove, the ring should be turned 90^{o} in order to let the flue gases pass. When the natural draught is high enough to overcome the pressure drop created by the catalyst, the ring should be turned back in position. It might be necessary to install a flue gas ventilator. The price of this catalyst is not known.

FIRECAT

The FIRECAT catalyst should be placed in the flue gas stream and works as a classic catalyst. At a high enough temperature not only the unburned gases, but also the partly oxidized particles are incinerated. It is possible to build this catalyst into existing stoves, but with the occurring problems it is not recommended. The costs of installing the catalyst in a new stove are about EUR 100. The catalyst should be cleaned one or two times a year. A bypass is needed to lead the flue gases past the catalyst for the first 30 minutes after firing the stove.

During start up of a stove equipped with a catalyst flue gases have to be bypassed during at least half an hour to prevent clogging of the catalyst with unburned particles and condensation of unburned gases. This reduces the overall reduction efficiency of the catalyst in situation where the stove is used for shorter periods as is the case for atmosphere heating stoves. There is a big chance that the user of the stove will forget bypass operation during start up resulting in clogging and fail functioning of the catalyst. This can result in insufficient in the chimney leading to emission of pollutants in the living environment. If the user does forget to cancel out the bypass operation there is no emission reduction at all. Installing an automatic bypass regulation in existing approved stoves (if available) would be costly. These reasons do not favour the implementation of a catalyst in stoves for atmosphere heating.

4.2.4 Approved stoves

An average approved stove is less polluting and has a better thermal efficiency than the old unapproved stoves and open fire places. According to information from Milieu Centraal (website: www.milieucentraal.nl) costs of new stoves are between EURO 400 and EURO 4,000. The costs of an average new approved stove will be about EURO 2,000. A tile or soap stone stove has higher thermal efficiency and less emission than approved stoves and are more expensive (EURO 2,000 to 15,000). These stoves are frequently used in forested countries (e.g. Scandinavia, Germany, Austria, and Switzerland) for central heating of the homes and are used less frequently as atmosphere heating. This difference in application also is resembled in the more strict limits set in some European countries for emitted pollutants (see Table 4.18).

Stoves that comply with the standard DIN*plus* have lower emissions for PAH and C_XH_Y but not for PM compared to approved stoves [Koppejan, 2008]. The cost effectiveness of improved stoves is calculated in Section 4.2.6.

Table 4.18 Overview of European limit values for fireplaces and stoves [anonymous, ELV's]

Country	Document	CO [mg/Nm^3]	NO_X [mg/Nm^3]	C_XH_Y [mg/Nm^3]	PM [mg/Nm^3]	efficiency %
Europe	EN13240/13229	12,500				30/50/65
Germany	several	1.250 – 2.500			40 - 75	73/75
	DIN*plus*	1,500	200	120	75	72/75
Austria *)	15a B-VG (2011?)	1,100 mg/MJ	150 mg/MJ	80 (50) mg/MJ	60 (35) mg/MJ	78 (80)
Switzerland	LRV 08/11, QS 04/08	1,500			100/75	78/80
Scandinavia	Nordic Svan	2,500	150		8/5	73
France	Flamme Verte	3,750				70

*) In Austria limit concentrations are given in mg/MJ

4.2.5 Cost effectiveness of PM_{10} emission reduction

Cost effectiveness of PM_{10} emission reduction in EURO per kg PM_{10} reduction can be calculated by dividing the yearly costs of the reduction technology by the yearly emission reduction (see for calculation next two sections). In Table 4.19 cost effectiveness of emission reduction is given for Scenarios High and Low (see Appendix H) for replacement of unapproved stoves by approved stoves and implementation of electrostatic precipitators in approved stoves for additional PM_{10} emission reduction.

Table 4.19 Cost effectiveness of PM_{10} reduction for implementation of electrostatic precipitator in new approved inset and freestanding stoves

Reduction technology	Operational costs [Euro/year]	PM_{10} reduction [kg PM_{10}/year]		Cost effectiveness [Euro/kg PM_{10}]	
		Scenario Low	Scenario High	Scenario Low	Scenario High
Electrostatic precipitator (applied to existing stoves)	300	0.8	1.4	363	208
Replacement of unapproved stoves	100	2.0	3..5	50	29

From the table above it can be concluded that cost effectiveness of PM_{10} reduction on the basis of replacement of unapproved stoves by approved stoves is better than installing electrostatic precipitators. PM_{10} reduction strategy should be aimed firstly on quick replacement of unapproved stoves by new approved stoves. If additional PM_{10} reduction is necessary new approved stoves can be equipped with electrostatic precipitator devices.

In document 'Fine dust and BBT' [VROM, 2008] cost effectiveness of application of a lot of additional PM_{10} reduction technologies in industry is in the range 6 to 90 euro per kg PM_{10} reduction. On the other hand cost effectiveness of about EUR 200 per kg PM_{10} reduction is accepted for PM_{10} reduction of diesel exhaust gases by diesel particulate filters in traffic. Cost effectiveness of quick replacement of unapproved stoves by approved stoves lies in the range of industrial measures. Cost effectiveness of implementation of electrostatic precipitators is somewhat worse than for diesel particulate filters.

4.2.6 Replacement of all unapproved stoves by approved stoves

In the Scenarios Low and High a measure to reduce total emissions of stoves and open fire places is replacement of all unapproved stoves in the period up to 2020 by approved stoves. In that case an average PM_{10} emission reduction of about 64% per replaced unapproved stove can be achieved. Based on the cost of a new approved stove given in Section 4.2.4 the average cost of a new stove is taken as about EUR 2,000. An advantage of replacement is that operation of the stove needs similar maintenance compared to unapproved stoves (maybe even less maintenance). Life time of approved stoves is taken as twenty years.

The calculation of cost effectiveness is based on:

- investment of approved stove: EUR 2,000;
- life time: 20 years;
- PM_{10} reduction efficiency of replacement: 64%;
- average PM_{10} emission of unapproved stove: 3.1 kg/year (Scenario Low)
  5.4 kg/year (Scenario High)

4.2.7 Implementation of electrostatic precipitator in approved stove

In the description of the electrostatic precipitators on the market (see Section 4.2.2) the given investments are prices given by the suppliers of these separators. If these separators are standard in new stoves the extra costs of stoves purchased will be about the same as the given investment. If these devices have to be built in existing stoves labor cost will be high and has to be added to the given prices. The reduction devices have to be cleaned several times a year depending on intensity of use of the stove. To give an indication of minimum cost effectiveness of implementation of cleaning devices in this study cost effectiveness is based on new stoves with integrated cleaning devices and regular cleaning of the devices is done by the user itself (no labor costs). According to the available information an extra investment of EUR 1,500 can be seen as minimum extra cost for an electrostatic precipitator in new inset and freestanding stoves and the PM_{10} reduction efficiency of the electrostatic precipitators is about 75%.

At the moment there is no reliable information about functional life time of the electrostatic precipitator. For this study, TNO calculated cost effectiveness based on a life time of maximum 5 years because of cleaning of the devices done by unskilled people resulting in relative short life of the device.

The calculation of cost effectiveness is based on:

- additional investment cost: > EUR 1.500 per stove;
- life time of electrostatic precipitator: 5 years;
- PM_{10} reduction efficiency: 75%;
- average PM_{10} emission of approved stove (without cleaning device):
  1.1 kg/year (Scenario Low)
  1.9 kg/year (Scenario High)

4.3 Production costs of biofuels

4.3.1 Introduction

This section presents an overview of production costs of biofuels that are of interest for the Netherlands, for which production cost may be estimated, indicated, or inferred. Data on operation and maintenance or feedstock costs of biofuel plants is limited or incomplete, production costs can be very site specific, and due to the fact that future price developments of feedstocks and cost reductions of technologies are highly uncertain, in this section a very rough estimate is given on the biofuel production cost, based on a ‘what-if’ scenario.Therefore, the results have therefore a very large uncertainty.

4.3.2 Production costs of biofuels

Firstly, a number of reference biofuel plants are defined. Assumed prices of feedstocks are presented in Table 4.20. Some feedstocks or by-products are assumed to have increasing prices because of increased competition between food and feed on the one hand and the use of biocrops for biofuels on the other hand.

Table 4.20 Assumed prices of feedstocks and revenues of by-products of reference biofuel plants

Type of biofuel plant	Feedstocks				By-product		
	Frying/ animal fats	Canola oil	Glycerol (by-product)	Corn and grain	Power	Acid-free fats	DDGS
	[€/t]	[€/t]	[€/t]	[€/t]	[€/kWh]	[€/t]	[€/t]
2010							
Biodiesel small	275 [a]				0.10	300 [e]	
Biodiesel 'medium'	275 [a]				0.10		
Biodiesel large		207 [b]					
1st gen. bio-ethanol				94.2 [d]			132 [f]
2nd gen. bio-ethanol							
BioMCN I			150 [c]				
2015							
Biodiesel small	325 [a]				0.11	350 [e]	
Biodiesel 'medium'	325 [a]				0.11		
Biodiesel large		257 [b]					
1st gen. bio-ethanol				144.2 [d]			132 [f]
2nd gen. bio-ethanol							
BioMCN I			225 [c]				
2020							
Biodiesel small	375 [a]				0.12	400 [e]	
Biodiesel 'medium'	375 [a]				0.12		
Biodiesel large		307 [b]					
1st gen. bio-ethanol				194.2 [d]			132 [f]
2nd gen. bio-ethanol							
BioMCN I			300 [c]				

a The price of animal fats of € 275/ton in 2010 is based on Bondt and Meeusen (2008). Due to competition between feed and biofuel production, the price is assumed to increase by roughly 35% to € 375/ton in 2020.

b The price of Canola oil in 2010 is CND $275.6/ton = CDN $304/tonne = € 207/tonne, based on Bhardwaj, (2007). Due to competition between food and feed on the one hand and biofuel production on the other hand, the price of Canola oil is assumed to increase by approximately 50% to € 307/tonne in 2020.

c The price of glycerol is estimated at € 150/tonne in 2010. Due to competition between feed and biofuel production, the price is assumed to increase by 100% to € 300/tonne in 2020.

c The price of corn in 2010 is US $ 8.85/bushel = € 94.2/tonn (LECG, 2009). Due to competition between food and biofuel production, the price may increase by approximately 100% to € 194/tonne in 2020.

e The price of acid-free fats is estimated at € 300/tonne in 2010. Due to competition between feed and biofuel production, the price of acid-free fats is assumed to increase by 33% to € 400/tonne in 2020.

f The price of DDGS is US $176/ton = $194/tonne = € 132 /tonne (1.4708 US$/€ in 2008), based on Weiss et al (2009).

Sources: Bondt and Meeusen, 2008; LECG, 2009; Bhardwaj, 2007; Weiss et al, 2009.

In Appendix E the estimated production costs for biodiesel, bio-methanol, or bio-ethanol plants in the Netherlands for the period 2010-2025 are given. Capital costs per year are put at 12% of investment costs. Assumptions on operation and maintenance costs are further explained in footnotes of the tables of Appendix E. The estimated production costs (excluding transport, taxes and profits) of the biofuels can be summarised as followed (See also Figure 4.3 to Figure 4.5):

- Production costs of biodiesel range from € 0.30-0.58/l in 2010 to € 0.41-0.76/l in 2020.
- Production costs of bio-methanol range from € 0.22-0.30/l in 2010 to € 0.37-0.45/l in 2020.
- Production costs of bio-ethanol range from € 0.27-0.37/l in 2010 to € 0.47-0.57/l in 2020.

Figure 4.3 to Figure 4.5 show the estimated production costs of biofuels as a function of time.

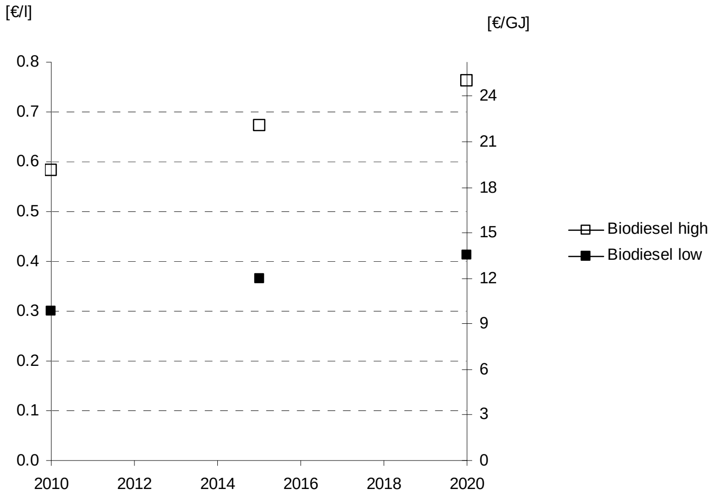

Figure 4.3 Estimated production costs of biodiesel for conditions in the Netherlands

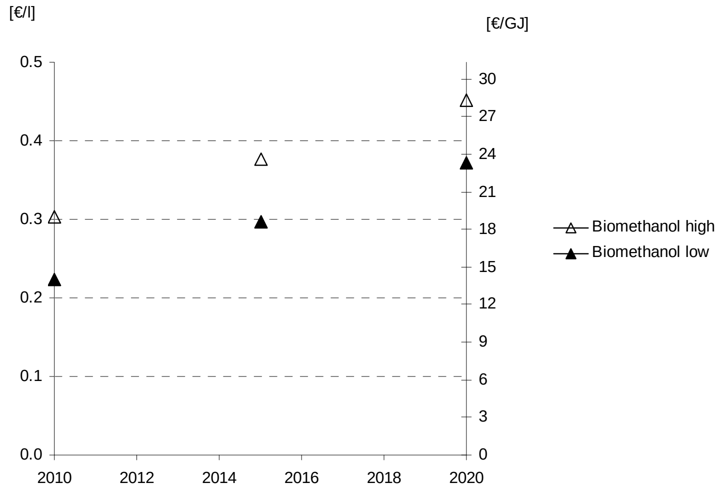

Figure 4.4 Estimated production costs of bio-methanol for conditions in the Netherlands

Note: The margin between low and high is assumed to be € 0.08/l.

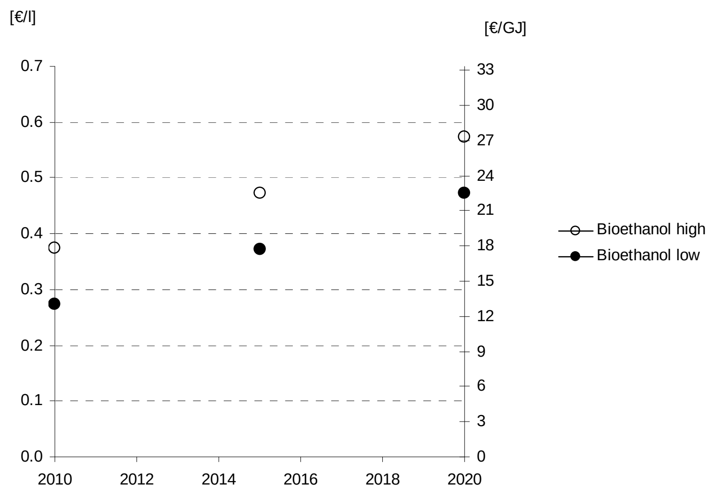

Figure 4.5 Estimated production costs of bio-ethanol for conditions in the Netherlands
Note: The margin between low and high is assumed to be € 0.10/l.

Some remarks regarding the figures presented above

- First of all, it is assumed that the costs of feedstock will increase due to increasing competition between food and feed on the one hand and use of such feedstocks for first generation biofuels on the other hand; such trends are predicted by many experts;
- The investment costs of first generation biofuel plants may decrease as a consequence of learning; however, the increasing cost of feedstock for such biofuel plants can exceed the learning effects;
- In the medium term (2020), second generation biofuels (based on lignocellulosic biomass) may capture the market; such biofuels will generally have higher capital costs than first generation biofuels, but lower feedstock costs; competition for lignocellulosic biomass will be much more limited than for feedstock for first generation biofuels; according to De Wilde and Londo (2009), cellulosic ethanol would cost US$ 0.57-0.65/l in 2030, which compares fair with Figure 4.5 for bio-ethanol (in €/l) for first-generation bio-ethanol; also according to De Wilde and Londo (2009), 2nd generation biodiesel (based on a Fischer-Tropsch process, or Biomass-To-Liquid, BTL, process) would cost US$ 63-78/l, which also compares fair with Figure 4.3 for biodiesel (in €/l) for current (first-generation) biodiesel production.
- Learning effects may be more pronounced for biofuels based on lignocellulosic biomass, as the technology is still in an early stage of development and the capital costs are higher than for current types (1st generation) of biofuel plants.
- Considering the remarks above, the uncertainty in the figures presented in this study is very large, and therefore should only be used as a first, rough indication.

5. Update of the emission impact analysis of combustion of biomass in stationary applications in 2020 of BOLK I

5.1 Introduction

In the integration phase of BOLK I, the NEC emissions from the use of biomass in stationary applications were projected [Hammingh, 2008]. The results are given in Appendix F. These estimates were based on the maximum values for emission factors, thus resulting in a worst-case scenario. In this study, the impact analysis of the use of biomass in stationary applications has been updated based on new population and emission factors estimates. It should be noted that the uncertainty in the presented numbers (population and emission factors) are large and therefore only give an order of magnitude estimation.

The impact analysis has been done for three population scenarios:

- The Updated Reference Projections (Daniëls and Van der Maas, 2009)
- The Scenario Low of this study, and
- The Scenario High Scenario of this study.

Compared to the Updated Reference projections, the Scenarios ‘Low’ and ‘High’ in 2020 assume more bioenergy use by co-firing in large-scale installations and in small-medium scale installations and more residential stoves (only in Scenario High). For a more detailed description of the assumptions of the several scenarios is referred to Chapter 2. The used emission factors for this impact analysis are based on the results presented in Chapter **Fout! Verwijzingsbron niet gevonden.**. See also these chapters for the assumptions used for estimating these inputs. Table 5.1 displays the used emission factors of this study compared to the emission factors used in BOLK Phase 1:

Table 5.1 Used emission factors in 2020: BOLK Phase 1 vs. Phase 2 (bold = updated)

Category/NEC component	NO_x		SO_x		NH_3		Dust		NMVOC	
	Phase 1	Phase 2	Phase 1	Phase 2	Phase 1	Phase 2	Phase 1	Phase 2	Phase 1	Phase 2
Co-firing	40	40	11	11	5	5	0.9	0.9	0	**2[a)]**
Waste Incineration (only biogenic)	35	35	1.3	1.3	1.3	1.3	0.5	0.5	1.3	1.3
Small-scale biomass combustion/stoves	150	**130**	30	**13**	9.0	**0**	108	**136/ 137[b)]**	43	**588/ 620[b)]**
Medium-scale biomass combustion	1020	**40**	0	**10**	0	**1.7**	29	**1.7**	4	**60**
Large-scale biomass combustion	1020	**n.d.**	0	**n.d.**	-	**n.d.**	29	**n.d.**	4	**n.d.**
Biogas from waste tips	250	**30**	27	**2**	0.0	**0.15**	1.2	**0.5**	0	**14**
Biogas from AWZI/RWZI	35	**30**	2	**2**	2.5	**0.15**	1.4	**0.5**	0	**14**
Agricultural biogas plants	250	**30**	108	**2**	5.0	**0.15**	10	**0.5**	0	**14**
Other biogas plants	-	**30**	-	**2**	-	**0.15**	-	**0.5**	-	**14**
Bio-oil/fat-fired engines	1020	**130**	0	**9**	0	**4.4**	29	**17**	4	**31**

a) NERI, 2007 b) for scenario High and Low respectively

Some remarks:

- The overall emission factor (biomass and fossil) for waste incinerators and coal-fired power plants are used. A specific emission factor for biomass alone cannot be distinguished as fossil and biomass flue gases are mixed and subsequently cleaned. The emission factor for co-firing in coal-fired power plants are assumed to be not dependend of the biomass co-firing fraction.

- The fuel input for waste incinerators in the Reference Scenarios is based on the total waste, not only biomass. It is assumed in this study that 48% of the heating value is renewable[14]. The number presented here therefore only represents the biogenic fraction.
- Due to a further differentiation of categories and the introduction of BEMS, the NO_x emission factor for medium-scale installations has significantly decreased compared to Phase 1, which assumed worst-case emission factors.

5.2 Results

Table 5.2, Table 5.3 and Table 5.4 show the results for the three scenarios and give an indication of the expected order of magnitude and distribution of the emissions for each biomass category.
Table 5.5 summarises the total expected emission levels associated with the combustion of biomass in stationary applications. For the assumptions and background data for the estimation of the emissions from biomass use in 2007 is referred to Appendix G. A detailed calculation of the emissions of wood stoves can be found in Appendix H. These results have been used as input for the tables below.

Table 5.2 Detailed results for 2020 for the Updated Reference Projections

	2020		NO_X		SO_x		NH_3		Dust		NMVOC	
	[PJ/a]	[PJ%]	[kton/a]	[wt%]	[kton/a]	[wt%]	[kton/a]	[wt%]	[kton/a]	[wt%]	[kton/a]	[wt%]
Co-firing gas/coal fired power plants	0	(0)	0	(0)	0	(0)	0	(0)	0	(0.0)	0	(0.0)
Waste Incineration (only biogenic)	48[a)]	(53)	1.7	(48)	0.06	(20)	0.061	(75)	0.02	(2.1)	0.1	(1)
Small-scale biomass combustion/stoves	8.1	(9)	1.0	(29)	0.10	(35)	N/A		1.11	(96)	5.0	(85)
Medium-scale biomass combustion	10.6	(11)	0.4	(12)	0.11	(36)	0.018	(22)	0.02	(1.6)	0.6	(11)
Large-scale biomass combustion	0	(0)	0.0	(0)	0.00	(0)	0.000	(0)	0.00	(0.0)	0.0	(0.0)
Biogas from waste tips	*0.2*	*(0.2)*	0.0	(0.2)	0.00	(0.1)	0.000	(0)	0.00	(0.01)	0.0	(0.1)
Biogas from AWZI/RWZI	*8.3*	*(9)*	0.2	(7)	0.02	(6)	0.001	(2)	0.00	(0.4)	0.1	(2.0)
Agricultural biogas plants	*2.4*	*(3)*	0.1	(2)	0.00	(2)	0.000	(0)	0.00	(0.1)	0.0	(0.6)
Other biogas plants	*1.6*	*(2)*	0.0	(1)	0.00	(1)	0.000	(0)	0.00	(0.1)	0.0	(0.4)
Total bio-gas engines	13	(14)	0.4	(11)	0.03	(8)	0.002	(2)	0.01	(0.5)	0.2	(3.0)
Bio-oil/fat-fired engines	0	(0)	0	(0)	0	(0)	0	(0)	0	(0.0)	0.0	(0.0)
Total	**80**		**3.5**		**0.3**		**0.08**		**1.2**		**6**	

a) based on the assumption that 48% of MSW fuel input in the Updated Reference Scenarios is biogenic
b) based on CxHy measurements

Table 5.3 Detailed results for 2020 for the Scenario Low

	2020		NO_X		SO_x		NH_3		Dust		NMVOC	
	[PJ/a]	[PJ%]	[kton/a]	[wt%]	[kton/a]	[wt%]	[kton/a]	[wt%]	[kton/a]	[wt%]	[kton/a]	[wt%]
Co-firing gas/coal fired power plants	89	(40)	3.6	(36)	1.00	(57)	0.45	(73)	0.1	(6)	0.2	(2)
Waste Incineration (only biogenic)	41	(18)	1.4	(15)	0.05	(3)	0.05	(8)	0.0	(1)	0.1	(1)
Small-scale biomass combustion/stoves	8	(4)	1.0	(10)	0.10	(6)	N/A		1.1	(78)	4.9	(56)
Medium-scale biomass combustion	49	(22)	2.0	(20)	0.49	(28)	0.08	(14)	0.1	(6)	3.0	(34)
Large-scale biomass combustion	0	(0)	*0.0*	(0)	*0.00*	(0)	*0.00*	(0)	*0.0*	(0)	*0.0*	(0)
Total bio-gas engines	37	(17)	1.1	(11)	0.07	(4)	0.01	(1)	0.0	(1)	0.5	(6)
Bio-oil/fat-fired engines	5.5	(2)	0.7	(7)	0.05	(3)	0.02	(4.0)	0.1	(6.8)	0.2[a)]	(2)
Total	**224**		**10**		**1.8**		**0.6**		**1.4**		**9**	

a) based on CxHy measurements

[14] This correction has not been done in the impact analysis in the previous phase of BOLK.

Table 5.4 Detailed results for 2020 the Scenario High

	2020		NO_X		SO_x		NH_3		Dust		NMVOC	
	[PJ/a]	[PJ%]	[kton/a]	[wt%]	[kton/a]	[wt%]	[kton/a]	[wt%]	[kton/a]	[wt%]	[kton/a]	[wt%]
Co-firing gas/coal fired power plants	89	(35)	3.6	(32)	1.0	(52)	0.4	(73)	0.1	(3)	0.2	(1)
Waste Incineration (only biogenic)	41	(16)	1.4	(13)	0.05	(3)	0.1	(8)	0.0	(1)	0.1	(0)
Small-scale biomass combustion/stoves	16	(6)	2.0	(18)	0.2	(11)	N/A	(0)	2.2	(87)	9.3	(69)
Medium-scale biomass combustion	51	(20)	2.0	(18)	0.51	(26)	0.1	(14)	0.1	(3)	3.0	(23)
Large-scale biomass combustion	0	(0)	*0.0*	(0)	*0.00*	(0)	*0.0*	(0)	*0.0*	(0)	*0.0*	(0)
Total bio-gas engines	50	(20)	1.5	(13)	0.10	(5)	0.0	(1)	0.0	(1)	0.7	(5)
Bio-oil/fat-fired engines	5.5	(2)	0.7	(6)	0.05	(3)	0.0	(4)	0.1	(4)	0.2[a)]	(1.3)
Total	**252**		**11**		**1.9**		**0.6**		**2.5**		**13**	

a) based on CxHy measurements

Table 5.5 Summary impact analysis 2020

	Scenario	2020 [PJ/a]	NO_X [kton/a]	SO_x [kton/a]	NH_3 [kton/a]	Dust [kton/a]	NMVOC [kton/a]
Estimated emissions in 2007		*71*	*5.3*	*0.5*	*0.1*	*2.2*	*10*
BOLK Phase 1	Reference Projections 2007	215	18	1.7	0.7	1.2	0.5
BOLK Phase 2	Updated Reference Projections 2009	80	3.5	0.3	0.1	1.2	6
	Scenario 'Low'	224	10	1.8	0.6	1.4	9
	Scenario 'High'	252	11	1.9	0.6	2.5	13

If the results are compared to the results of the first phase of BOLK, the following observations can be made:

- The estimated, updated annual emissions in 2020 determined in this study originating from the combustion of biomass in stationary applications are in the range of 4-11 kton/a for NO_x, 0.3-2 kton/a for SO_x, 1.2-2.5 kton/a for particulate matter, 0.1-0.6 for ammonia and 6-13 for NMVOC under the assumptions for the different scenarios. Significant to observe is that whether co-firing will take place on a large scale in 2020 can have a significant impact on the total emissions. In BOLK Phase 1 and in the Scenario Low and High, co-firing has been taken into account. In the Updated Reference Projections, co-firing is assumed to be zero due to the current absence of SDE subsidies. The amount of biomass used for that scenario is therefore significantly lower. This also mostly explains why the total emissions for that scenario are much lower, especially for NO_x, SO_x and NH_3 (originating from NH_3 slib from SCR installations). However, total NH_3 emissions are still low compared to e.g. emissions from agricultural activities. More specific information about fossil fuel replacement and associated emissions is required to determine the overall substitution effect of fossil fuels by biomass.
- In this study, the total estimated NO_x emissions are significantly lower compared to the previous phase for the low and high scenarios (including co-firing): 18 vs. 10-11 kton/a. Main explaination is that the NO_x emission factor for medium-scale installations (category 'combustion other') in this study been significantly decreased compared to the previous estimate. For this a maximum emission factor of 1020 g/GJ was assumed compared to the currently expected emissions limit values for 2020 of 130 g/GJ for bio-oil/fat-fired engines and 40 g/GJ for solid biomass-fired installations.
- Mainly due to a significant increase of the NMVOC emission factor for small- and medium solid biomass-fired installations, the total expected NMVOC emissions has increased significantly from 0.5 to 6-13 kton/a.

- Based on the presented figures, the contribution of wood stoves to the overall biomass emissions from stationairy sources is more than proportional for all scenarios for especially dust and NMVOC due to the absence of flue gas cleaning and less optimized combustion conditions. This explains also mainly the difference between the scenarios high and low as the fuel input for wood stoves doubles from 8 to 16 PJ/a between these two scenarios.

6. Conclusions and discussion

Status of biomass use (2007)
The biogenic fraction of municipal solid waste (MSW) combustion for heat and power represents with approximatey 28 PJ (2007) the largest contribution of biomass to the primary energy supply (0.8%). The next relatively large contribution comes from co-firing of biomass in power plants (15 PJ or 0.5% of the total primary energy supply)[15], followed by small-scale combustion (12 PJ or 0.3% of the total primary energy supply) and anaerobic digestion (7 PJ or 0.2% of the total primary energy supply). Figure 6.1 shows the status of the use of biomass in the Netherlands in 2007.

For all of these applications, there are no specific targets defined for biomass use in stationairy applications for the year 2020. The only prevailing target is the 14% renewable energy of total primary energy use, according to the European Union obligation for the Netherlands for 2020 (apart from a target of 10% for biofuels for transport in 2020).

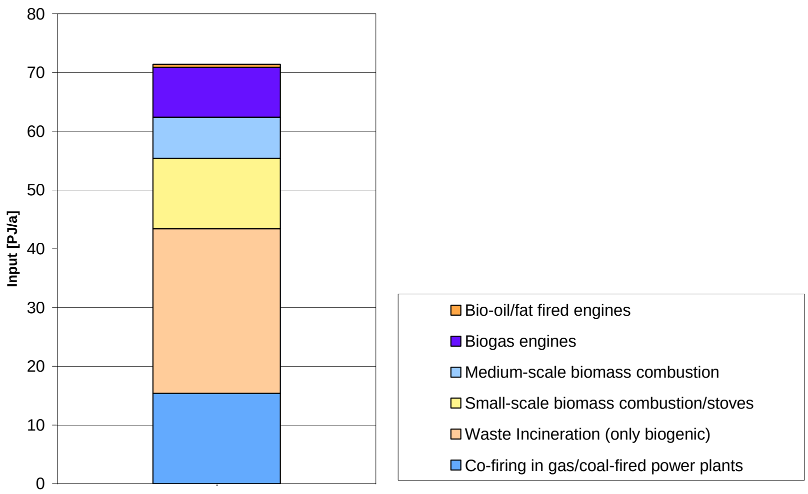

Figure 6.1 Status 2007 of the use biomass in stationairy applications in the Netherlands, based on CBS data [CBS, 2008]

Under current policies (amongst others no subsidy for co-firing), it is estimated in the Updated Reference Projections that the use of biomass from stationairy sources can contribute approximately 2% of the total projected primary energy use of 3,940 PJ in 2020.

In this study further research has been performed to current populations and possible developments of several types of stationairy biomass applications and small/medium scale fossil-fired CHP in the Netherlands. Futhermore, a literature search has been performed into the emissions of this type of installations and the effects and costs of emission reduction measures.

General observations

- Basic statistical data with enough detail and correlating relevant data (NEC emissions coupled with size, fuel (composition), flue gas cleaning measures, efficiency) was not found to be available for the studied categories and thus could not offer a profound statistical basis. No statistical enquires or measurements were performed in this study: results presented are based on available data and public literature and estimations.

[15] Whether or not co-firing of biomass is the largest contributor or not varies from year to year.

- Estimations of future contributions of specific bio-energy applications and medium-scale CHP is strongly dependend of subsidies and/or future obligations as these technologies are 1) currently not competative compared to large scale fossil applications,
  2) dependend of future policys on subsidies or obligations which are currently unknown/uncertain as well, and 3) dependent on technological and market developments (*e.g.* second generation biofuels).
- Actual emission factors can be very site specific and depend of a large number of factors (technology, fuel, permit, scale, emission-reducing measures). As such, there is is often not a single identifiable emission factor for a certain technology, but there will be a range of emission factors, sometimes limited by the emission limit.

> The above observations should be kept in mind when using the results of this study, especially when assessing the environmental effects of the use of a specific technology if estimated populations (with a high uncertainty) are multiplied by an estimated emission factor (with a high uncertainty). The numbers presented in this study should therefore used with care, but can give a first indication of expected effects.

Populations

Biomass and biogas installations

- Being emerging technologies, most biomass technologies are currently not economical feasible, the availability of a subsidy or renewable obligations now or in the future will have a crucial influence on the expected populations in 2020. Also permitting can be an issue. The uncertainty of future populations is therefore very high, and depends strongly on the assumptions made. In the Updated Reference Projections is e.g. assumed that no capacity will be maintained, if the SDE subsidy will not be available for that specific category (e.g. co-firing).
- Co-firing biomass has a large potential and a relatively cheap form of renewable energy. If co-firing of biomass in existing coal-fired power plants would be stretched to the limits permitted, the amount of biomass used would be increased from 800 kilotonnes (kt) in 2006 to an estimated approximately 2,800 kt/a (64 PJ/a) in 2020. This would be equivalent to a share of biomass in the fuel mix of these plants of 25%. This would entail an annual CO_2 emission reduction of 5.9 Mt compared to an average annual CO_2 emission reduction by co-firing of 2.1 Mt in 2007-2008. Additional CO_2 emission reduction could be realised around 2013 after modification of existing coal-fired plants (including the required permits), in principle a comparable amount of biomass could be co-fired in the different new coal-fired power units that are under construction or firmly planned. Taking into account the effects of competition on the electricity market, the potential of co-firing in both older and new coal-fired power plants would be around 4,460 kt/a of biomass (89 PJ/a), power generated of approximately 10,500 GWh, and a CO_2 emission reduction of 7.1 Mt of CO_2.
  These figures are *additional* compared to a recent (2008) analysis ‘Updated Dutch Reference Projections 2008-2020’ (Daniels and Van der Maas, 2009), in which co-firing was put a zero because of the current lack of subsidy for co-firing of biomass in the SDE. The maximum application of co-firing in coal fired power plants in 2020 in the Netherlands result in a share of 2.3% of renewables in primary energy use in 2020 (target of renewables: 14% in 2020).
- Similarily, the potential of biomass in medium-scale biomass combustion and anaerobic digestion plants with combined heat and power (CHP) is analysed. Its capacity could be increased from about 260 MW_e in 2008 to 620-800 MW_e in 2020, if subsidy in the SDE is sufficient to close the gap between the generation cost of biomass-fuelled power or CHP and that of a fossil fuel based alternative.

Also in this case, the analysis ‘Updated Dutch Reference Projections 2008-2020’ did not give credit to such a potential as this study did not assess the budget and tariff in the SDE prevailing in 2008 as sufficient to trigger new biomass-based capacity. Hence, the use of biomass in medium-scale biomass combustion and anaerobic digestion plants with CHP could contribute to the targeted 14% renewables in the primary energy consumption of 2020 by an amount of 2.2-2.5% in 2020, compared to merely 0.6% in the analysis ‘Updated Dutch Reference Projections 2008-2020’.

- Co-firing in coal-fired plants and additional medium-scale biomass combustion and anaerobic digestion plants with CHP - could be equivalent to an amount of biomass of 175-199 PJ/a in 2020, which is 144-166 PJ/a more than anticipated in ‘Updated Dutch Reference Projections 2008-2020’.
- Compared to the Reference Projections, the share of renewables could be increased by such an amount of biomass from 4.7% to 8.3-8.9% in 2020, thereby narrowing the gap between the result and the 14% target from 9.3% in case of ‘Updated Dutch Reference Projections 2008-2020’ to about 5.1-5.7% in case of the present study, if all biomass-related investments would be made and made assumptions are realistic.
- The main potential (in PJ), according to this study, for the application of biomass in the Netherlands is in co-firing biomass in coal-fired power plants, stand-alone biomass combustion and bio-gas in gas engines and waste incineration, all in the same order of magnitude. The use in cement factories in the future will be negligible and the use of bio-oil fired engines expected to be limited.

  In order to put all biomass options excluding biofuels into perspective, Figure 5.2 shows the aggregate result of the Updated Reference Projectection and the constructed projections (‘Low’ and ‘High’) in this study of the use of biomass in 2020. The amount of biomass for thermal applications and CHP or co-firing may be increased from 70 PJ (approximately 2% of total primary energy use) in 2007 to 224 PJ (5.6% of the total primary energy use) or 252 PJ (6.3% of the total primary energy use) in 2020. This may be compared to the smaller amount of approximately 80 PJ (2.0% of the total primary energy use) in 2020 in the ‘Updated Dutch Reference Projections 2008-2020’.

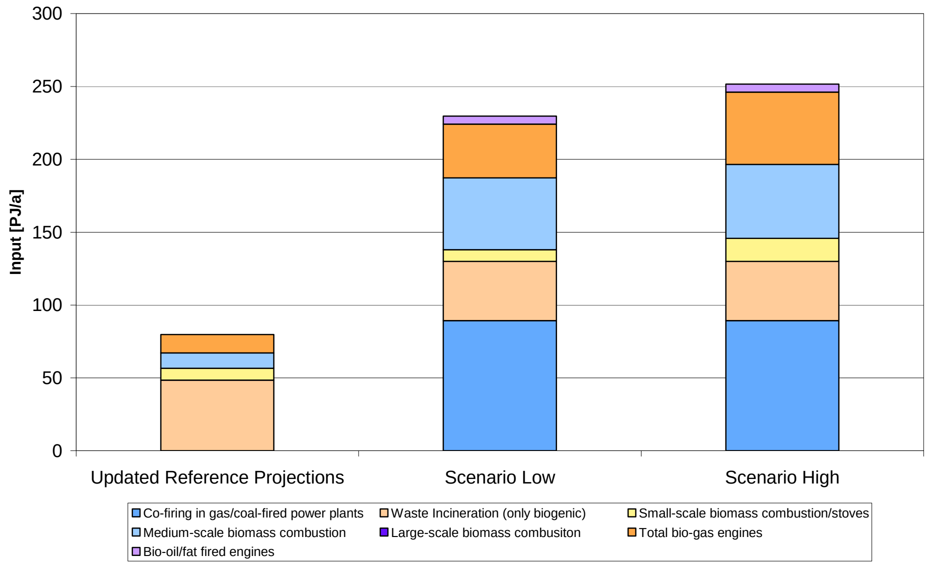

Figure 6.2 Results scenarios for 2020 on the biomass use in stationary applications in the Netherlands

Fossil fired CHP (medium-scale)

- In 2008, a few publications provided indications about the potential of medium-scale CHP based on gas-fired gas engines and gas turbines. They indicate that CHP could be increased to 6,000 MW_e in 2020. Other authors give an estimate for CHP based on gas

engines of 3,560 MW_e in 2010 and 2020, of which 3,000 MW_e in the horticulture sector.
The contribution of gas-turbines for CHP is limited. In the framework of the present study, two 'what-if'scenarios have been constructed which project a gas-fired capacity ranging from 4,500 MW_e (scenario 'low') to 5,500 MW_e (scenario 'high') in 2020, which is approximately 20-50% more than is assumed in the Updated Dutch Reference Projections. Scenario 'high' is based on the assumption that the cogeneration capacity increases by 150 MW_e per year, which is comparable with the realisation in the period 1998-2007. The 'low'scenario assumes half of that rate.

Biofuels production in the Netherlands

- Biodiesel is currently the biofuel with the largest (projected) production in the Netherlands, i.e. 2,156 kt/a around 2012; the production of bio-ethanol may be around 619 kt/a around 2012, and that of bio-methanol 800 kt/a (maximum); The biodiesel, bio-ethanol, and bio-methanol plants considered here represent a total fuel production that is equivalent to approximately 108 PJ/a. This is approximately 2.8% of the primary energy demand projected for 2020, and equal to approx. 16% of the primary energy use in transport.
- No biofuel production capacity data other than known until 2012 is available for estimating the dutch biofuel capacity in 2020. The Dutch and European biofuel targets do not specify what fuel is to be used or whether or not it would be produced in the Netherlands or elsewhere; the EU policies only prescribe the amount of biofuels as a percentage of the energy use for transport in 2020.
- Several plans for biofuel plants have been identified for the coming years. However, the realisation of these plans under the current economic conditions is very uncertain. It is reported that existing installations encounter financial problems.
- Bio-methanol is currently produced on one location in the Netherland, with partially depreciated installations. It is unknown if a new build plant would be economically feasible.
- There are currently no known plans for Fischer-Tropsch fuel production in the Netherlands.

Wood stoves

- The current information on wood fired household stoves in the Netherlands is not very up to date. Both the population of stoves and the amount of wood fired are not updated since 2003. Therefore the emissions calculated are also not up to date.
- Within the population of stoves it is visible that the number of unapproved and open fire places are decreasing in favor of an increase in approved stoves. Based on these changes it is estimated that the number of stoves in 2020 lies between 687.000 and 828.000, the biggest contribution is made by the approved freestanding stoves. Both ends have been used in the scenarios.
- For the situation in 2020 it is possible that people who have a stove are going to use it more. One reason for an increasing use is the increase in prices of other home warming facilities. Therefore current and higher estimates for the number of burning hours per year have been used in the scenarios.
- As result of the input data in the scenarios, the wood consumption in Scenario High is doubled compared to Scenario Low. Emissions directly linked to the wood consumption (CO_2, NO_X and SO_2) are doubled as a result.

Biomass transshipment and storage

- The expectation is that the main type of imported biomass will be wood pellets. Reported expected volumes are in the range of 13-20 Mton/a in 2020.

Emission factors

Medium scale biomass-fired installations and fossil-fired installations

- In general, the highest emission factors can be found for biomass-fired installations compared to gas-fired installations. This is due to the relatively clean combustion character of natural gas (low sulphur content, low dust, availability of low NO_x combustion).
- Currently Dutch emission factors are dependent on the size of an (bioenergy) installation and the year of construction. Smaller and older installations still have less strict emissions limits than newer and larger installations. To prevent that stimulating smaller installations will result in higher emissions, new dutch legislation (Besluit Emissie-eisen Middelgrote Stookinstallaties = BEMS) is currently under development, taking the new best available technologies (BAT) into account.
  The introduction of the BEMS will have a moderating effect on the future emission limit values compared to the current situation where emissions limits (and thus emissions) can vary much more due to e.g. size of the bio-energy-installation and date of permit. Furthermore, the introduction of the BEMS will tighten the current emission limits for a number of technologies.
- There are no detailed statistical data available correlating size, type of installation, fuel, gas cleaning equipement and (measured) emissions for the relevant medium-scale installations, making it difficult to determine accurate and statical reliable emission factors for NEC components for these types of installations. To improve the presented data, it would require substantially more effort by performing an extensive project to gather and process this relevant statistical data and perform a specific emission measurement program. Emission factors have been estimated based on literature (which in turn are often based on estimations too) and/or own estimations.

Biomass transshipment and storage

- Due to a lack of available dutch public measurement data on the dust emissions of bulk transshipment and storage of biomass feedstocks, emission factor have been estimated based on indicative numbers.
- Based on these emission factors and roughly estimated volumes for 2020 it is estimated that PM10 emissions are in the order of 0.016-0.02.tonne/year. This is 0.04-0.05% of the total PM_{10} emissions of the Netherlands in 2008. Although this contribution to the national total PM_{10} emissions is rather small, these emissions could contribute to increased local PM_{10} concentrations. The emissions of these activitities are expected to be limited, based on first order estimates, due to the expectation that wood pellets are transshipped and stored in closed systems and wood chips are not very sentitive to dusting.

Wood stoves

- In the Dutch Emission Inventory a set of emission factors is described in the methodology report. These factors have not been updated for about ten years. Compared to other biomass applications the emission factors of NMVOC and dust are relatively high.

Biofuel production

- The emissions for the various types of biofuel processes vary widely. This can be attributed to the variation in types of production processes and also the type of permit (with or without combustion plant).
- For several biofuel plants in the Netherland emission permits have been studied and emission factors of NEC pollutants have been determined. The indicated emissions are allocated to the biofuel product. Due to the complexity of biofuel plants (often multiple

(wet) input and multiple output), this study gives a first indication of expected emissions. The expected emissions can be very location specific.

- With respect to the expected NEC emissions: the NMVOC emissions will arise mainly from the biofuel production/storage itself and are in the range of a maximum of 0.26-1.4 g/GJ fuel. Especially NO_x and SO_x emissions will arise from the required heat and power utilities for the biofuel production process, although SO_x emissions are expected to be very low when natural gas is used for firing. Per GJ product, the NO_x emissions are low compared to the emissions during end use. SO_x emissions are in the range of 0.2-1.9 g/GJ fuel NO_x emissions are in the range of 0.5-2.3 g/GJ fuel
- NH_3 emissions are expected to be limited and are not mentioned in permits.
- No significant dust emissions are expected from the biofuel production itself. Some biofuel production facilities use closed transport systems to prevent dust.

Costs and performance

Flue gas cleaning medium-scale biomass applications

- For all NEC pollutants, mature and effective emission reduction techniques are available.
- All cost data, both investment and operational cost data, show broad ranges due to the difference in processes, process conditions, size of equipment, amount of pollutants to be removed etc. For some emission reduction measures information in the open literature is scarce.
- More precise data can only be determined for a specific installation with specific process conditions.
- It appeared not possible to obtain a clear relation between costs and performance of a specific emission reduction technique due to lack of available information.
- No generalized conclusions can be drawn concerning the additional costs for retrofit compared to newly build emission reduction techniques. As retrofit costs are determined strongly by the existing set-up of a plant and the possibilities of fitting in a new emission reduction technology in the existing plant, no general cost factor should be used.
- By expressing the costs per unit of calorific value of the fuel, the overall efficiency of the bio-energy plant is not taken into account. Compared to large power plants, medium-scale bio-energy plants can have a higher overall efficiency.

Biofuel production

- With regard to the production costs of biofuels that are of interest for the Netherlands, no more than crude estimates or indicative data can be provided at this stage. There is a relatively large uncertainty with regard to current and future production costs. This is because (Dutch) data on actual operation and maintenance or feedstock costs of biofuel plants is scarce or incomplete.

Residential wood stoves

- There are several technologies available to reduce air pollutant emissions (dust and VOC) from stoves such as electronic precipitators, catalysts or using approved stoves in stead of unapproved.
- The PM_{10} cost effectiveness for installing approved stoves instead of unapproved stoves seems most advantegeous and is around 30-50 euro per kilogram reduced PM_{10} emission depending on the assumed wood use. Other benefits of improved stoves are that they also reduce the emission of CO, NMVOC and other products of incomplete burning.
  The PM_{10} cost effectiveness of electrostatic precipitators in new stoves is less favourable: at least 200 euro per kilogram PM_{10} emission prevented and this device does not reduce other pollutants. Cost of installing electrostatic precipitators in existing stoves is more expensive due to high labour costs associated with the integration of the device within the current configuration.

Impact analysis of combustion of biomass in stationary applications

- The updated annual emissions in 2020 estimated in this study originating from the combustion of biomass in stationary applications, are in the range of 4-11 kton/a for NO_x, 0.3-2 kton/a for SO_x, 1.2-2.5 kton/a for particulate matter, 0.1-0.6 for ammonia and 6-13 for NMVOC under the assumptions for the different scenarios. Significant to observe is that whether or not co-firing will take place on a large scale in 2020 can have a significant impact on the total emissions.
- In this study, the total estimated NO_x emissions are significantly lower compared to the previous phase for the low and high scenarios (including co-firing): 18 vs. 10-11 kton/a. Main explaination is that the NO_x emission factor for medium-scale installations (category 'combustion other') in this study been significantly decreased compared to the previous estimate, where a maximum emission factor of 1020 g/GJ was assumed compared to the currently expected emission limit values of 130 g/GJ for bio-oil/fat-fired engines and 40 g/GJ for solid biomass-fired installations.
- Mainly due to a significant increase of the NMVOC emission factor for small- and medium solid biomass-fired installations, the total expected NMVOC emissions has increased significantly from 0.5 to 6-13 kton/a.
- Based on the presented figures, the contribution of wood stoves to the overall biomass emissions from stationairy sources is more than proportional for all scenarios. This is especially the case for dust and NMVOC due to the absence of flue gas cleaning and less optimized combustion conditions. This explains mainly the difference between the scenarios high and low as the fuel input for wood stoves doubles from 8 to 16 PJ/a between these two scenarios.

7. Recommendations for further reseach

From this study the following recommendations have been drawn:

- To have a much more detailed insight in the correlation between installations and emissions, e.g. within existing structures at CBS/Emissieregistratie, it is recommended to improve the registration/availability and coupling of relevant data as current studies are often based on generic assumptions on populations and associated specific (international) emission factors.
- To have a more detailed insight in the cost for gas cleaning, an extensive collaboration and/or consultation with several flue gas cleaning equipment manufacturers would be recommended on the relation between removal technology, size, initial/end concentration, new/retrofit, process conditions on one hand and the associated investment and operating costs on the other hand. Even then however, a large spead in data can be expected, and the result will be time dependent.
- Improve the data on biomass storage and transshipment by performing specific emission measurements on this activity.
- Improve the data on NMVOC for the Dutch situation by measuring this component for a number of specific, representative installations.
- Improve the data on biofuel production emissions by further extending the studied permits and obtain actuel emission data (if possible/available) from biofuel producers.
- To initiate a better registration of wood use in residential heating
- To update the inventory of the existing population of woods stoves by a statistically sound method.
- It should be noted that although it would be desirable to have access to these data, the cost of obtaining them (and maintaining them) will be substantial.

8. Abbreviations

BEES	Besluit emissie eisen stookinstallaties
BEMS	Besluit emissie eisen middelgrote stookinstallaties
BOLK	Beleidsondersteunend Onderzoeksprogramma Lucht en Klimaat
CHP	Combined heat and power
ECN	Energy Research Centre of the Netherlands
NeR	Nederlandse Emissie Richtlijn
NMVOC	Non methane volatile organic components
PBL	Planbureau voor de Leefomgeving
TNO	Netherlands Organisation for Applied Scientific Research TNO

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Appendix A Classification dusting classes NeR 4.6 [Infomil, 2009]

	Produkt(specificatie)	Stuifklasse
Abbrände (pyrietas)		S2
Aluinaarde		S1
Bariet		S3
Bariet (gemalen)		S1
Bauxiet	China gecalcineerd	S1
	gecalcineerd	S1
	ruw bauxiet	S5
Bimskies		S4
Borax		S3
Bruinsteen		S2
Calcium Carbid		S1
Carborundum		S5
Cement		S1
	klinkers	S4
Cokes	steenkoolcokes	S4
	petroleumcokes, grof	S4
	petroleumcokes, fijn	S2
	petroleumcokes, gecalcineerd	S1
	fluid cokes	S1
Derivaten en aan-verwante produkten	aardappelmeel	S1
	aardappelschijfjes	S3
	alfalfapellets	S3
	amandelmeel	S3
	appelpulppellets	S3
	babassupellets	S3
	babassuschroot	S3
	beendermeel	S1
	beenderschroot	S3
	bierbostelpellets	S3
	bladmeelpellets	S3
	boekweitmeel	S1
	cacaobonen	S3[3)]
	corndistillergrainpellets	S3
	corndistillergrainmeel	S3
	corncobpellets	S3
	cornplantpellets	S3
	citruspellets	S3

	Produkt(specificatie)	Stuifklasse
Derivaten en aan-verwante produkten	D.F.G. pellets (maiskiempellets)	S3
	gerstemeel	S1
	gerstpellets	S3
	grondnoten	S5
	grondnotenpellets	S3
	grondnotenschroot	S3
	quarbeanmealpellets	S3
	quarbeanmeal	S3
	havermeel	S1
	haverpellets	S3
	hominecychoppellets	S3
	hominecychopmeel	S3
	katoenzaadpellets	S3
	katoenzaadschroot	S3
	kapokzaadpellets	S3
	kapokzaadschroot	S3
	kardizaadschroot	S3
	koffiepulppellets	S3
	kopra	S5
	kopracakes	S3
	koprachips	S3
	koprapellets	S3
	kopraschroot	S3
	lijnzaadpellets	S3
	lijnzaadschroot	S3
	lucernepellets	S3
	macojapellets	S3
	macojaschroot	S3
	macunameel	S3
	maisglutenpellets	S3
	maisglutenmeel	S3
	maismeel	S3
	maltsproutpellets	S3
	mangopellets	S3
	mangoschroot	S1
	maniokpellets, hard	S3
	maniokwortel	S3
	mengvoederpellets	S3
	millrunpellets	S3
	miloglutenpellets	S3
	milomeel	S3
	moutkiempellets	S3
	negerzaadpellets	S3
	negerzaadschroot	S3
	olijfpulppellets	S3
	olijfschroot	S3
	palmpitten	S5
	palmpittenpellets	S3
	palmpittenschroot	S3
	palmpittencakes	S3
	peanuthullpellets	S3
	pine-applepellets	S3
	pollardpellets	S3
	raapzaadpellets	S3
	raapzaadschroot	S3
	ricehullpellets	S3
	ricehuspellets	S3
	ricebran	S1
	roggemeel	S1
	roggepellets	S3
	safflowerzaadpellets	S3
	safflowerzaadschroot	S3
	salseedextractionpellets	S3
	salseedschroot	S1
	sesamzaadpellets	S3
	sesamzaadschroot	S3
	soiulacpellets	S3
	sorghumzaadpellets	S3
	sojapellets	S3

	Produkt(specificatie)	Stuifklasse
Derivaten en aanverwante produkten	sojachips	S3
	sojameel	S3
	sojaschroot	S3
	splentgrainpellets	S3
	suikerbietenpulppellets	S3
	suikerrietpellets	S3
	sweetpotatopellets	S3
	tapiochips	S1
	tapiocabrokjes	S1
	tapiocapellets, hard	S3
	tapiocapellets, natives	S1
	tarwemeel	S1
	tarwepellets	S3
	theepellets	S3
	tucumschroot	S3
	veevoederpellets	S3
	zonnebloemzaadpellets	S3
	zonnebloemzaadschroot	S3
Dolomiet	brokken	S5
	gemalen	S1
Erts	amarilerts, brokken	S5
	chroomerts	S4
	ijzererts (zie IJzererts)	
	kopererts	S4
	looderts	S2
	mangaanerts	S5[1]
	tantalieterts	S4
	titaanerts (zie Titaan)	
	zinkblende	S4
Ferrochroom, brokken		S5
Ferrofosfor, brokken		S5
Ferromangaan, brokken		S5
Ferrosilicium, brokken		S3
Fosfaat	gehalte vrij vocht >4 gew%	S4
Fosfaat	gehalte vrij vocht <1 gew%	S1
Gips		S3
Glasafval		S5
Graan	boekweit	S3
	gerst	S3
	gort	S3
	haver	S5
	haverscreenings	S3
	kaficorn	S3
	lijnzaadscreenings	S3
	maïs	S3
	milicorn	S3
	mout	S3
	raapzaadscreenings	S3
	ricehusk	S3
	rogge	S3
	rijst	S5
	sojagrits	S3
	sorghumzaad	S3
	tarwe	S3
Grind		
Grof toeslagmateriaal voor de betonmortel en betonproductenindustrie	(waaronder grind, lytag, kalksteen, lava, granulaat)	S5
Hoogovenslakken		S4
Huisvuil		...
IJzererts	Beeshoek, fijn erts	S5[1]
	Beeshoek, stuk erts	S5[1]
	Bomi Hill, stuk erts	S4
	Bong Range pellets	S5[1]
	Bong Range concentraat	S4[2]
	Braz. Nat. erts	S4
	Carol Lake pellets	S5[1]
	Carol Lake concentraat	S4[2]
	Cassinga, fijn erts	S4
	Cassinga, stuk erts	S5[1]
	Cassinga pellets	S5
	Cerro Bolivar erts	S4
	Coto Wagner erts	S5[2]
	Dannemora erts	S4
IJzererts	El Pao, fijn erts	S4
	Fabrica pellets	S5[1]
	Fabrica Sinter Feed	S5
	Fabrica Special pellet ore	S5
	F'Derik Ho	S4
	Fire Lake pellets	S5[1]
	Grängesberg erts	S4
	Hamersley Pebble	S5[1]
	Ilmeniet erts	S5
	Itabira Special sinter feed	S5
	Itabira Run of Mine	S5[1]
	Kiruna B, fijn erts	S5
	Kiruna pellets	S5[1]
	Malmberg pellets	S5
	Manoriver Ho	S4
	Menera, fijn erts	S5
	Mount Newman pellets	S4
	Migrolite	S4
	Mount Wright concentraat	S4[2]
	Nimba, fijn erts	S5
	Nimba erts	S4
	Pyriet erts	S4
	Robe River, fijn erts	S5[1]
	Samarco pellets	S5[1]
	Sishen, stuk erts	S5[1]
	Sishen, fijn erts	S5[1]
	Svappavaara erts	S4
	Svappavaara pellets	S4
	Sydvaranger pellets	S5[1]
	Tazadit, fijn erts	S5[1]
Kalkzout		S5
Kalk	brokken	S5
	gemalen	S1
Klei	bentoniet, brokken	S3
	bentoniet, gemalen	S1
	chamotte klei, brokken	S4
	chamotte klei, gemalen	S1
	kaoline (China)klei, brokken	S3
	kaoline (China)klei,gemalen	S1
Kolen	bruinkool, briketten	S4
	poederkolen	S1
	kolen	S4
	kolen	S2
	antraciet	S2
Kunstmest	ammonsulfaatsalpeter	S3
	diamfosfaat	S1
	dubbelsuperfosfaat, poeder	S1
	dubbelsuperfosfaat, korrels	S3
	kalkammon-salpeter	S3
	tripelsuperfosfaat, poeder	S1
	zwavelzure ammoniak	S3
Kyaniet		S4
Nepheline		S3
Olivin steen		S4
Ongebluste kalk		S1
Peulvruchten	bonen	S3
	erwten	S3
	guarsplit	S3
	linzen	S3
	lupinezaad	S3
	paardebonen	S3
	sojabonen	S3
	sojabeanhusk	S3
	sojascreenings	S3
	wikken	S3
Piekijzer		S4
Pyrietas		S2
Polymeerprodukten	kunststofpoeder	S1
Potas		S3
Puimsteen		S5
Roet		S1
Schroot, metaal		S4
Sillimaniet		S5
Sintels, slakken		S4
Sintermagnesiet		S3
Soda		S3
Suiker		S5
Talk	gemalen	S1
	gebroken	S3
Tapioca (zie Derivaten)		
Titaan	ilmeniet	S5
	rutiel	S3
	rutielzand	S3
	rutielslakken	S5
Toonaarde (zie Aluinaarde)		
Ureum		S3
Vanadiumslakken		S4
Veltspaat		S5
Vermiculiet	brokken	S3
	gemalen	S1
Vliegas		S1
Vloeispaat		S5
Wolastonie		S5
Wegenzout		S5
Zaden en aanverwante produkten	darizaad	S3
	kanariezaad	S5
	kardizaad	S3
	koolzaad	S3
	lijnzaad	S5
	maanzaad	S5
	millietzaad	S5
	mosterdzaad	S5
	negerzaad	S5
	paricumzaad	S3
	raapzaad	S5
	safflowerzaad	S5
	sesamzaad	S5
	tamarinzaad	S3
	zonnebloemzaad	S5
Zand	fijn zand	S2
	grof zand (waaronder beton-, metsel- en filterzand voor de betonmortel en betonproductenindustrie)	S4
	olivin zand	S4
	rutielzand (zie Titaan)	
	zilverzand	S3
	zirconzand	S3
Zwaarspaat		S5
Zwavel	grof	S4
	fijn	S1

[1] Geldt voor opslag; laden en lossen S4.
[2] Geldt voor opslag; laden en lossen S5.
[3] Voorlopige indeling.

Appendix B Emission factors bulk transshipment

Table B.1 Ranges of emission factors bulk transhipment for different materials (in German)

Emissionsfaktoren

Tabelle 3.109: Übersicht über in der Literatur angegebene Emissionsfaktoren für den Schüttgutumschlag [kg/t]

Literaturquelle		Angewandte Emissionsminderung	PM2.5	PM10	TSP
Getreide					
UBA, 1989		*keine Angabe*			1.4
EPA, 1995		*keine Angabe* (1)	0.042	0.147	0.3
Dreiseidler *et al*, 1999		Nach Minderung		0.1-0.2	0.1-0.5
Mulder, 1995		*keine Angabe*	0.00005	0.035	
Trenker und Höflinger, 2000 [1]	verschiedene landwirtschaftliche Produkte	*keine Angabe*	0.001 - 0.007	0.005 - 0.021	0.01 - 0.045
CEPMEIP, 2002	verschiedene landwirtschaftliche Produkte	*keine Angabe*	0.004	0.025	0.1
Kohle					
UBA, 1989		*keine Angabe*			0.2
Dreiseidler *et al*, 1999	Braunkohle	Nach Minderung		0.01	0.025
	Steinkohle	Nach Minderung		0.04	0.1
Mulder, 1995		*keine Angabe*		0.0005	
Trenker und Höflinger, 2000 [1]	Braunkohle	*keine Angabe*	0.001	0.004	0.009
	Steinkohle	*keine Angabe*	0.0005	0.001	0.003
Eisenerz					
UBA, 1989		*keine Angabe*			0.2
Jockel, 1992		*keine Angabe*			0.07-0.175
Mulder, 1995		*keine Angabe*		0.0005	
Dreiseidler *et al*, 1999		Nach Minderung		0.03	0.075
Trenker and Höflinger, 2000 [1]		*keine Angabe*	0.03	0.105	0.217
CEPMEIP, 2002		*keine Angabe*	0.008	0.094	0.2
N,P,K - Dünger					
Mulder, 1995		*keine Angabe*		0.01	
Dreiseidler *et al*, 1999		Nach Minderung		0.02	0.05
Trenker and Höflinger, 2000 [1]		*keine Angabe*	0.048	0.151	0.32
CEPMEIP, 2002		*keine Angabe*	0.004	0.032	0.1
Andere Industrieprodukte					
Mulder, 1995		*keine Angabe*		0.0005-0.2	
Trenker and Höflinger, 2000 [1]	verschiedene Industrieprodukte;	*keine Angabe*	0.01 - 0.058	0.034 - 0.188	0.074 - 0.400
Dreiseidler *et al*, 1999		Nach Minderung		0.004-0.08	0.01-0.2
CEPMEIP, 2002		*keine Angabe*	0.001-0.007	0.014-0.07	0.035-0.175

[1] Laut Winiwarter *et al.*, 2001 (gerundet).

Appendix C Emission reduction measures biofuel production

Biodiesel, Heros Sluiskil BV. – biodiesel

Data from [Gedeputeerde staten van Zeeland, 2007 (1)]

Process:

- Methanol is stored in tanks with a fixed roof, in combination with vapour return.
- Chemical spill detection and repair management
- Air with methanol vapours are used in the combustion for steam production, reducing methanol emissions to zero

Combustion plant:

- Low-NO_x burners (best available technology)
    - It is a little strange that this is mentioned in the permit, because the combustion plant must comply with a different permit (Gedeputeerde staten van Zeeland, 2007 (2)).

Biopetrol Industries AG – biodiesel

Data from reference (Gedeputeerde staten van Zuid-Holland, 2006)

Process:

- All vapours are sent to the off-gas cleaners to remove methanol

Combustion plant:

- Low-NO_x burners (best available technology)

Abengoa – bio ethanol

Data from reference (Gedeputeerde staten van Zuid-Holland, 2007)

Process:

- Ethanol is recovered from fermentation-CO_2 for economical reasons. Remaining CO_2 that contains small amounts of VOC is compressed and sold.
- Measurement protocol in accordance with "Meetprotocol voor lekverliezen"
- Vapour treatment with yield of at least 98%

Transshipment:

- Vapour balance and vapour treatment
- Close transport system (to prevent dust)
- Dust filters of maximum 5 mg/Nm^3

Combined heat and power (Combustion plant):

- Low-NO_x burners (best available technology)

Combustion plant:

- Low-NO_x burners (best available technology)

Dryers (Combustion plant):

- Low-NO_x burners (best available technology)

All combustion plants together:

- NO_x emission trading

Nedalco – bio ethanol

Data from [Gedeputeerde staten van Zeeland, 2003]

Process:

- CO_2 from fermentation: Counter current scrubber for ethanol recovery (economical reasons)
- CO_2 from fermentation: Bio-filter with yield of 80% to break down ethanol
- Pressure vacuum valves (*1) to prevent transshipment emissions
- Carbon filter to clean replaced vapours from containers (trucks)
- Containment program for maintenance and losses from chemical spills

Changes for the new quay for transport by ship (Gedeputeerde staten van Zeeland, 2006).

- Welded connections
- Gastight explosion-proof (classified) pump
- Over pressure and thermal expansion resistant pipes and shut off valves
- Vapour return
- Barge terminal (to enable ships to turn off the engine)

(*1) Translation of “Drukvacuumventielen”

BioMCN – bio methanol

Data from [Gedeputeerde staten der Provincie Groningen, 2008]

Process:

- Emission trading NO_x
- Low-NO_x burners (best available technology)
- Seal lubricant scrubbers
- Note: vapour return was investigated but not applied. The new permit (Gedeputeerde staten van Zeeland, 2006) demands a new investigation because the size of the factory was increased.
- Chemical spill prevention management

Appendix D Summary dutch permits biofuel production

Table D.1 Summary of permits of the processes for bio-diesel, bio-ethanol and bio-methanol

Company / installation	Product	Production Volume (ton/yr)	NO_x	SO_x	VOC	Particulate matter	NH_3
Heros Sluiskil BV (Rosendaal Energy) [Gedeputeerde staten van Zeeland, 2007 (1)]	Biodiesel	250.000	*See:* *Combustion plant*	Not mentioned in permit	Determination of methanol spill in accordance to 2 documents (*) - Permit does not state specific value	Permit: "Not relevant "	Not mentioned in permit
Biopetrol Industries AG [Gedeputeerde staten van Zuid-Holland, 2006]	Biodiesel + Glycerol	400.000 biodiesel, 60.000 glycerol, 60.000 re-esterified fatty acids	200 mg/Nm^3 for 2 oil heaters of 0.8 MWth each	See: combustion plant	Off-gas cleaners (methanol): 150 mg/Nm^3, does not exceed 0.5 kg/hr Chemical spill: to be determined	Not mentioned in permit	Not mentioned in permit
Abengoa bioenergy Netherlands BV [Gedeputeerde staten van Zuid-Holland, 2007]	Bio ethanol	320.000 + 80.000	Not mentioned in permit	Not mentioned in permit	50 mg/Nm^3 for ethanol, fusel oil, tert-butyl-ether for (1) filling storage tank (2) transshipment (3) dryers (combustion) VOS from fermentation is sold with compressed CO_2	Permit does not state specific values: No transshipment when wind is strong, maximum allowed level in chute was determined	Not mentioned in permit

(Table continues on the next page)

Company	Product	Production Volume (ton/yr)	NO_x	SO_x	VOC	Particulate matter	NH_3
Nedalco [Gedeputeerde staten van Zeeland, 2003, Gedeputeerde staten van Zeeland, 2006]	Bio ethanol	32.000			Transfer losses of ethanol: 1135 kg/yr + 5800 kg/yr		
BioMCN [Gedeputeerde staten der Provincie Groningen, 2008]	Bio methanol	Max. 500.000 *bio*-methanol + min. 500.000 methanol (from natural gas)		See: combustion plant	Permit does not demand a maximum emission, but does state the expected emissions Note: methane and other VOC are mentioned in the same paragraph in the permit: 130 + 3 ton/yr methane + 7 ton /yr VOC (mix) Max. allowed concentration: 50 mg/m^3 + 32+8 ton/yr methanol from transshipment –	Permit does not demand a maximum emission	

(*) Documents: "Diffuse emissies en emissies bij op- en overslag" and "Meetprotocol voor lekverliezen". The latter is available online: www.infomil.nl .
Note: It is not possible to determine the total yearly emissions for spills unless these are mentioned specifically in the permit.
Note: The NeR (Nederlandse emissie richtlijn) allows more emissions than the permit of Nedalco
Note: the permit of BioMCN distinguishes between methanol production from natural gas and glycerol. The maximum allowable concentrations change.

Table D.2 Summary of permits of the combustion plants bio-diesel, bio-ethanol en bio-methanol

Company	Fuel	Heat	Energy (*3)	NO_x	SO_x	VOC	Particulate matter	NH_3
Heros Sluiskil BV (Rosendaal Energy) [Gedeputeerde staten van Zee-land, 2007a]	Heros Sluiskil BV Biodiesel factory obtains heat and power from the biomass combustion plant, (Gedeputeerde staten van Zeeland, 2007 (2)).							
Biopetrol Industries AG, stoomboiler [Gedeputeerde staten van Zuid-Holland, 2006]	Natural gas + biogas (unknown ratio)	Steam: 50 MWth + Oil heaters: 2 x 0.8 MWth	0.10 GJ/GJ biodiesel (with biodiesel assumed the as only product)	Steam: 70 mg/Nm^3 = 30 ton NO_x/yr Oil heaters: 200 mg/Nm^3	SO_2: 20 mg/Nm^3 = 8.6 ton/yr (*1)(S originates from biogas)		Not mentioned in permit	
Abengoa bioenergy Netherlands BV [Gedeputeerde staten van Zuid-Holland, 2007]	Natural gas	CHP: 115 MWth Combustion plant: 60 MWth Dryers: 3 x 19 MWth	0.58 GJ/GJ ethanol	CHP: 31 mg/Nm^3 bij 15% O_2 = 26.2 g NO_x / GJ = 84 ton/yr Combustion plant: 70 mg/Nm^3 = 38 ton/yr Dryers: 110 mg/Nm^3 = 3 x 14 = 42 ton/yr	Not mentioned in permit		Not relevant for combustion plant	
Nedalco [Gedeputeerde staten van Zeeland, 2006]	Nedalco obtains betrekt all utilities (steam) from Cerestar (Gedeputeerde staten van Zeeland, 2006)							

(Table continues on the next page)

Company	Fuel	Heat	Energy (*3)	NO_x	SO_x	NM-VOS	Particulate matter	NH_3
BioMCN [Gedeputeerde staten der Provincie Groningen, 2008]	Natural gas / Glycerol (in reformers) Natural gas (in steam superheater)	Power of reformers unknown Steam superheaters: 2 x 15 MW	Value not available [GJ/GJ methanol]	100 mg/m^3 for combustion natural gas 150 mg/m^3 for glycerol combustion (*2) 80 mg/m^3 for 2 steam superheaters of 15 MW Permit does not state requirements for flares or start up preheater	Permit does not demand a maximum emission Yearly load: Reformer 1, 100% natural gas: 1.7 ton/yr Reformer 1, 50% natural gas, 50% glycerol: 2.4 ton/yr Reformer 2, 100% natural gas, 1.3 ton/yr Steam superheaters: 219 kg/yr and 149 kg/yr		Permit does not demand a maximum emission	

(*1) Value is 2/7th of NO_x value

(*2): Total power of glycerol combustion is not mentioned and requirements for glycerol combustion are unclear

(*3): Based on 8000 hrs of operation/yr and a lower heating value of biodiesel of 36.7 MJ/kg (lower value from [Bjarne Munk Lyshede, 2008]), a lower heating value of ethanol of 28.9 MJ/kg and a lower heating value of methanol of 20.1 MJ/kg – only when sufficient information was available

Appendix E Reference biofuel plants in the Netherlands

The following tables indicate the estimated production costs for reference plants for biodiesel, bio-methanol, or bio-ethanol in the Netherlands for 2010, 2015, and 2020, respectively. In Table 2.10 reference is made for prices of feedstocks and revenues of by-products.

Table E.1 Reference biofuel plants for conditions in the Netherlands in 2010

Biofuel	**Feedstock**	**Capacity Biodiesel**	**Capacity glycerol**	**Capacity acid-free fats**	**Investment**	**Capital costs**	**O&M costs [a b]**	**Capital and O&M costs/l**	**Feedstock costs**	**Feedstock costs/l**	**Total costs per l and per GJ**	
		[kt/a]	**[kt/a]**	**[kt/a]**	**[M€]**	**[M€/a]**	**[M€/a]**	**[€/l]**	**[M€/a]**	**[€/l]**	**[€/l]**	**[€/GJ]**
Biodiesel												
	Animal fats, C3 fats	4.4	(0.44)[c]	44	10	1.20	0.70	-2.44 [c]	15.0	3.02	0.58	17.8
	Frying oil and animal fats	100	(10)		78	9.36	3.90	0.03 [c]	31.0	0.27	0.30	9.2
	Palm oil, rape oil, Canola oil, animal fats	800			670	80.40	26.80	0.12	178.0	0.20	0.32	9.7
Bio-ethanol		Bio-ethanol/ -methanol	DDGS									
		[Ml/a]	[kt/a]		[M€]	[M€/a]	[M€/a]	[€/l]	[M€/a]	[€/l]	[€/l]	[€/GJ]
	Corn and grain	480	325		500	60.00	35.00	0.09 [d]	113.8	0.19	0.27	12.9
	Waste	33.5			60	7.20	6.00	0.31				16.7
Bio-methanol	Glycerol [d]	253			70	8.40	10.50	0.07	37.5	0.15 [d]	0.22	14.1

a O & M = Operation and Maintenance. These costs are estimated at 4% of the investment costs of a large biodiesel plant, 5% for a medium-scale biodiesel plant, and 7% for a small one.

b The annual O& M cost is estimated at 7% of the investment cost of a large bio-ethanol plant, 10% for the medium-scale bio-ethanol plant, and 15% for methanol production.

c Cost of capital and O&M per l biodiesel, after subtraction of revenue of electricity (€ 0.10/kWh) - in case of digestion of glycerol - or glycerol (150 €/t) and acid free fat (€ 300/t).

d Net per l of biofuel. In case of bio-methanol, the price of glycerol is estimated at € 150/t, and in case of bio-ethanol the revenue of DDGS is estimated at € 132/t.

Table E.2 Reference biofuel plants for conditions in the Netherlands in 2015

Biofuel	**Feedstock**	**Capacity Biodiesel**	**Capacity glycerol**	**Capacity acid-free fats**	**Investment**	**Capital costs**	**O&M costs [a b]**	**Capital and O&M costs/l**	**Feedstock costs**	**Feedstock costs/l**	**Total costs per l and per GJ**	
		[kt/a]	**[kt/a]**	**[kt/a]**	**[M€]**	**[M€/a]**	**[M€/a]**	**[€/l]**	**[M€/a]**	**[€/l]**	**[€/l]**	**[€/GJ]**
Biodiesel												
	Animal fats, C3 fats	4.4	(0.44)[c]	44	10	1.20	1.00	-2.90 [c]	17.7	3.57	0.67	20.5
	Frying oil and animal fats	100	(10)		78	9.39	3.90	0.10 [c]	36.6	0.32	0.42	12.9
	Palm oil, rape oil, Canola oil, animal fats	800			670	80.40	26.80	0.12	221.0	0.25	0.37	11.1
Bio-ethanol		Bio-ethanol/ -methanol	DDGS									
		[Ml/a]	[kt/a]		[M€]	[M€/a]	[M€/a]	[€/l]	[M€/a]	[€/l]	[€/l]	[€/GJ]
	Corn and grain	480	325		500	60.00	35.00	0.09	174.2	0.29	0.37	17.6
	Waste	33.5			60	7,20	6,00	0.31				21.4
Bio-methanol	Glycerol [d]	253			70	8.40	10.50	0.07	56.3	0.22 [d]	0.30	18.8

a O & M = Operation and Maintenance. These costs are estimated at 4% of the investment costs of a large biodiesel plant, 5% for a medium-scale biodiesel plant, and 7% for a small one.

b The annual O& M cost is estimated at 7% of the investment cost of a large bio-ethanol plant, 10% for the medium-scale bio-ethanol plant, and 15% for methanol production.

c Cost of capital and O&M per l biodiesel, after subtraction of revenue of electricity (€ 0.11/kWh) - in case of digestion of glycerol - or glycerol (€ 225/t) and acid free fat (€ 350t).

d Net per l of biofuel. In case of bio-methanol, the price of glycerol is estimated at € 225/t, and in case of bio-ethanol the revenue of DDGS is estimated at € 132/t.

Table E.3 Reference biofuel plants for conditions in the Netherlands in 2020

Biofuel	**Feedstock**	**Capacity Biodiesel**	**Capacity glycerol**	**Capacity acid-free fat**	**Investment**	**Capital costs**	**O&M costs [a b]**	**Capital and O&M costs/l**	**Feedstock costs**	**Feedstock costs/l**	**Total costs per l and per GJ**	
		[kt/a]	**[kt/a]**	**[kt/a]**	**[M€]**	**[M€/a]**	**[M€/a]**	**[€/l]**	**[M€/a]**	**[€/l]**	**[€/l]**	**[€/GJ]**
Biodiesel												
	Animal fats, C3 fats	4.4	(0.44)[c]	44	10	1.20	1.00	-3.36 [c]	20.4	4.12	0.76	23.5
	Frying oil and animal fats	100	(10)		78	9.36	3.90	0.09 [c]	42.2	0.37	0.47	14.3
	Palm oil, rape oil, Canola oil, animal fats	800			670	80.40	26.80	0.12	264.0	0.29	0.41	12.6
Bio-ethanol		Bio-ethanol/ -methanol	DDGS									
		[Ml/a]	[kt/a]		[M€]	[M€/a]	[M€/a]	[€/l]	[M€/a]	[€/l]	[€/l]	[€/GJ]
	Corn and grain	480	325		500	60.00	35.00	0.09	234.6	0.39	0.47	22.3
	Waste	33.5			60	7.20	6.00	0.31				26.1
Bio-methanol	Glycerol [d]	253			70	8.40	10.50	0.07	75.0	0.30 [d]	0.37	23.5

a O & M = Operation and Maintenance. These costs are estimated at 4% of the investment costs of a large biodiesel plant, 5% for a medium-scale biodiesel plant, and 7% for a small one.

b The annual O& M cost is estimated at 7% of the investment cost of a large bio-ethanol plant, 10% for the medium-scale bio-ethanol plant, and 15% for methanol production.

c Cost of capital and O&M per l biodiesel, after subtraction of revenue of electricity (€ 0.12/kWh) - in case of digestion of glycerol - or glycerol (€ 300/t) and acid free fat (€ 400/t).

d Net per l of biofuel. In case of bio-methanol, the price of glycerol is estimated at € 300/t, and in case of bio-ethanol the revenue of DDGS is estimated at € 132/t.

Appendix F Projected emissions BOLK I (Phase 1)

Reference: Hammingh, 2008

	Bio-energy use 2020 (PJ)	Source of emission factors Boersma et al., 2008	Air pollutant emissions				
			NO_x	SO_2	NH_3 (kt)	PM_{10}	VOCs
Co-firing in coal and gas power plants	107	Table 4-1	4.3	1.2	0.5	0.1	n.a.
Waste incineration installations	80	Table 4-4	2.8	0.1	0.1	0.0	0.1
Other bio-energy combustion[1]	8.6	Table 4-24	8.8	n.a.	n.a.	0.3	0.0
Wood stoves	8.1	Table 4-21	1.2	0.2	0.1	0.9	0.4
Sewage sludge gas combustion	2.9	Table 4-5	0.1	0.0	0.01	0.0	0.0
Landfill gas combustion	1.2	Table 4-27	0.3	0.0	n.a.	0.0	0.0
Other sources (e.g. co-fermen-tation manure)	0.8	Table 1-1	0.2	0.1	0.00	0.0	0.0
Total	215		17.6	1.7	0.7	1.2	0.5

[1] This comprises mainly clean wood and waste wood biomass combustion installations and small- to medium-scale diesel generators using palm oil. n.a. =F information not available

Appendix G Estimated emission factors and emissions from biomass combustion 2007

Table G.1 Estimated/used emission factors in g/GJ for 2007, see Table 3.1 and Section 3.2 for details and background information

Category/NEC component	NO_x	SO_x	NH_3	Dust	NMVOC	Remarks
Co-firing	40	11	5	0.9	2.0	Estimate Phase 1 + new NMVOC data
Waste Incineration (only biogenic)	35	1.3	1.3	0.5	1.3	Estimate Phase 1
Small-scale biomass combustion/stoves	111	15	N/A	181	748	Based on data Emission Registration, assumed for all small scale population
Medium-scale biomass combustion	130	10	1.7	5	60	based on max. current NOx limit, SNCR assumption for NH3
Biogas from AWZI/RWZI	195	0.5	0.0	0.5	14	All biogas engines assumed to have equal emission profile, data, NOx based on biogas engines, no deNOx assumed thus no NH_3 emissions, NMVOC on internional data (no oxycat assumed)
Biogas from waste tips	195	0.5	0.0	0.5	14	
Agricultural biogas plants	195	0.5	0.0	0.5	14	
Other biogas plants	195	0.5	0.0	0.5	14	
Bio-oil/fat fired engines	130	9	4.4	17	31	Mainly based on BIOX permits, NMVOC based on CxHy

Table G.2 Estimated results for 2007

	2007		NO_X		SO_x		NH_3		Dust		NMVOC	
	[PJ]	[PJ%]	[kton/a]	[wt%]	[kton/a]	[wt%]	[kton/a]	[wt%]	[kton/a]	[wt%]	[kton/a]	[wt%]
Co-firing in gas/coal fired power plants	15.4	(22)	0.6	(12)	0.17	(38)	0.077	(62)	0.014	(1)	0.03	(0)
Waste Incineration (only biogenic)	28	(39)	1.0	(19)	0.035	(8)	0.035	(28)	0.014	(1)	0.04	(0)
Small-scale biomass combustion/stoves	12	(17)	1.3	(25)	0.18	(39)	-	-	2.2	(97)	8.97	(94)
Medium-scale biomass combustion	7	(10)	0.9	(17)	0.070	(15)	0.012	(10)	0.035	(2)	0.42	(4)
Biogas from AWZI/RWZI	2	(3)	0.4	(7)	0.001	(0)	0.000	(0)	0.001	(0)	0.03	(0)
Biogas from waste tips	1.9	(3)	0.4	(7)	0.001	(0)	0.000	(0)	0.001	(0)	0.03	(0)
Agricultural biogas plants	3.4	(5)	0.7	(13)	0.002	(0)	0.000	(0)	0.002	(0)	0.05	(0)
Other biogas plants	1.2	(2)	0.2	(4)	0.001	(0)	0.000	(0)	0.001	(0)	0.02	(0)
Bio-oil/fat fired engines	0.5	(1)	0.1	(1)	0.005	(1)	0.002	(2)	0.009	(0)	0.02	(0)
Total	71		5.3		0.46		0.12		2.2		9.6	

a) based on CxHy measurements

Appendix H Total emissions residential wood stoves 2020

Introduction
In order to decide which measures should be taken, it’s important to know how important issues are in the future. However future developments are based on assumptions, therefore the assumptions that are made are explained in this chapter. The assumptions on the population of stoves are explained in section 2.3.3. In this section, two scenarios are calculated: Scenario Low is considered to be conservative, whether in Scenario High an assumption is made that the use of stoves increases. In this chapter only emissions from the consumption of wood is considered, since the total emission caused by the burning of waste is much lower then the emission caused by the burning of wood (at least by a factor of ten for PM_{10})

Wood use and burning time
In order to calculate emissions of stoves in 2020, it is not enough to estimate the amount of stoves, but also the wood consumption and burning time should be calculated. In (Koppejan, 2008) an assumption is made regarding the number of hours a stove is used for both the current situation and for 2020. These burning hours are presented in Table H.1 . In this report the assumption is made for Scenario Low that the current burning hours will still be correct for 2020. In Scenario High it is assumed that the burning hours increase to the number given in (Koppejan, 2008) for 2020. This assumption is based on the fact that some sources already mention an increase in wood consumption (VROM, mijnhaard.nl). Furthermore, an increase in gas prices or increased popularity caused by climate change neutral heating might cause an increase in burning hours. The burning hours of open fire places do not increase. The reason for this assumption is the fact that open fire places are only used for atmospheric heating and it is expected that this habit will hardly change.

Table H.1 Burning hours per year per type of stove

	Burning hours per year	
Type of stove	**Scenario Low**	**Scenario High**
Open fire place	70	70
Inset stove approved	280	490
Inset stove unapproved	280	490
Freestanding stove approved	490	858
Freestanding stove unapproved	490	858

The amount of wood used in one hour is dependent of the type of stove used. Hence an unapproved stove needs more wood for the same heat supply. The amount of wood used in different stoves is calculated by using the current wood consumption per stove type and divide it by the number of stoves and the number of burning hours (as used in Scenario Low). The result of this calculation is reported in Table H.2 .

Table H.2 Wood consumption per stove type in kilogram per hour

Type of stove	**Wood consumption per hour**
Open fire place	5.83
Inset stove approved	1.99
Inset stove unapproved	2.79
Freestanding stove approved	1.71
Freestanding stove unapproved	4.07

Wood consumption and emissions in 2020
In this section two scenarios are defined for the year 2020:

1. **Scenario Low**
    - Current amount of burning hours
    - Conservative amount of stoves

2. **Scenario High**
    - Increased amount of burning hours
    - Increased amount of stoves

First the wood consumption in 2020 is calculated by multiplying the amount of stoves with the burning hours and the wood consumption. The result of this estimation is reported in Table H.3 .

Table H.3 Estimated wood consumption in 2020 in kilo tonnes per year

	Wood consumption [ktonnes in 2020]	
Type of stove	**Scenario Low**	**Scenario High**
Open fire place	58	70
Inset stove approved	78	164
Inset stove unapproved	105	220
Freestanding stove approved	198	418
Freestanding stove unapproved	70	148
Total	**508**	**1,020**

The results of the wood consumption as shown in Table H.3 makes clear that the wood consumption more or less doubles in Scenario High compared to Scenario Low. Furthermore, the wood consumption in approved freestanding stoves is around 40% of the total wood used.

Total emissions
The amount of wood consumed in Table H.3 is multiplied by the emission factors presented in Table 3.5. The calculated emissions are presented in Table H.4 .

Table H.4 Emissions caused by stoves in 2020 in tonnes per year

			Scenario Low			
Type of stove	**PM_{10}**	**$PM_{2,5}$**	**NO_X**	**SO_2**	**NMVOC**	**CO_2**
Open fire place	145	139	116	12	1,159	98,464
Inset stove approved	117	109	156	16	467	132,254
Inset stove unapproved	314	293	209	21	1,255	177,642
Freestanding stove approved	297	277	396	40	1,188	336,369
Freestanding stove unapproved	209	195	139	14	837	118,452
Total	***1,082***	***1,013***	***1,016***	***102***	***4,906***	***863,181***
			Scenario High			
Type of stove	**PM_{10}**	**$PM_{2,5}$**	**NO_X**	**SO_2**	**NMVOC**	**CO_2**
Open fire place	175	168	140	14	1,401	119,017
Inset stove approved	246	230	328	33	985	278,972
Inset stove unapproved	659	615	439	44	2,637	373,247
Freestanding stove approved	627	585	836	84	2,507	709,893
Freestanding stove unapproved	443	414	295	30	1,773	250,943
Total	*2,151*	*2,012*	*2,039*	*204*	*9,303*	*1,732,073*

In Scenario High the emissions are more or less doubled. The emissions of the open fire places increase less; this is the result of the assumption that the open fire places will not be used more extensive in Scenario High. Furthermore, the scenarios show that the dominating type of stove will be the freestanding approved stove when the emissions of NO_X, SO_2 and CO_2 are considered. However, the emissions of particulate matter and NMVOC are dominated by the unapproved stoves. The reason for this effect is caused by the type of emission, emissions of CO_2, NO_X and SO_2 are directly caused by the amount of wood consumed and are not effected by the type of stove (although more NO_X emission is formed at higher temperatures, this effect is negligible at temperatures under 1000^oC).