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NEEDS

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Contents

1 Introduction

This report describes the investigations executed within WP 13 of the NEEDS Research Stream 1a. An overview over the development of technologies for biomass electricity systems from the present to the remote future is given and the pathways of key bioenergy systems are outlined on the background of three different scenarios. Technical, economic as well as socio-economic details are given.

Since the aim is to give an overview and such an outlook can not be exact as a study for existing systems, the focus is laid on the current and prospectively future most significant bioenergy technologies and biomass types. With the same philosophy, the life cycle inventories are established concentrating on the significant elements of the life cycles under investigation.

Details will be discussed in the related sections.

2 Bioenergy technologies today

2.1 Overview

Bioenergy technologies can be subdivided in biomass supply and biomass usage. In the next two sections, a brief description of the supply and of the usage of biomass is given. Subsequently, the selection for the present reference technologies is made and their technical and cost data are described.

2.2 Description of different technological options

2.2.1 Supply of Biofuels

2.2.1.1 General overview

In order to retrieve a choice of biomass sources, which are significant for the future, we consider the technical potentials of different biomass sources. Ericsson and Nilsson (2004) derive biomass potentials for different scenarios listed in Table 1. This table displays the shares of the single biomass types in the respective scenarios. From this, we can see that biomass from forests has a share of the total biomass potential, which remains approximately constant in the scenarios on future development of biomass harvest depicted in Table 1, whereas energy crops, i.e. cultivated biomass, have increasingly high potentials in moderate to long term.

Within the individual countries, the conditions partly differ significantly, especially concerning the different shares of agricultural and forest areas. The biomass residues with the largest unused potentials are primarily residual forest wood and straw. Furthermore, the energy crops show significant potentials. These types of biomass are described in the following and form the base for the selection of biomass for detailed investigation.

Table 1: potentials of different biomass sources in the EU-25 in exajoule (10^{18} J) per year. Agricultural area for energy crops is displayed in million hectares

	Forest biomass	Crop residues	Energy crops		Total
	[EJ/yr]	[EJ/yr]	[EJ/yr]	[Mha]	[EJ/yr]
Scenario 1: short-term (10-20 years)	1.7	0.9	1.8	11.6	4.4
Scenario 2a: moderate-term (20-40 years), low biomass harvest	1.7	0.9	5.1	29.1	7.7
Scenario 2b: moderate-term (20-40 years), high biomass harvest	2.2	0.9	6.1	29.1	9.2
Scenario 3a: long-term (over 40 years), low biomass harvest	1.7	0.6	13.4	77.3	15.7
Scenario 3b: long-term (over 40 years), high biomass harvest	2.2	0.6	16.1	77.3	18.9

Source: Ericsson, Nilsson 2004 IFEU 2006

2.2.1.2 Residues

Biomass residues stem from a wide range of processes. Agriculture and forestry provide the largest share of residues in many countries, followed by the wood industry, residues industry waste management, food industry, and other sources. Potentials, however, for the single residues from food industry and others are low (Fritsche et al. 2004), even if they might be of importance regionally, such as rice chaff, olive husks or others.

As mentioned in the previous section, the focus of this study will be on residual biomass of high potential throughout Europe, i.e. residual forest wood and residual cereal straw, which both are described in the following.

Residual forest wood

As shown in Table 1, residual forest wood has one of the highest potentials in the next decades. Since at present it is generally not used but remains in the forest, it is available for bioenergy without any economic loss in other areas.

Residual forest wood constitutes a residue of timber production either during cutting (harvest) or during thinning (forest maintenance). Residual forest wood comprises the entire wood except for the industrially used timber being of higher quality. It includes the treetop material, boughs, parts of the trunk, qualitatively inferior wood and weak trees.

Cereal straw as an agricultural residue

Straw accumulates as a co-product with the harvest of feed and food grain, but also of oil plants. It often remains on the field as a soil and nutrient enhancer, but in many cases it is also used as litter or fodder. If it is pressed to bales during harvest, it can be used directly or after crushing as an energy source.

2.2.1.3 Energy crops

The energy crops, i.e. cultures grown purposefully for energetic use, represent different biomass types, from oil plants over herbaceous crops to wood from energy forests and from short rotation forestry (SRF). Plants or parts thereof may be converted to liquid or gaseous combustibles, such as bioethanol, biodiesel, or biogas before usage. Often, the per-hectare yield of these combustibles is much less than the yield of bioenergy plants, which can be utilised completely for power or heat production (see Table 2). Since agricultural area in Europe and elsewhere is restricted and there is an area competition between food production, requirements for urbanisation or transport purposes and for natural habitat, and bioenergy production, high-yielding energy crops are desirable. In the following, plants with a high yield of combustibles are described.

Short rotation forestry

SRF is applied for rapidly growing woods, which are felled at intervals of several years and shoot again. The poplar is a tree with a particularly high yield.

After the young poplars are planted, they are harvested in cycles of several years. The expenditure for the care is relatively small; only a fertilisation is necessary after every harvest. The harvest is performed with machines, which chop the harvest property directly to wood chips.

Table 2: energy yield from one hectare (ha) of energy crops

	Biomass yield in tons	**Yield of final energy in GJ**
Solid biofuels		
Short rotation poplar	20	180
Triticale (whole plant)	14	170
Miscanthus × giganteus	16	180
Liquid biofuels		
Sugar beet ethanol	56	110
Wheat ethanol	7 (grains)	55
Rapeseed oil	3.5 (seeds)	40
Biodiesel from rapeseed oil	3.5 (seeds)	40
Biomass-to-liquid diesel (BTL) from poplar	20	90
Gaseous biofuel		
Biogas from corn	45	120

Source: own calculations IFEU 2006

Triticale (whole plant)

Any cereal can, apart from its use in food production, be grown also for energetic usage.

Triticale is a cross-breeding between wheat (*Triticum aestivum* L.) and rye (*Secale cereale* L.), which combines the yield and grain quality of wheat with the winter and illness resistance and unpretentiousness with regard to soil and water needs of the rye. If the grain is not used for feeding stuff or in food production, the entire overground plant mass can be used as an energy carrier. Triticale can be grown and harvested by traditional means and is subsequently available in bales or, where appropriate, after crushing, for the direct use for the disposal. (MPIZ 2005)

Perennial grasses

An abundance of perennial grasses is currently examined for their possible applications as energy carriers. The advantages lie in their mostly fast growth, therefore in high biomass production, in small expenditures for the field works and in often very low fertiliser requirement.

Miscanthus (*Miscanthus × giganteus*) is a grass species, which is denoted by an especially high mass growth. *Miscanthus × giganteus* is a hybrid, which is propagated by means of rhizomes. It has a high solar radiation efficiency, nitrogen efficiency, and water use efficiency, but for high yields it nevertheless needs a lot of water. Furthermore, a relatively mild climate is advantageous, as the growing period is determined by the last spring and the first autumn frosts. Consequently, the available sorts of Miscanthus are suitable especially for the Mediterranean countries. (CRES et al. 2005)

Giant reed (*Arundo donax*) is a grass growing in Europe and within almost all subtropical and warm-temperate zones of the world. The prevalence is due to the diverse uses through the human being and the exporting of giant reed rhizomes through farmers, emigrants etc. Giant reed is suitable for warm climate zones, but similar to Miscanthus high water availability is necessary in order to reach maximum yields. The yield seems to be to a large extent independent from the fertilising amount and is about in the level of Miscanthus. (CRES et al. 2005)

For both perennials no harvesters are established yet; often modified maize choppers (without row splitter) are used.

2.2.2 Conversion and usage technologies

The conversion and usage technologies are diversified as far as the kinds of biomass. One possibility is the direct combustion of biomass for heat and/or electric power production. In this case there are in turn different possibilities: biomass can be used in medium-size power plants by way of mono-combustion as well as by way of co-combustion together with fossil fuels such as hard coal in large power plants. Another option is the gasification of biomass with subsequent combustion technologies, which allows efficient power and heat production.

There are also further options, which will not be considered for different reasons: for instance, pyrolysis has smaller prospects because of its lower efficiency and the disproportionately high costs (cf. CRES et al. 2005). The unused potential of the fermentation processes for biogas production lies below that of the solid biofuels (Fritsche et al. 2004). For this reason, details of these technologies are not described here.

2.2.2.1 Direct combustion of biomass for power production

Mono-combustion of biomass in combined heat/power plant

A moving grate stoker with downstream steam turbine is suitable for the combustion of biomass for electric power production. This technology has the advantage of having been widely applied during the last decades and thus features considerable experience. At the same time, it has good future opportunities with respect to other technologies discovered recently or newly such as ORC or steam engine since higher efficiency of the steam turbine is to be expected also in the long run (see section 3.4), because technological development continues also for the steam turbine, so that with increasing time higher efficiency is to be expected.

Co-combustion of biomass in coal-fired power plant

The co-combustion of biomass in large power plants is a further forward-looking option since the size leads to relatively low costs. Also, among other things the electrical efficiency is very high, in the range of a coal-fired plant. Also the emission control is efficient and very thorough, so that also the use of relatively pollutant-containing biomass can be possible without exceeding the valid limits. Furthermore, many problems which show up in combustion of pure biomass are reduced or excluded. Those problems are especially regarding the ash content – amount, ash melting, and slagging of the combustion chamber.

2.2.2.2 Gasification of lignocellulose

The following sections describe the different concepts of the generation of synthesis gas-like fuel gases and the raw gas conditioning.

Overview of the different technologies

The production of synthesis gas-like fuel gases for electric power production from solid biofuels can be carried out according to three different concepts:

- Fixed-bed gasification
- Fluidised-bed gasification
- Entrained-bed gasification

For fossil combustibles, i.e. hard coal and lignite, these procedures are mature to a large extent. The gasification product, a synthesis gas, served in this case mostly as input for the Fischer-Tropsch synthesis generating transportation fuels or chemicals, but recently also for the electric power production with gas and steam turbines (IGCC). For combustible biogenes the only technical route was long time particularly the production of fuel gases for electric power production with gas turbines or engines, then additionally for fuel cells and meanwhile also for the transportation fuel production according to the Fischer-Tropsch process. Even for fuel gas generation for engines and turbines numerous problems still occur and the plants have mainly demonstration or “semi-commercial” character. Considering the clearly higher claims of fuel cells onto the synthesis gas in comparison with engines and turbines, we experience for all technologies a stage of development that is still relatively far away from a commercial application. Some concrete problems:

- All single-stage procedures are unsuitable for herbaceous crops (Straw, Triticale usw.): the high K and Cl content of these materials facilitates slagging and corrosion. According to the process the herbaceous crops must be conditioned extensively (dust-fine grinding or pelletisation).
- For wood, the direct entrained bed gasification is unfavourable (dust-fine grinding).
- Fixed-bed gasifiers are limited to power capacities up to 5 MW (Meyer et al. 2004) and yield raw gases with extremely high tar content, fluidised-bed gasifiers yield raw gases with high dust content.
- Multi-stage processes (e.g. “Blauer Turm”, Choren, FZK) supply better raw gases, are more flexible with regard to the input and thus are able to accept larger biomass potentials, however, they are more extensive.
- As biomass accrues locally, in most concepts smaller system sizes than for fossil combustibles are planned, which leads to higher specific costs (economy of scale).

For solving these problems all gasifier types are further developed.

Table 3 summarises some features of the gasification concepts; Table 4 summarises information on some existing plants.

Table 3: different gasification concepts properties

	Fixed-bed	**Fluidised-bed**	**Entrained-bed**
Input size	coarse-grained	fine-grained	dust
Conditioning efforts	if any, agglomeration	small	grinding
Oxygen demand	small – medium	medium	high
Decomposition of carbohydrates	hardly	predominant	complete
Carbon gasification yield			
from	80%	80%	95%
to	90%	95%	
Space/time yield	small – medium	medium – high	very high
Controllability	good	very good	very good
Typical examples	Lurgi, BGL	HTW, KRW, IGT, U-Gas	Texaco, SCGP, GSP, Destec, Prenflo

Source: Meyer et al. 2004 IFEU 2006

Single-step processes

Fixed-bed gasifiers

Fixed-bed gasifiers can be constructed as co-current or counter-current gasifiers (combustible and oxidising agent move into the same direction and/or against each other). Counter-current gasifiers are characterised by high thermal efficiency, produce, however, very tarry gases; co-current gasifiers are less efficient, but supply purer raw gases. The gasification occurs autothermically; air, oxygen or an oxygen/steam mixture can be used as gasifying media. Further distinguishing features are the ash removal (wet = molten or dry) and the pressure range. All fixed-bed gasifiers require granulated feedstock, therefore e.g. for straw generally a pelletisation is necessary. At least when fed with biomass, fixed-bed gasifiers are supposed to be suitable only for small capacity (Hofbauer und Kaltschmitt 2004, Meyer et al. 2004).

Fluidised-bed gasifiers

Among these processes we distinguish bubbling and circulating fluidised beds. In both cases sand that serves as heat carrier is held by the inflowing gasifying medium in levitation. With the bubbling fluidised bed the sand remains in the reactor, with the circulating one it is carried away with the fuel gas, deposited in a cyclone, and reintroduced into the reactor. The gasification occurs autothermically or allothermically when with circulating fluidised beds the sand is heated up before the reintroduction; as gasifying media air, oxygen, and/or steam can be used. The pressure range is a further distinguishing feature. The raw gas quality is moderate. With regard to the particle size of the combustible the fluidised-bed gasification is relatively robust. Large capacities can be implemented probably well. However, fluidised-bed gasifier have not established themselves also for fossil combustibles (Example Berrenrath).

Entrained-bed gasifiers

Entrained-bed gasification is the most important concept for fossil combustibles besides the fixed-bed gasification. Because of the necessary small particle size of the feedstock entrained-bed gasifiers are discussed for biomass only within the framework of multistage procedures (see below). (Pyrolysis coke can be grind more easily to dust as wood or straw.) Entrained-bed gasifiers can be driven autothermically or allothermically and with air, oxygen and/or steam.

Table 4: existing plants with biomass gasification

City /country	Capacity MW$_{therm}$	Fuel	Concept	Product	Status
Fixed-bed gasification					
Gazel / Belgium	0.15	wood chips (short rotation)	co-current, autothermic (air)	electricity (gas engine)	since 2000 3000 h/yr
Eckenförde / Germany	0.18	wood chips	2-zones co-current, autothermic (air)	electricity (gas engine)	since 2001
Legnano / Italy	1		co-current	CHP	under construction
Rossano / Italy	3.8	olive pomace	counter-current	CHP	start of operation pending
Herning / Denmark	0.4	wood chips	co-current	CHP (gas engine)	7000 h
Wiener Neustadt / Austria	2	wood chips	2-zones co-current, autothermic (air)	CHP (gas engine)	since 2004
Fluidised-bed gasification					
Burlington / USA	60	wood chips	2 circulating (Silva Gas process), allothermic	co-combustion	since 2000
Lahti / Finland	70	wood off-cuts, wet biomass	Foster-Wheeler-gasifier	co-combustion CHP	since 1998
Värnamo / Sweden	7	wood off-cuts	circulating, pressurised, autothermic (air)	IGCC	after demonstration phase closed
Arbre / UK	9	wood chips	circulating, atmospheric, autothermic (air)	IGCC	since 1999
Güssing / Austria	8	wood chips	stationary 2-bet fluid., allothermic	CHP (gas engine)	since 2001
Entrained-bed gasification					
New Bern / USA	60	"black Liquor" (residue from paper production)	autothermal (air)	heat, steam	since 1997
Freiberg / Germany	1	pyrolysis products (coke dust)	Carbo-V process, autothermic (O_2/steam)	CHP, methanol, synfuels	test and demonstration phases
Freiberg / Germany	3	bio-oil / coke slurry	GSP process, pressurised, autothermic (O_2/steam)	syngas	test and demonstration phases

Source: Meyer et al. 2004 IFEU 2006

Multi-stage processes

The purpose of these processes is to make cleaner raw gases and to keep away materials that disturb the production of synthesis gas from the gasifiers (for example low-melting ashes). At the same time, in doing so, the input basis is widened since in particular herbaceous crops are problematic for single-stage procedures (see above). These procedures are discussed at this time particularly in connection with the Fischer-Tropsch synthesis of transportation fuels. Relevant concepts:

“Carbo-V” process by Choren. In the first stage biomass is transferred autothermically to pyrolysis gas and coke by means of low-temperature gasification with a steam/oxygen mixture (alternative: air). The two products are autothermically reformed in an entrained-bed gasifier with oxygen; energy is supplied by the gas.

Process by FZK. Biomass undergoes in decentralised form a flash pyrolysis (Lurgi-Ruhrgas mixed gasifier). Pyrolysis oil and coke are mixed to a slurry and reformed in central plants (entrained-bed gasifier, GSP gasifier, type "Schwarze Pumpe"). The process is supposed to be suitable for a great number of biomass types, also herbaceous crops (cf. Reinhardt et al. 2006). The availability of the components could be useful.

"Blauer Turm" by DM2. Biomass is smouldered. The pyrolysis coke is burned in a separate firing. With the heat both the smouldering and the reforming of the pyrolysis gas with steam is supported. With this, "Blauer Turm" represents the conversion of the use concept of coke and gas in the Carbo-V process.

Gas conditioning

For the use in combustion engines and gas turbines particularly the removal of dust and tar is necessary, for fuel cells furthermore the hydrogen share in the raw gas must be maximised and it must be separated from CO_2 and further unwanted gases.

Process and stage of development of the synthesis gas cleaning (Meyer et al. 2004): removal of

- Dust and ash. state of the art: different wet and dry filter types and separators
- Halogen, S and N compounds: state of the art: scrubber (absorber) with different washing-liquids; under development: adsorber
- Hydrocarbons/tar: state of the art: filter, scrubber and tar cracker; under development: catalytic systems

The existing plants clearly distinguish in terms of the kind of applied cleaning techniques, the respective number of stages, and the sequence of different processes. No typical sequence of cleaning steps can be derived from the available information, in particular no future development (however, a trend towards dry procedures exists).

For the use in fuel cells, the shift reaction (increase of the hydrogen share) occurs catalytically under addition of steam. Depending on the catalyst, the quality demands on the raw gas are different. Then the hydrogen is separated from the remaining gases by pressure swing absorption or other concepts. The different CO_2 and CO contents acceptable for different fuel cell types are not considered here.

During the following selection of the processes gas conditioning is considered as a component of the gasification process and basically described by an efficiency reduction.

2.3 Specification of present reference technologies

2.3.1 Biomass supply

For biomass supply, both residues and energy crops are chosen as inputs. Since herbaceous biomass such as straw as a biomass input is difficult to handle especially in gasifiers, depending on the bioenergy technology woody instead of herbaceous biomass is investigated.

2.3.1.1 Residues

1) Chips from **residual forest wood**. Forest wood residues have one of the largest potentials in the next decades and are available for bioenergy without any economic loss in other areas.

2) **Straw from wheat** as an agricultural residue. Wheat has in Europe the greatest share of the grown cereals. In the EU-28, the wheat straw share of all types of straw was a third, before corn straw (a fourth), barley (17 %), and others (IE 2006).

For the life cycle inventory, instead of a potential allocation, an alternative use of the residue is considered. In the case of residual forest wood, no other use is assumed. Since a sustainable forestry is supposed, taking out the wood diminishes the feedback of nutrients into the soil not significantly. Therefore, no extra expenditure is accounted for. In the case of straw, ploughing it into the soil is regarded as a typical alternative use. For this reason, the loss of nutrients fed back into the soil is considered.

2.3.1.2 Energy crops

Here: chips from poplar **short rotation forestry** (SRF). Poplar is commonly under discussion as a fast-growing tree suitable for SRF with relatively small expenditures for maintenance with respect to annual crops.

2.3.2 Conversion and usage technologies

2.3.2.1 Direct combustion of biomass for power production

For mono-combustion of biomass in a combined heat and power plant, the technology of a moving grate stoker at about 20 MW_{therm}, backpressure steam turbine with combined heat and power production is chosen. This technology is typical for bioenergy plants since process control and changing process conditions is easier than for an extracting condensing steam turbine even though efficiency is lower.

2.3.2.2 Gasification of lignocellulose

A selection of promising concepts with perspectives for the investigation in NEEDS is complicated because

- future models of one or several concepts can be by far “better” than contemporary concepts,
- for this reason, contemporary rankings are not directly portable into the future,

in addition, however, already today it is very hard to derive reliable base data and make choices due to only very limited data availability and representativeness.

Therefore only one generic high-efficiency gasification concept will be analysed. The gas conditioning is described by an efficiency reduction as mentioned above.

2.3.3 Technical specification of the selected bioenergy chains

In the sections above the kinds of biomass as well as the conversion and usage technologies, which are proposed for the environmental and economic analysis, were described. In Table 5, the life cycles resulting from that are combined.

Table 5: life cycles for reference technologies (today)

No.	Biomass		Conversion technology		Usage technology
1	Poplar from SRF	→	mono-combustion	→	CHP steam turbine
2	Straw	→	mono-combustion	→	CHP steam turbine
3	Poplar from SRF	→	generic gasifier	→	CHP internal combustion engine
4	Residual forest wood	→	generic gasifier	→	CHP internal combustion engine

For the conversion technology itself, generic plant models have been adopted that are not fixed to a certain process, type, or producer. Relevant figures adopted for describing the plants under analysis are shown in Table 6.

Table 6: overview of all reference bioenergy CHP plants for the current time horizon

Parameter	**Unit**	**Steam turbine**	**Gasifier / engine**
Size	MW_{el}	6	4
Electrical efficiency	%	20	25
Thermal efficiency	%	65	53
Technical life time	yr	15	15
Electricity production	kWh_{el} / yr	48 million	24 million
Full load hours	h / yr	8,000	6,000
Main data sources		IFEU 2006, Hartmann/ Kaltschmitt 2002, CRES et al. 2005	IFEU 2006, Hartmann/ Kaltschmitt 2002, CRES et al. 2005
			IFEU 2006

During the biomass combustion some ashes are created. The main part of these ashes from the grate and from the cyclone can be used as fertilisers .The filter ashes must be treated as hazardous waste (because of their content in heavy metals) and disposed of in landfills.

Table 7 lists the most important figures for the biomass production. Due to the significant influence of climate, poplar is displayed in two different columns representing typical central European and Southern European conditions. Besides, fertilisation is taken into account on the basis of the quantity of harvested nutrients. During the first two years of poplar cultivation (for which a rotation cycle of 20 years is assumed in the computation) some herbicides are used.

Table 7: overview of all reference biomass production schemes for the current time horizon

Parameter	**Unit**	**Short rotation poplar**	**Short rotation poplar (South)**	**Wheat straw**	**Residual forest wood**
Yield	$\frac{\text{t f.m.}}{\text{ha} \cdot \text{yr}}$	20	30	5	3.5
Bulk density	kg / m^3 (f. m.)	464	464		332
Moisture at harvest (wet basis)	%	50	50	15	50
Moisture at combustion / moisture at gasification (wet basis)	%	30 / 20	30 / 20	15 / –	– / 20
Lower heating value at combustion / at gasification	MJ / kg (f. m.)	13.0 / 13.6	13.0 / 13.6	13.7 / –	– / 14.5
Main data sources		IFEU 2006, Hartmann/ Kaltschmitt 2002, CRES et al. 2005, Luger 2002		IFEU 2006, Hartmann/ Kaltschmitt 2002, CRES et al. 2005	
					IFEU 2006

2.3.4 Key economic data of the selected technologies for electricity generation from biomass

Depending on the technological configuration of the biomass plant (including all necessary peripheral systems and components) the net investments of the energy conversion technology vary significantly within the costs groups construction technology, mechanical technology as well as electric and control systems.

Varieties, especially in biomass district heating systems (e.g. load changes, operational hours, local conditions), lead to broad differences in the plant's layout design and therefore in its costs structure. Due to this uncertainty the following costs only represent an order of magnitude. In certain cases considerably lower or higher costs might be achieved.

Construction Technology of Energy Conversion Techniques

Generally, the costs for construction technology of a biomass plant contain expenses for structural measures such as a vessel- and machine house or a fuel storage including their respective technical devices. For plants over 100 kW_{th} these costs sum up to about 20-40 % of the total investment costs in entirely new buildings, while for existing buildings the construction costs are significantly lower.

Mechanical Technology of Energy Conversion Techniques

This group of costs contains all mechanical components including storage- and conveyer-systems for biomass. These can be classified into the following essential plant components:

- Biomass vessel including feeding, ash discharge and ash storage,
- Cleaning of flue gas
- Mechanical technology of biomass storage, conveying, and feeding
- Water treatment
- Flue gas and air system (incl. ventilation) as long as not included in other groups mentioned above,
- Steam turbo set and/or gas turbine including the generator
- Connecting pipelines with pumps, containers (e.g. feeding water tank) and armatures incl. their insulation

The costs for biomass vessels strongly depend on the capacity and on the type of device. The type of fuel also has an influence on the costs. Combustion vessels for herbaceous crops, for example, have 10-50 % higher costs than comparable wood vessels with identical size.

Vessels with a thermal capacity over 100 kW_{th} are generally offered with an automatic fuel feed-in and are equipped with downstream dust separation equipment. Apart from the biomass vessel, the most expensive component in a combined heat and power plant is the steam turbine and/or the gas turbine.

Electric and Control systems for Energy Conversion Techniques

The costs for electric and control technologies are mainly affected by the entire electro technical coupling of plant and machinery systems. Furthermore, this group of costs contains the superior control and communication system, while the technique of measurement and control for single components is usually included in the delivery of the component supplier and thus belongs to the cost group for the mechanical technologies.

The costs for electric and control systems strongly depend on the size and complexity of the plant, the desired degree of automation and the respective boundary conditions, such as the existing electro technical infrastructure. Hence, the indication of specific values for these costs is associated with high uncertainties. The costs for electric and control systems constitute approximately 10 to 20 % of the costs for mechanical technologies.

Fixed Operational Costs

This group of costs contains all expenses for maintenance-, repairing- or servicing-measures, personal costs for the company's internal staff and expenditures for taxes and insurances. For an estimate of costs these expenditures can be set over the plant's overall life time and are defined as a share of the investment costs. Experience values according to VDI2067 1983 are listed below:

– Construction technology of the energy conversion	0.5-1.0 %/yr of investment costs,
– Mechanical technology of energy conversion	2.0 %/yr of investment costs,
– Electric and Control systems	1.0-1.5 %/yr of investment costs.

The costs for insurances consist of expenditures for liability-, machine- and other insurances (insurance for natural hazard etc.). These costs sum up to about 0.5 to 1 %/yr of the investment costs.

The cost data of the current biomass technologies considered in NEEDS, biomass CHP with steam turbine and biomass gasification CHP with internal combustion engine, are summarised in Table 8 .

Table 8 Cost data of current biomass CHP technologies in NEEDS

Costs		Steam turbine	Gasifier / engine
Spec. investment costs (overnight capital costs)	[€/kW$_e$]	2,500	2,350
- Construction technology	[€/kW$_e$]	2,000	1,950
- Mechanical technology	[€/kW$_e$]	350	200
- Electric and control systems	[€/kW$_e$]	150	200
Spec. demolition costs	[€/kW$_e$]	3	3
Fixed costs of operation	[€/(kW$_e$ · yr)]	150	161.5
Other variable costs	[€/MWh$_e$]	7.5	7.5

3 Bioenergy technology development pathways

This chapter describes the supposed development of bioenergy technology in the different scenarios used within this Research Stream RS 1a. In the first sections, strong and weak points and the main drivers influencing future development of bioenergy technologies are presented. Subsequently, the potential role of bioenergy within a future energy supply system and the resulting technology development perspectives are described. The last section focuses on the development of costs for the bioenergy technologies.

3.1 Bioenergy hot spots

Table 9 lists the key strong and weak points of bioenergy. This is to identify the major issues of concern related to the future use of bioenergy technologies.

Table 9: hot spots of bioenergy

Strong points	Weak points
Storability ⇒ Availability throughout the year Significant potentials in unused residues	Risk of lacking sustainability of energy crops if utilised in an intense manner (monocultures, large areas with the same crop): e.g. loss of biodiversity, increase of diseases/pests on biomass crops etc. Area competition between requirements for: – food (incl. organic farming) – sealing of natural ground and compensation areas – nature conservation – water protection and soil conservation – bioenergy and transport biofuels Usage competition between residues due to requirements for – bioenergy – transport biofuels – biobased materials Imports of biomass may damage ecosystems elsewhere if not controlled well Risks if using genetically modified cultures Risk of harvest losses due to extreme climate conditions

IFEU 2006

3.2 Main drivers influencing future technology development

The main driving forces influencing future development of bioenergy technologies are shown in Table 10. In the table, a rough quantitative indication of “strong driver”, “driver”, “neutral”, “inhibitor”, “strong inhibitor” is given. The differentiation between the three scenarios is only indicative and in single cases disputable.

From the table, it turns out that many typical characteristics of and opinions on biomass are inhibitors of bioenergy development, e.g. public concern about using food crops for non-food purposes or the competition between energy crops and other uses of agricultural area. Therefore, a favourable bioenergy policy has to consider these aspects. One example are emission restrictions: they may lead to an advanced technology development if they are reasonable, but also hinder a further development if not paralleled with competitive costs.

Table 10: main driving forces for bioenergy technology development. Green arrows show positive influence (driver), red ones negative influence (inhibitor). Grey arrows: driver does not influence the development

Driver / barrier	Very optimistic scenario	Optimistic-realistic scenario	Pessimistic scenario
General policy			
Climate protection aims	↑	↑	↗
Security of selling electricity (feed-in laws)	↑	↑	↑
Common Agricultural Policy - discoupling from supply, support for energy crops	↑	↑	↑
Prospective energy price development	↑	↑	↑
Diversification of energy sources, energy import dependency	↗	↗	↗
Diversification of farmers' income	↗	↗	↗
Regional economy	↗	↗	↗
Biomass imports	↗	↗	→
Emission restrictions	↗↘	↗↘	→
Typical characteristics of biomass and attitude towards it			
Public concern on using food crops for bioenergy	↘	↘	↓
Possibility of direct replacement of fossil fuels	↑	↑	↗
Storage possibility / continuous energy availability	↑	↑	↗
Plant breeding, bio science	↗	↗	↗
Precision farming	↗	↗	→
Land use competition (en. crops): transport biofuels, biobased materials, food, nature conservation	↘	↘	↓
Competing other uses, fuel cost: restricted availability, use for biobased materials, for BTL	↘	↘	↘
Biodiversity (referring to energy crops)	↘	↘	↘
Environmental pressure on soil and water resources (referring to energy crops)	↘	↓	↓
General technology development			
Material science, corrosion knowledge	↗	↗	→
Synthesis gas cleaning (hot gas instead of wet scrubbing)	↗	↗	→
Standardisation, fuel specifications	↗	↗	→

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3.3 The potential role of bioenergy in a future energy supply system

3.3.1 Basis

Currently, biomass plays an important role among the renewables: 44% of renewable energy in the EU is bioenergy, most of it traditional biomass technologies such as household wood combustion (EC 2005a). The "White Paper for a Community Strategy and Action Plan" outlines a scenario in which 1995's bioenergy use was to triple until 2010 (from 45 to 135 Mtoe). This aim is not realistic anymore – the growth of the bioenergy sector since then has been less than half of the rate necessary for reaching the aim.

Regarding electric power, today in the EU-25 about 50 TWh (in 2002, EC 2004) electricity are produced from solid biomass, biogas, and biowaste. That is 13% of the electricity production from renewable energies – or about 2% of the European gross power demand of 2,800 TWh (BMU 2006). Power production from bioenergy is growing by about 7% each year (EC 2004).

Since bioenergy technology is restricted by the potential of available biomass, in chapter 3.3.3 the potential of available biomass is described.

3.3.2 General political goals

Some important goals laid down in the Annex to the EC "Biomass Action Plan" (EC 2005b) are:

- Capturing the to date unused potentials of biomass without harming the resources (as soil, biodiversity and water) and the domestic food production;
- Capturing all cost-effective forms of biomass power generation, and thereby removing the technical and legislative limitations for their future development;
- Using combined heat/power from biomass in order to improve the efficiency;
- Modifying the biofuels standards to allow an increasing use of oils in the biodiesel production.

All these aims are directed to urge the EU Members to settle measurements for improving the demand for biomass and thus its supply, and for developing the research.

3.3.3 Potential of biomass

3.3.3.1 Energy crops

The technical potential of agricultural area in the EU-28 is about 15 million hectares in 2000 and over 66 million hectares in 2020 due to population figures remaining constant and higher yield expectations. This is on the basis of a "current policy" scenario maintaining the current agricultural and energy policy until 2020. In an environmentally-oriented scenario the figures will increase from 12 million hectares in 2000 to 29 million hectares in 2020 (IE 2006).

For energy from energy crops, the technical potential in the EU-28 is about 1,200 PJ in 2000 and about 7,800 PJ in 2020 on the basis of a "current policy" scenario. In an environmentally-oriented scenario the figures will increase from 1,000 PJ in 2000 to 2,600 PJ in 2020 (IE 2006).

3.3.3.2 Forest wood

Forest wood has a technical potential (firewood, logging residues and the unused growth) in the EU-28 of about 3,000 PJ in 2000 and about 2,500 PJ in 2020 (IE 2006).

3.3.3.3 Residues

The technical potential of biomass residues, considering straw and other agricultural waste as well as residues from food and wood processing, in the EU-28 is about 3,700 PJ in 2000 and about 4,000 PJ in 2020 (IE 2006). In the further assumptions in the scenarios, focus is laid on lignocellulosic material such as straw and wood, which has a share of about two thirds among all kinds of residues.

3.3.3.4 Outlook for 2050

From the technical potentials in IE 2006, data is derived for 2050 on the basis of IFEU 2004 taking the German situation as an approximation for the European one. This is a rather careful assumption since Germany has less per-capita resources in terms of agricultural area than the Eastern European countries whereas in those countries efficiency in agriculture (especially yield) is assumed to increase significantly from the currently low levels, in particular due to increased use of fertilisers, and therefore leading to large areas available for other uses such as bioenergy. This leads to an increase in the potential of energy crops from 2020 to 2050 by 70 % in the base scenario, by 250 % in a “nature conservation” scenario. The amount of residues and forest wood (both combined in one figure) is nearly constant with respect to time.

Even with some differences in the scenarios in IE 2006 and IFEU 2004, these factors seem to be applicable justifiably also for the European data.

From this, Table 11 can be derived. The total bioenergy available sums up, depending on the scenario, to nearly 20 EJ or about 15 EJ in 2050, respectively depending on the scenario.

Table 11: biomass potential estimations in the EU-28 in petajoule per year

	“Current policy” scenario			**Environmentally-oriented scenario**		
	Energy crops	**Forestry and residues**	**Sum**	**Energy crops**	**Forestry and residues**	**Sum**
2000	1,200	6,700	7,900	1,000	6,700	7,700
2025	8,000	6,500	14,500	2,600	6,500	9,100
2050	13,000	6,500	19,500	9,000	6,500	15,500

IFEU 2006

This bioenergy is to be subdivided into bioenergy for electricity, heat, and biofuels for transport. Provided that nearly all the electricity and heat from biomass can be produced in CHP, biofuels for transport are the largest competitor with electricity from biomass. From the Biomass Action Plan (EC 2005a) and especially the biofuels directive (EC 2003) it is derived that biofuels for transport are to have a significant share in the fuel market, not only until 2010 (5.75 %), but still increasing further ahead (2020: 10 %).

From this, it seems to be reasonable to allocate half of the bioenergy potential to transport biofuels and half of it to electricity in CHP. Other allocations would be possible, but since a “biomass-friendly” scenario would increase also the use of transport biofuels, this division is the first possible approach leading to a share of biofuels in the transport sector of about 12 to

20 % in 2025 (own calculations on the basis of EC 2006). The electric power producible from this is therefore between 600 and 800 TWh in 2050.

To confirm these figures, they are set in relation to the total expected electricity production in Europe. EC 2006 supposes the power production in the EU-28 to steadily increase, with a slight slowdown as from 2025. It estimates the total power produced in 2030 to be 4,900 TWh. With this trend, keeping in mind the increasing cost for fossil fuels as described by Nitsch et al. 2004, a realistic figure for the total electricity generation in 2050 may be about 5,000 TWh, leading to a bioenergy share in power production of 12-16 %. This fits well with the share of bioenergy in electricity generation approximated to be about 12 % of the total electricity generation (Nitsch et al. 2004). This is data for German conditions under the assumptions: high energy efficiency, high RE share, but restrictions due to nature conservation while maintaining food production within Europe on a 100 % self-sufficiency basis.

3.3.4 Scenarios

"Very optimistic scenario"

On the basis of the previous section, in the "very optimistic scenario", 2050 horizon, transport biofuels and power/CHP production will consume all the biomass available, thereof 50 % for electricity in CHP. In this scenario, also worldwide the energy sector will use a significant part of the biomass available. In order to keep the share for transport biofuels high, in this case all heat production from biomass will be transformed to CHP production until 2050 with feeding the surplus electricity into the grid.

In 2025, 40 % of the biomass potential available is used for transport biofuels and 40 % for power/CHP production, while 20 % are in part unused or remain for heat production. This is already a very optimistic assumption since this would necessitate the construction of more than 4,000 medium-size biomass CHP plants (30 MW biomass input) or similar efforts in order to consume this biomass amount, and considerable efforts also to make the biomass potential accessible.

For an overview, see Table 12.

"Pessimistic scenario"

The "pessimistic scenario" assumes that there will not be any development in politics going further than the feed-in laws, certification schemes, and the other policy measures already taken by the national governments. The EU targets as set out in EC 1997 will not be met as EC 2004 already stated that the aim of meeting 22 % of electricity demand by renewable energy sources becomes very ambitious since growth in the bioenergy sector is lacking behind.

In this scenario, the trend of the past of an increase of 7 % in the sector of power from biomass, leading to a doubling every 10 years, seems appropriate for the next decade. This rate fits to that one proposed by US Vision 2002. From 2015, no significant increase seems appropriate due to saturation effects with the legislation in force. This will lead to the figures listed in Table 12.

"Optimistic-realistic scenario"

The "optimistic-realistic scenario" assumes that small-scale biomass heat will continue to grow as well. Today, it accounts for a share of 23 % of the environment-oriented scenario in Table 11 (IFEU 2006 on the basis of EC 2004).

Given that the largest share of bioenergy is in the heat sector and that swapping all small-scale biomass heaters to CHP units is quite difficult due to costs and reachable efficiency, a share of 50 % of the biomass potential used for heat production seems appropriate in 2050 whereas the other 50 % are divided equally between power or CHP production and transports. In 2025, 20 % of the biomass potential available remain unused, whereas 40 % are used for heat production, and 20 % each in the transport sector and for electricity production. The absolute and relative figures are listed in Table 12.

Table 12: proposal of biomass usage for electricity in the EU-28 in percent of the biomass potential and in petajoule per year

	"Very optimistic scenario"		**"Optimistic-realistic scenario"**		**"Pessimistic scenario"**	
2005	10 %	750 PJ	10 %	750 PJ	10 %	750 PJ
2025	40 %	3,600 PJ	20 %	1,800 PJ	16 %	1,500 PJ
2050	50 %	8,000 PJ	25 %	4,000 PJ	10 %	1,500 PJ

IFEU 2006

3.4 Technology development perspectives

3.4.1 Overview

Since the targets outlined in section 3.3 are related to the potential of available biomass, there are no technology improvements necessary for reaching these targets.

However, there are some technological developments to be expected. Since the technologies under investigation are known and proven since many decades and main technological changes seem to be executed since long time, there will not be any major breakthroughs anymore, but rather gradual changes. Since technologies may change independently from the scenarios, there are parameters dependent on the scenarios and some independently changing in all scenarios.

3.4.2 Parameters dependent on the scenarios

Due to the restricted availability of biomass, one issue for all bioenergy technologies is the conversion efficiency from biomass energy to electric energy. Therefore, for the direct combustion technology a gradual change from the low-efficiency backpressure steam turbines to extracting condensing turbines seems probable, even with the more complex process control and less flexible completion of demand involved. Again higher efficiencies should be possible with biomass integrated gasification combined cycle (biomass IGCC) plants (not investigated in this study) or with gasification combined with a fuel cell.

Similar as for the bioenergy technologies, for the biomass production chains the area efficiency, i.e. the per-hectare yield of biomass is important since a high yield leads to a high energy output from the same area. Therefore and for cost reasons, plant breeding will be executed for energy crops like for food crops. Potential effects resulting from the use of genetically modified crops are not addressed.

The future emissions of bioenergy plants will be influenced by the legislation on emission control. In turn, this is influenced by the pressure of immissions and thus the amount of bioenergy plants. Therefore, generally saying, the more biomass plants are built, the stricter the emission laws will be. This is true for critical parameters such as particulate matter, CO, and NO_X. In Austria, baghouse filters are standard already nowadays. Therefore, for plants of 5 MW biomass feed power and more, a 50% decrease in particulate matter seems to be appropriate if total plant capacity is growing by a factor of ten, while a 25% decrease may be appropriate for a five-fold increase of total plant capacity. Further decreases are difficult (or expensive) to obtain with nowadays' technologies. For CO, better combustion control might reduce emissions as well by 50% and 25%, respectively. An emission difficult to reduce is NO_X. Technologies reducing NO_X regularly produce precursor substances for particulate matter, such as ammonia from SNCR or SCR, or are rather expensive. For this reason, a reduction in NO_X significantly below the values obtained today seems out of scope (IFEU 2006).

3.4.3 Parameters changing independently

One of the most environmentally significant processes in agriculture is nitrogen fertilisation. For nitrogen fertiliser production, large amounts of fossil primary energy are necessary. Due to its application on the field, fertiliser cause high emissions of ammonia and nitrous oxide. While the mechanisms of nitrous oxide emissions are complex and understood only in part, there are some means of reducing ammonia emissions and thus reducing acidification and eutrophication. It is proposed that in the long run (2050) average ammonia emissions may decrease due to laws requiring such methods.

3.4.4 Development pathways

Figure 1 shows the future pathways of the main bioenergy raw materials and the most important usage options in CHP plants. The reasons for the selection of the single materials and plants for the current reference systems are valid also for the future development. Besides that, short-rotation poplar is estimated to have no market significance in the pessimistic scenario (until 2050) and in the optimistic-realistic scenario until 2025. For the reasons mentioned above in section 3.4.2, steam-turbine technology will be converted to an extracting condensing turbine in 2050's "optimistic-realistic" scenario and in both time horizons of the "very optimistic" scenario. For gasification, one high-efficiency system with use of the hydrogen-rich synthesis gas in a fuel cell is investigated. This will take effect only in the "optimistic" scenarios (for the reasons, see Technical Report 9.4).

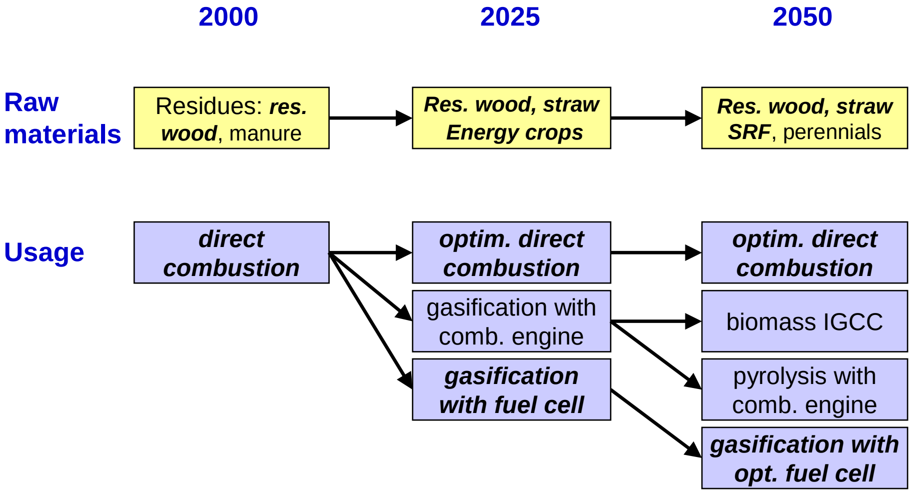

Figure 1: future pathways of the main bioenergy raw materials and the most important usage options in power / CHP plants. The options investigated in this project are in bold italics.

A summary of the proposed pathways for the bioenergy development is given in Figure 1, Table 13, and Table 14.

Table 13: development pathways proposed for the biomass raw materials

Scenario	**2005**	**2025**	**2050**
“pessimistic”	Straw Residual forest wood Poplar from SRF (only as a reference technology)	Straw Residual forest wood Poplar from SRF	Straw Residual forest wood Poplar from SRF
“optimistic-realistic”		Straw Residual forest wood Poplar from SRF	Straw Residual forest wood Poplar from SRF
“very optimistic”		Straw Residual forest wood Poplar from SRF	Straw Residual forest wood Poplar from SRF

Table 14: development pathways proposed for the technologies

Scenario	**2005**	**2025**	**2050**
“pessimistic”	Backpressure (BP) steam turbine Gasifier → gas engine	BP steam turbine	BP steam turbine
“optimistic-realistic”		BP steam turbine Gasifier → fuel cell	Extraction condensing (EC) steam turbine Gasifier → fuel cell
“very optimistic”		EC steam turbine Gasifier → fuel cell	EC steam turbine Gasifier → fuel cell

3.5 Development of costs (a bottom-up assessment)

There tends to be no cost reduction potential for construction technology of biomass conversion techniques. Also the specific costs of mechanical components are not anticipated to decrease for larger plants. Despite cost reduction potential in these components a constancy in costs is expected due to the necessary additional extensive systems engineering for plants with capacities above 1 MW. Such plants are equipped with an automatic ash removal and are partly designed as grate-stoker furnace, which lead to higher costs compared to other types such as an underfeed furnace.

Furthermore, cost reduction potentials for plants above 1 MW are counterbalanced by the fact that for larger power plant capacities extraction condensing turbines are used instead of less expensive extraction back-pressure turbines. Moreover, such larger turbines are multi-stage machines (instead of single-stage machines) that have higher costs but also higher efficiencies.

Over the last years the research and development activities in biomass power plants in the small scale small capacity range have generally been very modest, because efficiency improvements could be achieved mainly due to an increase of the steam inflow parameters (pressure and temperature). Necessarily advanced parameters, however, are not achievable in the smaller range of performance (firing thermal capacity below 100 MW).

Another aspect relevant for cost development is the flue gas cleaning. The choice of flue gas dust removal devices is influenced by the requirements concerning the rest dust concentration of the flue gas. Depending on legal regulations there are options for using different dust removal devices. In plants below 5 MW there are no prescriptive limits for dust concentration. For these plants multi cyclones featuring a comparably high residual dust concentration are the most economic dust removal systems. For thermal firing capacity over 5 MW there are stricter limits for dust removal requiring more complex dust removal facilities (mainly with electric or fabric filter instead of/or additionally to the multi cyclone). This however increases the costs significantly.

The fixed operational costs are anticipated to stay constant in their share to the investment costs.

4 Specification of future technology configurations

4.1 Future technology specification

In this paragraph, the specifications assumed for future bioenergy technologies are outlined. As mentioned in the introduction, the focus is laid on the description of some key technologies and the significant elements within each life cycle. For this reason and/or due to a disproportionately high effort it would have caused, certain aspects are disregarded here. Some important points in this context are described here below.

- The consequences of GMOs utilisation to improve the agronomic performance and the yield amount are not considered.
- Climate change and connected risks (due to desertification or changing in precipitations) are not modelled here. According to the actual temperature increase, some Mediterranean ecosystems could shift toward a hotter, drier climate, thus decreasing yields, whereas colder climate zones could become more adapted to cultures for warmer climate and increase yields.
- Importing bioenergy, which may be economically feasible in some cases of biomass with high energy content such as oils or – to a lower extent – wood, is disadvantageous in environmental terms. The current discussions on sustainability certification for biofuels show that not only within Europe, but all over the world we have competition for area and that especially in third countries it is hard to ensure sustainable land use.
- Policy (such as CAP) might influence results more than other parameters. The development of bioenergy depends clearly on the economy of producing biomass. However, in this context, future changes in policy can not be foreseen and thus not modelled.

4.1.1 Biomass CHP plants

The following boundary conditions apply for the future biomass CHP plants:

- **Plant size:** the size of the plants is held constant in order to avoid larger biomass inputs and thus longer transport distances necessary with increasing plant size (IFEU 2006). However, due to the fact that the syngas quality for fuel cell usage has to be different from that for use in internal combustion engines, the size of the gasifier had to be adapted to the data available.
- **Efficiency:** the electrical efficiency of the steam turbine depends on the type of steam turbine (backpressure or extracting condensing, IFEU 2006 on the basis of different sources). In the case of higher electrical efficiencies, lower total efficiencies are gained (IFEU 2006).
- **Life time:** life time is held constant on a low level. This is in order to rather overestimate plant construction and dismantling which is of less importance with respect to the fuel (biomass) expenditures.
- **Emissions:** particulate matter (PM_{10}) and CO emissions are reduced as described in section 3.4.2. Other emissions are changing according to the combustion efficiency (if inventory-related) or remain constant.

The bioenergy technology data is summarised in Table 15. Since the gasification life cycle in the future scenarios incorporates a fuel cell being investigated in WP 9, the data given for the future development of the gasification, as far as applicable, refer only to the gasifier, not to the fuel cell.

Table 15: overview of all future bioenergy CHP plants in the different scenarios

Parameter	**Unit**	**2000**		**Scenarios**	**2025**		**2050**	
		Steam turbine	**Gasifier / engine**		**Steam turbine**	**Gasifier**	**Steam turbine**	**Gasifier**
Size	MW$_{el}$	6	4	"pessim."	6	n/yr	6	n/yr
				"opt.-real."	6	n/yr	9	n/yr
				"very opt."	9	n/yr	9	n/yr
Electrical efficiency	%	20	25 (gasifier eff.: 78)	"pessim."	20	n/yr	20	n/yr
				"opt.-real."	20	(77)	30	(78)
				"very opt."	30	(78)	30	(79)
Thermal efficiency	%	65	53	"pessim."	65	n/yr	65	n/yr
				"opt.-real."	65	n/yr	50	n/yr
				"very opt."	50	n/yr	50	n/yr
Life time	a	15	15	"pessim."	15	15	15	15
				"opt.-real."	15	15	15	15
				"very opt."	15	15	15	15
Electricity production	GWh$_{el}$/yr	48	24	"pessim."	48	n/yr	48	n/yr
				"opt.-real."	48	n/yr	72	n/yr
				"very opt."	72	n/yr	72	n/yr
Full load hours	h/yr	8,000	6,000	"pessim."	8,000	6,000	8,000	6,000
				"opt.-real."	8,000	6,000	8,000	6,000
				"very opt."	8,000	6,000	8,000	6,000
PM, CO emissions	%	100	100	"pessim."	100	n/yr	100	n/yr
				"opt.-real."	100	n/yr	75	n/yr
				"very opt."	75	n/yr	50	n/yr
Main data sources	IFEU 2006, Hartmann/ Kaltschmitt 2002, CRES et al. 2005 and others							
n/yr	not applicable. For certain values, see Technical Reports of WP 9							IFEU 2006

4.1.2 Biomass provision

Biomass provision in the future will change caused by different effects: First of all, due to plant breeding, the yield of a crop may increase over the years. Biomass yield of **poplar** from short rotation forestry is estimated to increase by 10 % in the next 20 years ("very optimistic" scenario) and by 10 or 20 %, respectively, until 2050 ("optimistic-realistic" and "very optimistic" scenario). This is not as much as achievable with annual crops such as triticale or other cereals, but this is due to the fact that the breeding of poplar as a plant growing more slowly takes more time (IFEU 2006). Since the nutrient demand is correlated to the yield, with increasing yield the nutrient demand is assumed to increase proportionally. (Breeding towards lower nutrient content is of minor importance and not considered here.) **Straw** yield is influenced by breeding as well, however, since breeding is on grain yield, straw yield is not growing linearly. As described earlier, in 2050 an average reduction of ammonia emissions of 60 % due to improvements after nitrogen fertiliser application seems possible (IFEU 2006).

Bulk density, moisture, and energy content are not influenced by time horizon and scenarios.

Table 16: overview of all reference biomass production schemes for the current time horizon

Parameter	**Unit**	**Scenarios**	**2025**			**2050**		
			Short rotation poplar	**Wheat straw**	**Residual forest wood**	**Short rotation poplar**	**Wheat straw**	**Residual forest wood**
Yield	$\frac{\text{t f.m.}}{\text{ha} \cdot \text{yr}}$	"pessim."	20	8	3.5	20	8.5	3.5
		"opt.-real."	20	8	3.5	22	8.5	3.5
		"very opt."	22	8	3.5	24	8.5	3.5
Bulk density	kg/m³ (f. m.)	"pessim."	464		332	464		332
		"opt.-real."	464		332	464		332
		"very opt."	464		332	464		332
Moisture at harvest (wet basis)	%	"pessim."	50	15	50	50	15	50
		"opt.-real."	50	15	50	50	15	50
		"very opt."	50	15	50	50	15	50
Moisture at combustion / gasification	% (wet basis)	"pessim."	30 / 20	15 / –	– / 20	30 / 20	15 / –	– / 20
		"opt.-real."	30 / 20	15 / –	– / 20	30 / 20	15 / –	– / 20
		"very opt."	30 / 20	15 / –	– / 20	30 / 20	15 / –	– / 20
LHV at combustion / gasification	MJ / kg (f. m.)	"pessim."	13.0 / 13.6	13.7 / –	– / 14.5	13.0 / 13.6	13.7 / –	– / 14.5
		"opt.-real."	13.0 / 13.6	13.7 / –	– / 14.5	13.0 / 13.6	13.7 / –	– / 14.5
		"very opt."	13.0 / 13.6	13.7 / –	– / 14.5	13.0 / 13.6	13.7 / –	– / 14.5
Ammonia emissions from field	% of 2005	"pessim."	100	100	100	40	40	40
		"opt.-real."	100	100	100	40	40	40
		"very opt."	100	100	100	40	40	40
Main data sources	IFEU 2006, Hartmann/ Kaltschmitt 2002, CRES et al. 2005, Luger 2002, and others							

IFEU 2006

4.2 Economic data

Based on the bottom-up assessment of cost development for biomass technologies for electricity generation as outlined in chapter 3.5, the following cost development can be derived for the considered current technologies biomass CHP with steam turbine and biomass CHP based on gasification and internal combustion engine (Table 17).

Table 17: Scenario-dependent cost development for the biomass electricity generation technologies considered in NEEDS

Parameter	**Unit**	**Scenarios**	**2025**		**2050**	
			Steam turbine	**Gasifier**	**Steam turbine**	**Gasifier**
Spec. investment costs (overnight capital costs)	[€/kW$_e$]	“pessim.”	2,500	2,250	2,500	2,150
		“opt.-real.”	2,500	2,150	2,150	2,050
		“very opt.”	2,150	2,000	1,900	1,900
- Construction technology	[€/kW$_e$]	“pessim.”	2,000	1,850	2,000	1,750
		“opt.-real.”	2,000	1,750	1,650	1,650
		“very opt.”	1,650	1,600	1,400	1,500
- Mechanical technology	[€/kW$_e$]	“pessim.”	350	200	350	200
		“opt.-real.”	350	200	350	200
		“very opt.”	350	200	350	200
- Electric and control systems	[€/kW$_e$]	“pessim.”	150	200	150	200
		“opt.-real.”	150	200	150	200
		“very opt.”	150	200	150	200
Spec. demolition costs	[€/kW$_e$]	“pessim.”	3	3	3	3
		“opt.-real.”	3	3	3	3
		“very opt.”	3	3	3	3
Fixed costs of operation	[€/(kW$_e$ · yr)]	“pessim.”	188	169	188	161
		“opt.-real.”	138	118	118	113
		“very opt.”	97	90	88	88
Other variable costs	[€/MWh$_e$]	“pessim.”	7.5	7.5	7.5	7.5
		“opt.-real.”	7.5	7.5	7.5	7.5
		“very opt.”	7.5	7.5	7.5	7.5

IER 2006

5 Results for future technology configurations

5.1 Key emissions and land use

A “minimum air pollutant list” to be used for the external cost assessment was defined between RS 1a and RS 1b. The most relevant emissions related to the biomass power plants are shown in the annex in a comprehensive way. The emissions shown in Figure 2 were analysed to be relevant for the biomass power plant technology. They are referring to electricity delivered to the grid and the respective amount of process heat from CHP, allocated by exergy to one kilowatt hour electricity.

In Figure 2 short rotation poplar and straw as energy crops are compared regarding their emissions. For the comparison, the total amount of emissions and the contribution of different production steps have to be regarded separately. Therefore, the bars in Figure 2 are disaggregated into the different processing steps (construction, operation, fuel, dismantling).

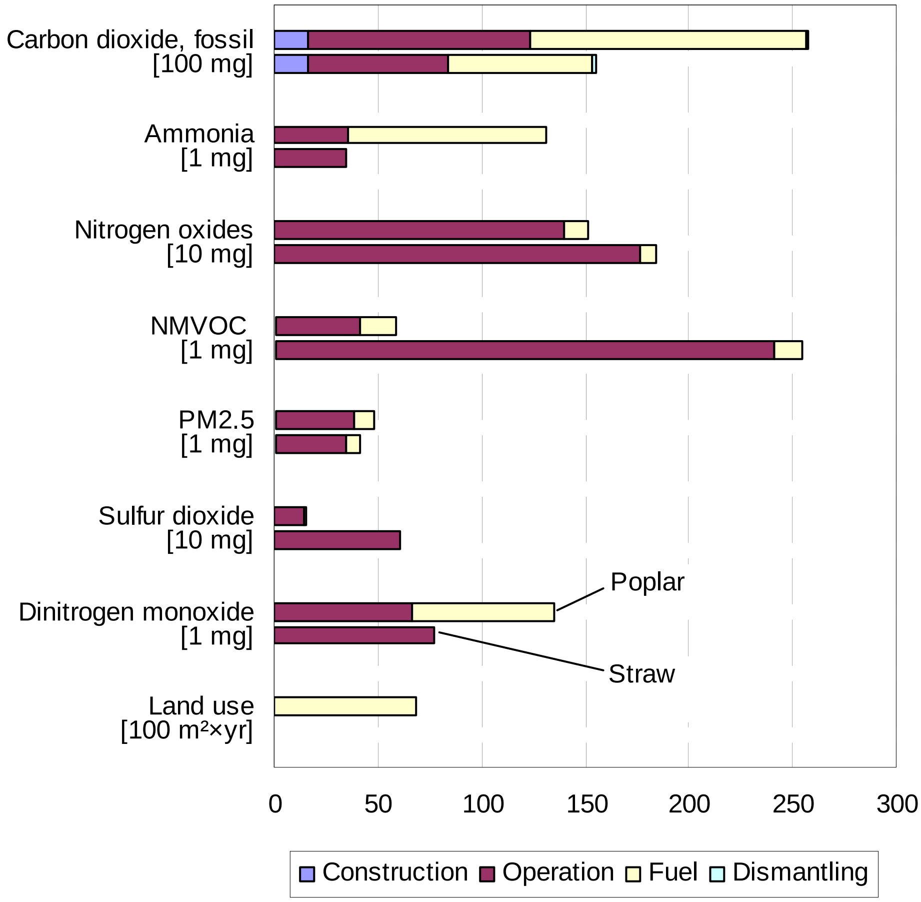

Figure 2: parameter analysis for steam turbine CHP plants fired with short rotation poplar and straw (‘realistic-optimistic’ scenario 2025) per kWh_{el}

5.1.1 Parameter analysis

The specific **land use** (occupation of agricultural and forestal area) is much higher for the short rotation poplar in comparison to straw. This is due to the fact that setting up energy crops has a rather high specific land demand compared to the area needed for storage, the combustion plant itself, etc. whereas to residual materials such as straw or forest wood no land use is assigned. In the case of energy crops, land use is of restricting importance within Europe and elsewhere in the world since the production of energy crops increasingly competes with alternative uses of the agricultural and forestal areas. Most important competitors are traditional food production, the use of wood for construction and pulp production or emerging uses of biomass like crops for transport biofuels, biobased material, green power and green heat. Also sustainability goals like the EU Habitats Directive or Birds Directive compete for agricultural and forestal land area.

Apart from land use, many emissions are strongly influenced by the type of biomass used. Energy crops such as short-rotation poplar, miscanthus or whole-plant cereals need nutrients for their growing. Nitrogen is one of these nutrients and agriculture typically provides it by means of synthetic fertilisers. The production of these fertilisers is highly energy-intensive and thus results in **fossil carbon dioxide** emissions. Furthermore, **ammonia** and **dinitrogen monoxide** (laughing gas) are emitted during fertilizer production and after application on the field due to microbial activities of certain nitrogen compounds in the soil. All three emission categories are higher for short rotation poplar than for straw. As straw is regarded as residual material, no fertilizer use is assigned. In addition to fertilizer production and application also the transport has an influence on the higher fossil carbon emissions in the case of poplar as it is transported at a higher humidity.

For **nitrogen oxides** and **sulphur dioxide**, there too are to some extent differences between the woody biomass (poplar) and the herbaceous biomass (straw). In direct combustion, the content of sulphur and other matter in the biomass directly influences the emissions. With respect to woody biomass, straw has a higher content of sulphur. Therefore the emissions of sulphur dioxide from straw combustion in the steam turbine are higher than from poplar combustion. The same is – to a lesser extent – valid for nitrogen. With its higher nitrogen content, straw shows also slightly higher nitrogen oxide emissions in the steam turbine CHP production than poplar.

Both **non-methane volatile organic compounds** (NMVOC) and **fine particulate matter** ($PM_{2.5}$) are generated during the combustion process. Whereas $PM_{2.5}$ do not differ very much between the different bioenergy paths, NMVOC are much higher for straw usage than for wood usage. The reasons are differences in the type of combustion processes. Wood can be burned in a circulating fluidised-bed burner whereas straw needs a moving-grate stoke, a cigar burner or other technologies leading to rather high NMVOC emissions.

5.1.2 Contribution analysis

Generally spoken, the **construction** phase and the **dismantling** of the bioenergy plants do not influence the results very much as compared to the influence of the operation and fuel production phases. This is due to the fact that the supply of energy crops requires some input (unlike solar energy or wind) and, due to the necessity of some kind of combustion, also the operation causes significant emissions. All investigated gaseous emissions regarding construction and dismantling contribute to hardly more than 10 % or less to the life cycle emissions.

Emissions mainly influenced by the **fuel crop production** are fossil carbon dioxide, ammonia and dinitrogen monoxide. They are released from fertilised fields and from nitrogen fertiliser production. These emissions have a significant share in fuel production for the short-rotation poplar case, whereas in the straw path, their share in fuel production is nearly invisible. As stated above, straw is regarded as residual material and therefore no fertilizer is assigned. As only agricultural and forestal areas have been regarded, land use only occurs in the fuel production phase for poplar. For straw as a residual material no land use has been assigned.

The emissions mainly influenced by the **operation** phase can be distinguished easily: nitrogen oxides, non-methane volatile organic compounds (NMVOC), fine particulate matter ($PM_{2.5}$) and sulphur oxides. These are mainly emissions that occur during combustion processes. There are significant differences between straw and poplar which have already been explained.

There may be a good potential to reduce emissions in the future. The right choice in biomass to be used in a bioenergy path could reduce emissions such as sulphur dioxide and nitrogen oxides. The related choice of the combustion technology could reduce NMVOC. In the next paragraph future pathways of bioenergy technologies are analysed with regard to their influence on land use and emissions.

5.2 Future development

The future development of emissions and land use highly depends on the implementation of new technologies and/or changes in the legal set-ups. Major improvements could be higher technical efficiencies in power plants, higher yields in the bioenergy crop production and the implementation of emission-reducing technologies due to stricter laws.

Land requirement for the production of bioenergy crops will decrease in future. Due to plant breeding, the yields of poplar may increase by 20 % until 2050. This will significantly reduce the **land use** for the required amount of biomass for energy production.

Apart from land use, also emissions will be reduced to varying extents. With the adoption of the far more efficient extracting condensing turbines the production of one kilowatt hour electricity will require less biomass. The reduced input of biomass will lead to a relative reduction of **all emissions**. In the case of **fossil carbon dioxide, ammonia** and **fine particulate matter** ($PM_{2.5}$) additional measures will lead to further emission reductions. Filters will reduce emissions of $PM_{2.5}$ and improved fertilizing methods will have a positive impact on the ammonia emissions from fields. The future legal set-up will play a big role in giving incentives for the implementation of these methods and measures.

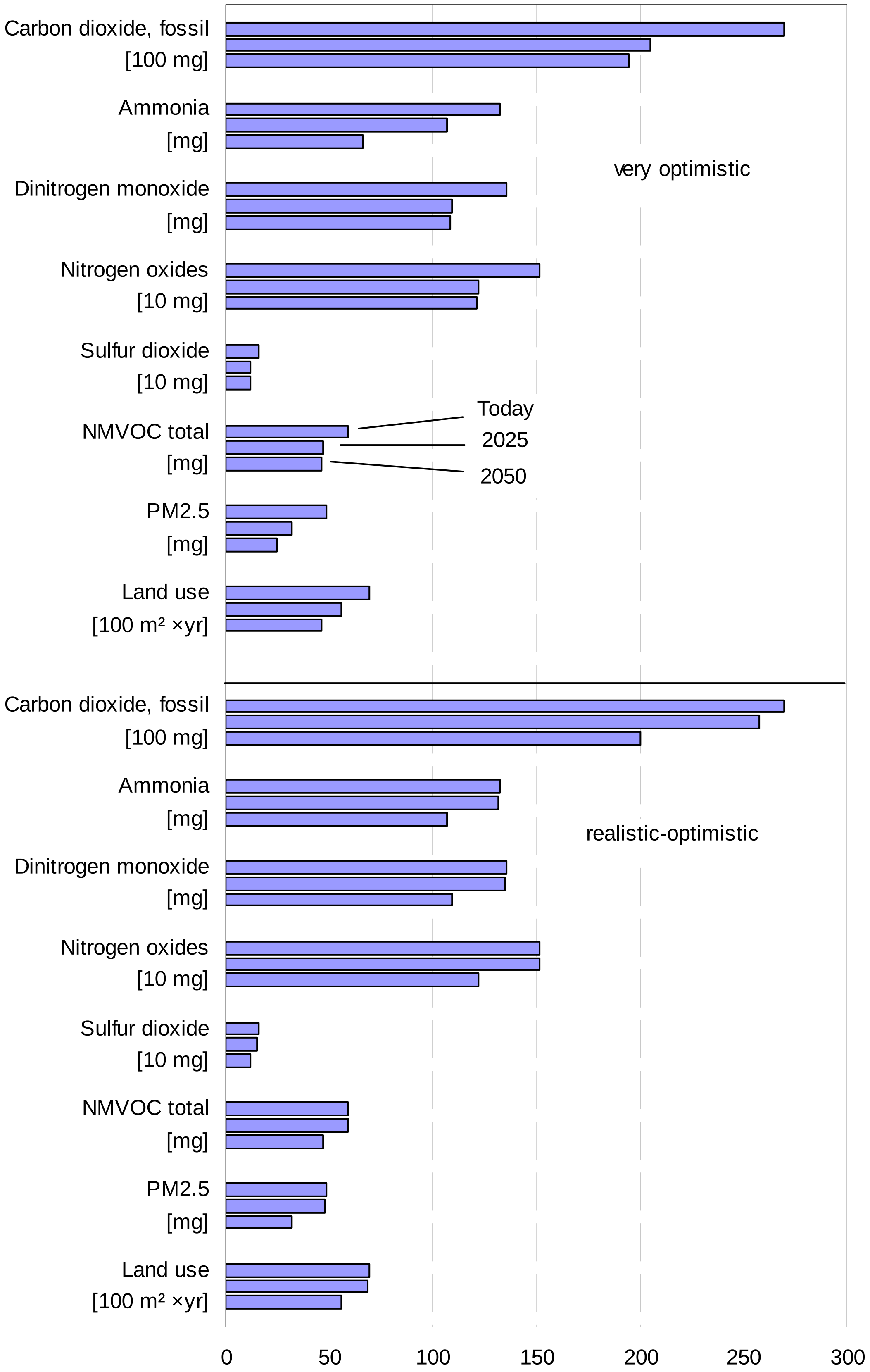

Figure 3: future development pathways for the ‘very optimistic’ and the ‘realistic-optimistic’ scenario regarding poplar in steam-turbine CHP plants, per kWh_{el}

In Figure 3, future developments of relevant emissions and the land use are demonstrated by means of poplar. In the case of straw the same future technological and legislative changes have been assumed. Therefore, the future relations between emissions of straw and poplar are comparable to those displayed in Figure 3.

The future development pathways are shown for two of three analysed scenarios (very optimistic, optimistic-realistic, pessimistic). The scenarios differ with regard to the time frame of the implementation of new technologies. In the ‘very optimistic’ scenario improved technologies will be introduced already in 2025, in the ‘realistic-optimistic’ scenario they will be introduced in 2050 and in the ‘pessimistic’ scenario they will not be introduced at all. As no significant changes in emissions can be expected without the implementation of new technologies, the ‘pessimistic’ scenario is not shown in Figure 3.

In the ‘very optimistic’ scenario, developments through technical improvements are thought to occur mainly before 2025. Therefore, hardly any emission changes occur between 2025 and 2050. Exemptions are carbon dioxide, ammonia and PM2.5 emissions due to further legal restrictions in 2050 and a reduced land use due to a further yield increase in 2050. In the ‘realistic-optimistic’ scenario, changes occur between 2025 and 2050 with the implementation of new technologies.

As power plants require the input of electricity, the origin of this electricity might have an influence on the emissions of the power plants. Three possibilities have been regarded. The ‘440 ppm’ mix is analysed as standard in all three above mentioned scenarios. It aims at limiting the CO_2 emissions to 440 ppm in order to limit the global warming to 2 °C. As comparison a ‘business as usual’ scenario is regarded in the pessimistic scenario and a scenario where electricity is provided purely by renewable energy is regarded in the optimistic scenario. However, only very slight differences occur. The influence of the electricity’s origin on the emissions of bioenergy paths can be neglected.

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7 Annex

Parameter	Path	Unit	Scenario	2025		2050	
				ST po	**ST st**	**ST po**	**ST st**
				kWh$_{el}$	**kWh$_{el}$**	**kWh$_{el}$**	**kWh$_{el}$**
Ammonia	air	kg	Pessim.	1,31E-04	3,52E-05	8,18E-05	3,52E-05
			Opt.-real.	1,31E-04	3,52E-05	1,07E-04	2,84E-05
			Very opt.	1,07E-04	2,84E-05	6,59E-05	2,83E-05
CO$_2$, fossil	air	kg	Pessim.	2,59E-02	1,56E-02	2,55E-02	1,54E-02
			Opt.-real.	2,58E-02	1,55E-02	2,00E-02	1,20E-02
			Very opt.	2,05E-02	1,22E-02	1,95E-02	1,19E-02
N$_2$O	air	kg	Pessim.	1,35E-04	7,75E-05	1,35E-04	7,75E-05
			Opt.-real.	1,35E-04	7,75E-05	1,09E-04	6,25E-05
			Very opt.	1,09E-04	6,25E-05	1,09E-04	6,25E-05
NO$_x$	air	kg	Pessim.	1,51E-03	1,84E-03	1,52E-03	1,84E-03
			Opt.-real.	1,51E-03	1,84E-03	1,22E-03	1,48E-03
			Very opt.	1,22E-03	1,49E-03	1,22E-03	1,48E-03
NMVOC	air	kg	Pessim.	5,92E-05	2,55E-04	5,91E-05	2,55E-04
			Opt.-real.	5,91E-05	2,55E-04	4,74E-05	2,05E-04
			Very opt.	4,74E-05	2,05E-04	4,66E-05	2,05E-04
PM$_{2.5}$	air	kg	Pessim.	4,82E-05	4,16E-05	4,84E-05	4,16E-05
			Opt.-real.	4,80E-05	4,14E-05	3,17E-05	2,68E-05
			Very opt.	3,17E-05	2,68E-05	2,46E-05	2,17E-05
SO$_2$	air	kg	Pessim.	1,55E-04	6,11E-04	1,55E-04	6,11E-04
			Opt.-real.	1,54E-04	6,10E-04	1,23E-04	4,91E-04
			Very opt.	1,24E-04	4,92E-04	1,22E-04	4,91E-04

Table 18: minimum air pollutant list of the reference plants (current time horizon)