VLEEM II

Monograph on Biomass

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1 Introduction

The aim of this monograph is to provide basic information on the

- potential
- technologies
- and future development options

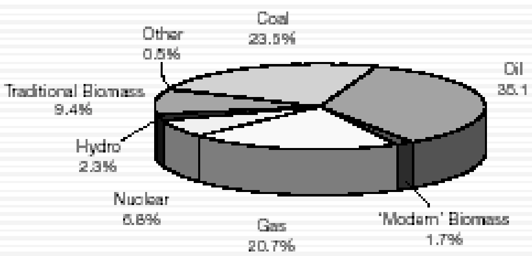
of biomass technologies.

2 Biomass: General Overview and World Outlook

Biomass is plant or animal matter. Using biomass (or fuels or wastes derived from biomass) as a source of energy entails burning it to yield heat that can then drive engines or generate electricity. The energy in biomass is chemical in nature; it does not suffer from the problem of intermittence that is inherent to wind and solar resources. In this respect, biomass more nearly resembles fossil fuels than it does other renewables. Indeed, geologists tell us that fossil fuels are simply fossilized biomass.

For most of recorded history, biomass was mankind's principal energy source, mainly in the form of wood used for cooking and heating and as foods to "fuel" human labour and beasts of burden. With the industrial revolution, fossil fuels captured this dominant role. Today biomass still accounts for over 11% of worldwide primary energy consumption (see Figure 1-1).

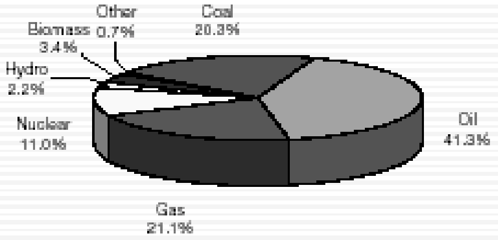
FIGURE 1-1: PRIMARY ENERGY SOURCES IN THE WORLD, BY SOURCE, 1999



Population: 5.9 billion
Total energy use: 9,700 Mtoe (million tonnes of oil equivalent)
Per capita energy use: 1.6 toe per capita

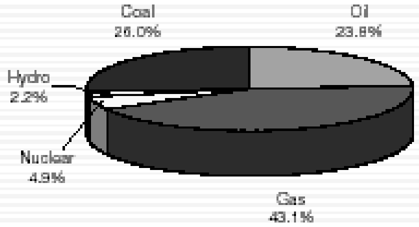
The distribution of primary energy sources varies between industrialised, transition, and developing countries. Today in developing countries, biomass is a significant source and accounts for one fourth to one third of all energy consumption. On the other hand, the use of biomass in transition-economy countries is nearly non-existent. In industrialised nations, the share of biomass as an energy source is relatively low with 3-4%. The Figures 1-2 to 1-4 illustrate the distribution of primary energy sources in the three different categories in 1999.

FIGURE 1-2: PRIMARY ENERGY SOURCES IN INDUSTRIALISED COUNTRIES, BY SOURCE, 1999



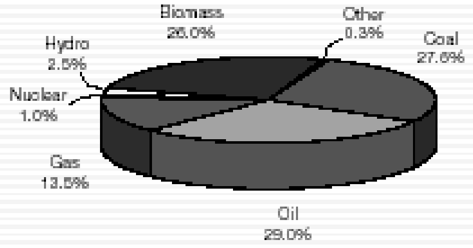
Population: 1.1 billion
Total energy use: 5,200 Mtoe (million tonnes of oil equivalent)
Per capita energy use: 4.7 toe per capita

FIGURE 1-3: PRIMARY ENERGY SOURCES IN TRANSITION-ECONOMY COUNTRIES, BY SOURCE, 1999



Population: 0.35 billion
Total energy use: 1,000 Mtoe (million tonnes of oil equivalent)
Per capita energy use: 2.9 toe per capita

FIGURE 1-4: PRIMARY ENERGY SOURCES IN DEVELOPING COUNTRIES, BY SOURCE, 1999



Population: 4.4 billion
Total energy use: 3,500 Mtoe (million tonnes of oil equivalent)
Per capita energy use: 0.78 toe per capita

Today, biomass accounts for more than one fourth of primary energy use in developing countries, and according to some sources this figure can be as high as one third. In some of the least developed countries, the biomass share of primary energy exceeds 90%. It has been called "the poor man's oil" because its direct use by combustion for domestic cooking and heating ranks it at the bottom of the ladder of preferred energy carriers. Existing biomass-using technologies are relatively inefficient; thus, biomass provides less energy service than the proportion of total energy it represents, and women and children in rural areas spend considerable time collecting daily fuelwood needs. Biomass energy use today also contributes to indoor air pollution and associated negative health impacts. Furthermore, most biomass energy today comes from natural forests, contributing to deforestation in some countries.

Biomass Potential

Biomass has the potential to provide a much higher level of energy services, in environmentally friendly ways, if the production and conversion of biomass is modernised. Modernisation would mean that is produced and converted efficiently and cost-competitively into more convenient forms such as gases, liquids, or electricity. Then, it would not only be more widely used, but also other benefits, such as reduced indoor pollution, would ensue.

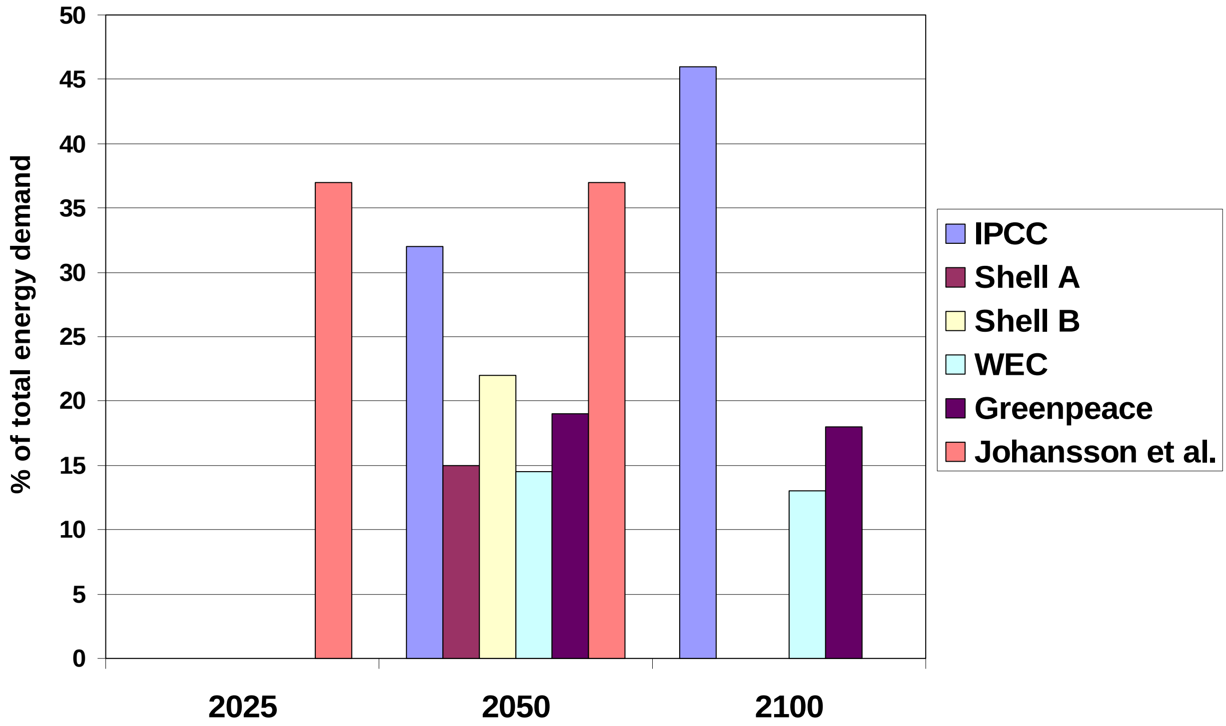
To estimate the future potential of biomass, a number of international organisations and companies have formulated energy scenarios in order to envision the potential contribution of biomass energy to the world's energy supply in the twenty-first century. The table below gives a summary of these studies. Although the percentile contribution of biomass varies considerably, the absolute potential contributions of biomass in the long term is high (ranging from about 100 to 300 EJ per year).

Potential Contribution of Biomass – Future Scenarios

Source	Time frame (Year)	Projected global energy demand (EJ/year)	Contribution of biomass to energy demand EJ/year (% of total)	Remarks
IPCC (1996)	2050 2100	560 710	180 (32%) 325 (46%)	Biomass intensive energy system development
Shell (1994)	2060	1500 900	220 (15%) 200 (22%)	-Sustained growth* -Dematerialization+
WEC (1994)	2050 2100	671-1057 895-1880	94 – 157 (14 – 15%) 132 – 215 (15 – 11%)	Range given reflects the outcome of three scenarios
Greenpeace (1993)	2050 2100	610 986	114 (19%) 181 (18%)	Fossil fuels are phased out during the 21st century
Johansson et al. (1993)	2025 2050	395 561	145 (37%) 206 (37%)	RIGES model calculation

These scenarios are also illustrated by the graph below.

Potential Contribution of Biomass – Future Scenarios



Such visions of large contributions by biomass to global energy supply are plausible because ongoing technological advances offer the promise of being able to turn biomass into more desirable forms of energy (such as electricity and liquid and gaseous fuels) in ways that are both environmentally friendly and economically competitive with fossil fuel alternatives. These technological advances are of comparable significance to the fundamental technological developments (steam turbines and internal combustion engines) that were largely responsible for the expansive growth in global fossil fuel use that began late in the nineteenth century.

Because populations are growing, an important question is whether there are sufficient land resources to both feed future populations and sustain the magnitude of biomass energy development implied by the different scenarios.

Using Degraded Lands for Biomass Energy

To help insure a minimum of competition between agriculture and energy production, a number of analysts have proposed that developing countries target degraded lands for energy production. Grainger and Oldeman et al. have estimated that developing countries have over 2,000 million hectares of degraded lands, and Grainger estimates that some 621 million of these are suitable for reforestation. This is consistent with estimates that previously forested area suitable for reforestation amounts to 500 million hectares, with an additional 365 million hectares available from land in the fallow phase of shifting cultivation.

3 Potential of Biomass and Waste of EU-15 Countries

3.1 Introduction

This Chapter focuses on the potential of biomass and waste in the EU-15 countries. Each of the EU-15 countries is analysed to a certain extent (except Luxembourg, which is included in the overview of Belgium). The analysis shows the current use of biomass, the potential of biomass products from e.g. forests and agriculture, the potential of waste (for power generation) and the potential of energy crops. The time horizon is 2050. As far as possible, the potential of these categories of biomass and waste is disaggregated. However, the purpose of the analysis is not so much to give an in-depth analysis of biomass and waste of each EU-15 country, but to present a broad overview of biomass potentials within the EU-15 countries with the time horizon of 2050.

The EU-15 countries are presented in alphabetical order. At the end of the Chapter, the potential of biomass and waste by EU-15 country is summarised. The summary does not have the intention to give a direct relation with the primary energy demand in the timeframe 2000-2050, as scenarios until 2050 show a wide divergence with regard to total primary energy demand.

3.2 Austria

3.2.1 Introduction

Austria is one of the EU-15 countries with a large share of biomass in total primary energy use. §1.2.2 gives a condensed view of the technical potential of biomass, waste, and energy crops.

3.2.2 Technical potential of biomass, waste, and energy crops

In 2001, the use of biomass and waste amounted to 144 PJ (11% of the primary energy use). Table 1.1 shows that biomass, waste, and energy crops (including short rotation forestry) could provide some 200 PJ in 2010, and approximately 300 PJ in 2050 (Internet source 1).

Table 1.1 *Targets 2010 and technical potential of biomass, waste, and energy crops Austria*

	(Technical) potential biomass, waste, and energy crops [PJ]		
	2001	2010	2050
Wood products			
Forestry (including bark, saw dust)	115	151	175
Black liquor	19	19	19
Demolition wood	1	1	7
Subtotal wood products	*135*	*171*	*201*
Agricultural residues	1	9	19
Biogas (agriculture)	<1	1	16
Organic residues from industry	<1	5	24
Sewage sludge	<1	1	2
Municipal solid waste	6	8	11
Energy crops (rape, grain, etc.)	1	4	25
Short rotation forestry	<1	1	6
Total	144	200	~300

Energy from biomass represents a fraction of 11-12% of the total primary energy consumption. Particularly wood and wood products are used in several sectors:

- Residential buildings (space heating and hot water).
- Paper and pulp industry (electricity and process heat).

- Wood processing industry (utilisation of waste wood, saw dust, etc.).

In the aforementioned publication the area needed for short rotation forestry and energy crops is not provided. According to EECInetwork (Internet source 2), 3,800 ha were used for production of rape seed for biodiesel, and only 100 ha for short rotation forestry. There are two estimates of the potential of energy crops in Austria (Table 1.2).

Table 1.2 *Estimates of potential of energy crops Austria*

Category	Area available [million ha]	(Technical) potential energy crops [PJ]
EECINetwork	0.15	22
De Noord *et al*, 2004	0.162	31

According to (De Noord *et al*., 2004) the potential of energy crops would be 31 PJ, based on an area available of 0.162 million ha. The figure of 25 PJ (Table 1.1) is equivalent to 0.13-0.17 million ha. The area used for agriculture is 3.47 million ha. Therefore, the figure 25 PJ would imply that 4-5 percent of the agricultural land would be used for energy crops. This seems to be realistic.

3.3 Belgium and Luxembourg

3.3.1 Introduction

Currently, biomass and waste are used in Belgium only to a limited extent. The use and potential of biomass and waste of Luxembourg is still more limited; it has been included in this section on Belgium. The potential of biomass, waste, and energy crops is highlighted in §1.3.2.

3.3.2 Tentative estimate of technical potential biomass, waste, and energy crops

The biomass resources of Belgium and Luxembourg are far from being exploited to their limits. In 2000, biomass and waste accounted for 24 PJ. Table 1.3 shows the potential of biomass, waste, and energy crops, partly based on the report of the AMPERE commission (Internet source 3) and on (Internet source 4). The technical potential of biomass, waste, and energy crops could be 155-185 PJ. The area for energy crops and reforestation is estimated at 0.2 million ha, one-sixth of the area that was deemed available by the AMPERE commission[1].

Table 1.3 *Tentative estimate of technical potential biomass, waste, and energy crops Belgium[1]*

	(Technical) potential biomass, waste, and energy crops [PJ] 2000	2050
Wood products (industrial by-products, black liquor)	} 16	30
Agricultural residues		15
Industrial residues		10
Biogas (agricultural residues, sewage treatment, landfill gas)	1	75
Municipal solid waste[2]	7	15
Energy crops and reforestation (≤0.2 million ha)	P.M.	35
Total	24	180

1 Data refer to Belgium and Luxembourg.
2 Figures based on energy content of biomass and waste, with correction for waste based on fossil fuels.

(De Noord *et al*., 2004) assume a potential of energy crops of about 3 PJ, based on a land area of 14,000 ha. This is 1 percent of the agricultural land (1.544 million ha). The estimate of 35 PJ in Table

[1] The report of the AMPERE commission gives an estimate of the potential of biomass, waste, and energy crops of 360-400 PJ. The commission, however, assumes that 1.2 million ha (equivalent to 240 PJ) would be used for energy crops.

1.3 is based on the assumption that ≤0.2 million ha is used for energy crops and reforestation, or 13 percent or less of the agricultural area. This is highly ambitious, but possibly achievable.

3.4 Denmark

3.4.1 Introduction

Renewable energy is central to the energy objectives of the Danish government. §1.4.2 presents the main figures and targets with respect to biomass, waste, and energy crops in Denmark.

3.4.2 Technical potential of biomass, waste, and energy crops

In 1996, the Danish government endorsed the current energy strategy, 'Energy 21' (Internet source 5). According to this plan, the contribution of renewable energy to the total energy use will rise to 35% (235 PJ) in 2030. Figure 1.1 shows a graphical presentation of the targets for renewable energy.

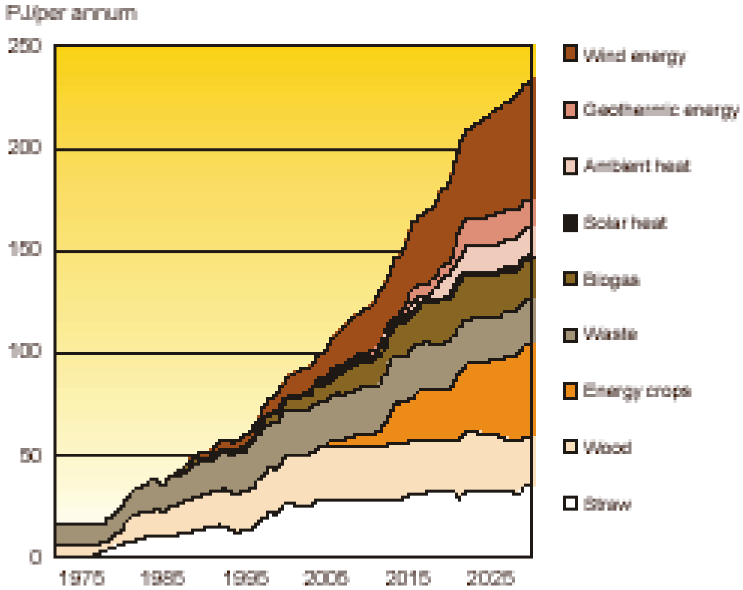


Figure 1.1 *Renewable energy use in Denmark projected in 'Energy 21'*

'Energy 21' (1996) sets targets for biomass, waste, and energy crops in Denmark, amounting to 88 PJ in 2005, and 145 PJ in 2030. These targets may be met in the following way (Table 1.4).

Table 1.4 *Biomass, waste, and energy crops in Denmark according to 'Energy 21' (1996)*

<table>
<tr><th></th><th colspan="3">(Technical) potential biomass, waste, and energy crops [PJ]</th></tr>
<tr><th></th><th>2000</th><th>2005</th><th>2030</th></tr>
<tr><td>Small-scale plants</td><td rowspan="2">37</td><td>19</td><td>11</td></tr>
<tr><td>Large-scale plants</td><td>36</td><td>80</td></tr>
<tr><td>Biogas</td><td>3</td><td>9</td><td>30</td></tr>
<tr><td>Municipal solid waste[1]</td><td>24</td><td>24</td><td>24</td></tr>
<tr><td>Total</td><td>64</td><td>88</td><td>145</td></tr>
</table>

1 Figures based on energy content of biomass and waste, with correction for waste based on fossil fuels.

In 1997, 21 PJ of wood was used for energy purposes, mainly for combined heat and power (CHP). Currently, only 700 ha are used for growing energy crops. Wood, straw, and waste, will be gradually supplemented by energy crops after 2005. According to 'Energy 21' energy crops will contribute 45 PJ - based on an area of 0.3 million ha - in 2030 (Internet source 6, 7).

There are two estimates of the potential of energy crops in Denmark (Table 1.5).

Table 1.5 *Estimates of potential of energy crops Denmark*

Category	Area available [million ha]	(Technical) potential energy crops [PJ]
'Energy 21'	0.30	45
De Noord *et al*, 2004	0.126	23

The figure of 45 PJ in 2030 from 'Energy 21'is a rather firm estimate. This amount of energy crops would imply that 0.3 million ha would be used for energy crops, equivalent to 11 percent of the agricultural land (2.689 million ha). This is ambitious, but possibly achievable.

3.5 Finland

3.5.1 Introduction

Finland is one of the EU-15 countries with the highest share of biomass in total primary energy use (18.5% in 1997). According to recent plans, this share will increase further (§1.5.2).

3.5.2 Technical potential of biomass and waste

The 'Action Plan for Renewable Energy Sources in Finland' (2000) (Internet source 8, 9) calls for an increase of 50% of the use of renewable energy in 2010, and a doubling of the use of renewable energy in 2025 compared to 1995. This may be achieved as follows (Table 1.6).

Table 1.6 *Targets and technical potential biomass (and waste) in Finland cf. Action Plan*

	(Technical) potential biomass and waste [PJ] 2000	2010	2025
Industry (including bark, black liquor)	280 (Industry, District heating and Small-scale use combined)	218	255
District heating		41	75
Small-scale use (e.g. wood)		66	90
Municipal solid waste[1]	2	5	5
Total	282	330	425

1 Figures based on energy content of biomass and waste, with correction for waste based on fossil fuels.

In 2000, the total amount of wood based fuel was approximately 280 PJ. Combined heat and power (CHP) production is a natural choice in Finland since industry and municipalities need both heat and electricity. Thus most of the biomass-based energy originates from CHP plants.

Biomass and waste could provide 425 PJ, which is 30% of the primary energy use projected for the year 2025 (1,420 PJ). This estimate is in alignment with Spitzer (Internet source 11), who analysed the fuel wood potential of European countries. According to this source, Finland would have a potential of 350 PJ, excluding black liquor, etc.

Presently, approximately 1000 ha are used for energy crops (Internet source 10). (De Noord *et al.*, 2004) assume that the potential of energy crops is 15 PJ, based on approximately 0.1 million ha. This is equivalent to 4 to 5 percent of the agricultural land (2.259 million ha). The potential of biomass and waste of Table 1.6 (425 PJ) could fulfil 30% of the primary energy demand in 2025 in a cost-effective way. Therefore, energy crops seem to be of minor importance to Finland.

3.6 France

3.6.1 Introduction

Wood energy comprises 4% of the primary energy use of France. The focus is mainly on the use of (fuel) wood in industry and households. §1.6.2 presents the potential of biomass and waste.

3.6.2 Tentative estimate of technical potential of biomass, waste, and energy crops

Presently, 40 Mt of biomass is used for energy purposes, most of it as fuel wood in households and industry. Total 6.3 million households use wood stoves for heating applications.

Table 1.7 presents a tentative estimate of the technical potential of biomass, waste, and energy crops (about 1,350 PJ) that is partly based on (Internet source 12, 13).

Table 1.7 *Tentative estimate of technical potential biomass, waste, and energy crops France*

	(Technical) potential biomass, waste, and energy crops [PJ]		
	2000	Remaining potential	Technical potential
Wood products			
Standing forest	385 (Standing forest, Forest residues, By-products of industry)	140	575 (Standing forest, Forest residues, By-products of industry)
Forest residues		35	
By-products of industry		8	
Wood waste		7	
Agricultural residues (including waste)	P.M.	100	100
Anaerobic digestion	7	93	100
Municipal solid waste	76	P.M.	75
Energy crops & reforestation (≤3 Mha)	P.M.	500	500
Total	468	882	1,350

The technical potential of fuel wood - 575 PJ according to Table 1.7 - is in close agreement with an estimate by Spitzer (Internet source 11), viz. 540 PJ. Other categories - agricultural residues (mainly straw), materials for digestion, and energy crops - have been estimated very tentatively. (De Noord *et al*., 2004) assume a potential of energy crops of 280 PJ, based on 1.4 million ha. This would imply that 4-5 percent of the agricultural land (29.972 million ha) would be used for energy crops. The figure of 500 PJ (Table 1.7) is equivalent to ≤3 million ha, or 10 percent of the agricultural land. This is rather ambitious, but possibly achievable.

3.7 Germany

3.7.1 Introduction

The potential of Germany is based on Kaltschmitt *et al.* (Internet source 14), who distinguish:
(1) Straw, residues and residual products (§1.7.2).
(2) Woody biomass (§1.7.3).
(3) Biogas (§1.7.4).
(4) Energy farming (§1.7.5).
In §1.7.6, the potential of biomass, waste, and energy crops of Germany is summarised.

3.7.2 Straw, residues, and residual products

This category includes straw and other residues and residual products that may be used for energy purposes, e.g. biomass from maintenance of landscape, public gardens, roadsides, etc.

Straw

Straw generating crops like grain, maize, and oilseeds are grown on 7.7 – 8.1 million ha. Today, the use of straw for energy is marginal. Taking into account competing needs like ground cover, 20% of the straw – 20% of the straw from oil seeds, 15% of the straw from maize, and 30% of the remaining straw (mainly from grain) – is assumed to be available for energy. Assuming that 8.1 million ha is used for grain, maize and oilseeds, the technical potential amounts to 130 PJ.

Biomass from landscape maintenance
Biomass from landscape maintenance includes material from public gardens, sports fields, and roadsides. In case of landscape maintenance, 25-50% of the material is deemed available, and for the balance ⅓ to ⅔. This category has a technical potential of 10-20 PJ (Table 1.8).

Table 1.8 *Technical potential of straw, residues, and residual products Germany*

Category	Contents	Technical potential [PJ]
Straw	Straw from grain, maize, oilseeds	130
Landscape maintenance	Biomass from landscape maintenance, etc.	*10-20*
Total		130

Note Italics (biomass from landscape maintenance): more suitable for anaerobic digestion than as a fuel.

3.7.3 Woody biomass
This category includes wood from forests and landscape maintenance, residual industrial wood, and residual wood from end use.

Wood from forests and landscape maintenance
In Germany 10.7 million ha is forested, 66% of which is coniferous forest and 34% deciduous forest. Most of the forest is cultivated and used for wood production (industrial wood products). The technical energy potential of thin wood is 130 PJ, and that of forest residues 178 PJ. Thus, the technical energy potential of thin wood and forest residues is approximately 308 PJ.

About 15 million m^3 of fuel wood - equivalent to 140 PJ - could be made available in addition to the current amount of fuel wood. Also, wood could become available from landscape maintenance (e.g. roadsides) to the tune of 0.27 million tonnes per year, equivalent to 4.4 PJ.

Residual industrial wood
An estimated 8 million m^3 of wood products – equivalent to 65 PJ – is available as residual wood from the wood industry. In addition to the current use of residual wood (feedstock and fuel), an estimated 3.65 million tonnes per year – equivalent to 58 PJ – could become available.

Residual wood from end use
Wood may also be a residual product from end use, e.g. demolition wood. Part of it may be contaminated, but another fraction may be relatively clean wood. In Germany this category of wood is estimated at 5.1-7.2 million tonnes per year, equivalent to 80-112 PJ.

The technical potential of woody biomass is estimated at 590-620 PJ (Table 1.9).

Table 1.9 *Technical potential of woody biomass Germany*

Category	Contents	Potential woody biomass [PJ]
Wood from forests	Thin wood	130
	Forest residues	178
	Additional fuel wood	140
	Landscape maintenance	4
Residual wood		
Industrial wood		58
Wood from end use	Demolition wood, clean wood	80-112
Total		590-620

3.7.4 Biogas based on anaerobic digestion

Biogas may be produced from manure, harvesting residues, residues from the food and beverage industries, landscape maintenance, and organic waste from kitchen, garden, and marketplaces.

Manure from agriculture

The amount of manure (including manure fixed by straw) from cattle, pigs, and chicken in stables is estimated at 15.5 million tonnes, equivalent to 4.5 billion m^3 of biogas and 96 PJ. This technical potential of manure is based on a share of cattle of 82%, pigs 13%, and chicken 5%.

Residues from crop harvesting

This category includes vegetable residues from crops that may be used for anaerobic digestion (biogas production), e.g. leafs from beet and potato. Also, some part of grass from permanent pasture may be used for digestion. The technical (excluding straw) is estimated at 26-47 PJ.

Residues from the food and beverage industries

The technical potential of anaerobic digestion of residues from the food and beverage industries is estimated at 6-12 PJ.

Residues from landscape maintenance

Biomass from landscape maintenance has a technical potential of 10-20 PJ, when used as a fuel (§1.7.2). If it would be used for anaerobic digestion, the energy equivalent would be 6-12 PJ.

Organic waste from kitchen, garden, and marketplaces

The amount of organic waste from kitchen and garden is 100 kg per inhabitant. Some 90% of it - 7.4 million tonnes - could be available for anaerobic digestion. Another 0.2-0.3 million tonnes could be available from marketplaces. This category of organic waste is equivalent 12 PJ.

Sewage treatment and landfill gas

The potential of sewage treatment and industrial wastewater purification is estimated at 19 PJ, and that of landfill gas at 11-15 PJ in 2010, and 2-4 PJ in 2020.

Summary

The total technical potential of biogas, exclusive of digestion of straw (but sewage treatment and tip gas included), is estimated at 165-200 PJ in 2020 (Table 1.10).

Table 1.10 *Technical potential biogas, including sewage treatment and landfill gas, Germany*

Category	Contents	Technical energy potential [PJ]
Manure from agriculture	Cattle, pigs, and chicken in stables	96.5
Residues from harvesting	Leafs from beet and potato, grass from permanent pasture	26.5-46.6
Residues from the food and beverage industries		6-12
Residues from landscape maintenance		6-12
Organic waste from kitchen, garden, and marketplaces		12
Sewage treatment		19
Landfill gas		2-4
Total		165-200

3.7.5 Energy farming

Winter rape is currently grown on 334,000 ha for non-food purposes – mainly for production of RME, an additive for gasoline and diesel (Internet source 15). In 2000, 1.1 million ha fallow land would be available for energy farming. In is assumed that in the long term, 2 million ha would be available for energy farming.

There are three ways to utilise energy from energy crops, viz.

- Conversion into vegetable oils (mainly rape).
- Use as a solid fuel (e.g. straw or whole plants like grain).
- Anaerobic digestion (biogas).

It is assumed that one-third of the above mentioned 2 million ha is used for each of the three ways to utilise energy from energy crops. Table 1.11 shows the resulting technical potential.

Table 1.11 *Technical potential of energy crops on 2 million ha Germany*

Energy crop utilisation	Cultivated area [million ha]	Useful energy [million tonnes]	Technical energy potential [PJ]
Vegetable oils	0.67	Rape oil: 2.3	34.2
		Plant residues: 1.4	21.8
		Straw: 2.8	41.6
Solid fuel	0.67	6.9	122
Digestion	0.67	8.7	79
Total	2.00	22.1	300

There are two estimates of the potential of energy crops in Germany (Table 1.12).

Table 1.12 *Estimates of potential of energy crops Germany*

Category	Area available [million ha]	Technical potential woody biomass [PJ]
Kaltschmitt *et al.*, 2003[1]	2.0	300
De Noord *et al.*, 2004	0.806	188

1 Internet source 14.

The figure of 300 PJ implies that 2.0 million ha would be used for energy crops, equivalent to 11-12 percent of the agricultural land (17.279 million ha). This is rather ambitious, but possibly achievable.

3.7.6 Summary of the technical potential of biomass, waste, and energy crops

Table 1.13 shows the technical potential of biomass, waste, and energy crops of Germany, estimated at 1,200 – 1,250 PJ. In 2000, biomass and waste amounted to 295 PJ (IEA, 2002), with data with regard to the energy content of waste corrected for waste based on fossil fuels.

Table 1.13 *Technical potential of biomass, waste, and energy crops of Germany*

	Useful energy [Mt/a]	Useful energy, dry weight [Mt/a]	Biogas production [Mm³/a]	Technical potential [PJ/a]
Solid fuels				
Straw	9.3	7.6	-	130
Thin wood	8.4	7.0	-	130
Forest residues	11.5	9.6	-	178
Additional fuel wood	9.0	7.5	-	140
Landscape maintenance	0.27	0.2	-	4
Industrial wood	3.65	3.1	-	58
Demolition wood, etc.	5.1-7.2	4.3-6.0	-	80-112
Subtotal solid fuels	*47.2-49.3*	*39.3-41.0*	-	*720-752*
Biomass/effluents for digestion				
Manure	162	15.5	4,500	96.5
Residues from harvesting	9.7-17.7	1.7-2.9	1,300-2,100	26.5-46.6
Food and beverage industries	3.1-4.7	0.5-1.0	300-575	6.4-12.2
Landscape maintenance	0.8-1.6	0.4-0.9	280-560	6-12
Organic waste (kitchen, garden, and marketplaces)	7.65	1.5	580	12.5
Sewage treatment		2	1,950	19.5
Tip gas (2020)			200-400	2-4
Subtotal digestion	*183-194*	*22-24*	*9,100-10,660*	*165-200*
Energy crops (≤2 million ha)		22.1		300
Total				1,200-1,250

3.8 Greece

3.8.1 Introduction

Although Greece has a significant biomass potential, only a minor fraction of this potential is used at this date. §1.8.2 presents the technical potential of biomass, waste, and energy crops.

3.8.2 Tentative estimate of the technical potential of biomass, waste, and energy crops

In 2000, the contribution of biomass to the primary energy use of Greece was 40 PJ, consisting of 29 PJ of wood for domestic heating applications, and 11 PJ wood products and agricultural residues used in the wood industry and agro-industries, as well as energy utilisation of biogas.

Greece is considered one of the most erosion-affected regions of EU and the cultivation of perennial energy crops in hilly areas may significantly reduce erosion risks. Productive forests occupy 2.5 Mha or 19% of the total land area of Greece. Considering the total round wood consumption of 900,000 m^3 by the sawmills and an average of 40% residues production, large amounts of wood residues could be used for energy by the sawmills themselves. It is assumed that the technical potential of forest residues, fuel wood, etc. is 75 PJ.

According to recent estimates, 5.5-7.5 million tonnes of field crop and arboricultural residues could be exploited for energy purposes on an annual base. These residues could originate from cereals, maize, cotton, tobacco, sunflowers, loppings, vines and wood pith. It is assumed that the technical potential could be approximately 5 million tonnes, which is equivalent to 75 PJ.

Table 1.14 shows the current use of biomass and waste and a tentative estimate of the technical potential of biomass, waste, and energy crops, amounting to 225 PJ (Internet source 16).

Table 1.14 *Tentative estimate of technical potential biomass, waste, energy crops Greece*

	(Technical) potential of biomass, waste, and energy crops [PJ]	
	2000	2050
Forest residues and fuel wood		
Industrial wood residues	11	
Domestic use of fuel wood	29	
Subtotal forest residues and fuel wood	*40*	*75*
Agricultural residues	P.M.	75
Biogas (agricultural residues, landfill gas)	P.M.	10
Industrial and municipal solid waste	3	10
Energy crops & reforestation (≤0.4 Mha)	P.M.	55
Total	42	225

(De Noord *et al*., 2004) assume that the potential of energy crops is 182 PJ, based on an area of approximately 1.7 million ha. This is equivalent to 20 percent of the agricultural land (8.502 million ha). Table 1.14 presents an estimate of the potential of energy crops and reforestation of 55 PJ. This would be equivalent to ≤0.4 million ha, or about 5 percent of the agricultural land. This seems to be achievable.

3.9 Ireland

3.9.1 Introduction

Today, the use of biomass and waste in Ireland is still rather limited. However, based on recent plans the use of biomass, waste, and energy crops may be increased substantially (§1.9.2).

3.9.2 Tentative estimate of the technical potential of biomass, waste, and energy crops

Table 1.12 shows the current use of biomass, and a projection of biomass, waste, and energy crops in 2020. The technical potential of landfill gas is 20 PJ (equivalent to 300 MW), not all of which may be used (Internet source 17, 18). Recent publications indicate that the area covered by forest could be doubled by 2035 (Internet source 19). Today it stands at 0.615 million ha (Internet source 20). So, the amount of wood products could become much larger than today. The potential of biomass, waste, and energy crops is estimated at 150 PJ (Table 1.12).

Table 1.12 *Tentative estimate of technical potential biomass, waste, and energy crops Ireland*

	(Technical) potential biomass, waste, and energy crops [PJ]		
	2000	2020	2050
Landfill gas	0.9	15	
Solid residues			
From forestry and agriculture			
From industry			
Subtotal solid residues	*2.6*	*10*	*40*
Biogas	0.2	5	15
Municipal solid waste and other waste	2.2	5	10
Energy crops & reforestation (≤0.5 Mha)	P.M.	10	85
Total	5.9	45	150

According to (De Noord *et al*., 2004), the potential of energy crops is 39 PJ, based on a land area of 0.2 million ha. In the estimate of Table 1.12 it is assumed that ≤0.5 million ha would be used for energy crops and reforestation (providing 85 PJ). This would imply that 11 percent of the agricultural land (4.399 million ha) would be used for energy crops and reforestation. This seems to be rather ambitious, but possibly achievable.

3.10 Italy

3.10.1 Introduction

The use of biomass and waste in Italy is relatively modest up to now. The Italian government plans to increase the use of biomass and waste steadily (§1.10.2).

3.10.2 Potential of biomass, waste, and energy crops

Table 1.13 shows a tentative estimate of the use of biomass, waste, and energy crops in 2010 and the technical potential thereof, largely based on (Internet source 21).

Table 1.13 *Targets 2010 and technical potential of biomass, waste, and energy crops Italy*

	(Technical) potential biomass, waste, and energy crops [PJ]		
	2000	2010	2050
Forestry residues, fuel wood, and agricultural residues	51	165	300
Anaerobic digestion	5	10	40
Industrial and municipal solid waste	15	25	60
Energy crops and reforestation (≤3.0 million ha)	P.M.	P.M.	400
Total	71	200	800

According to (De Noord *et al.*, 2004), the potential of energy crops would be 423 PJ, based on an area of 2.93 million ha. This is roughly comparable with the figure of 400 PJ based on ≤2.5 million ha. An area of 2.5 million ha would imply that 16 percent of the agricultural land (15.556 million ha) would be used for energy crops. This is highly ambitious, but possibly achievable.

3.11 Netherlands

3.11.1 Introduction

Use of biomass and waste is gaining momentum in the Netherlands, although there is still a significant remaining potential. §1.11.2 gives an overview of the current use of biomass and waste, and the potential of biomass, waste, and energy crops in 2020 and the technical potential.

3.11.2 Technical potential of biomass, waste, and energy crops

There are roughly three main areas of biomass and waste conversion in the Netherlands:

- Incineration of municipal solid waste with energy recovery (mainly electricity generation).
- Combustion, in households (wood stoves), or on a larger scale – power generation or co-combustion/gasification of biomass or e.g. demolition wood in coal-fired power plants.
- Anaerobic digestion, including sewage treatment, landfill gas, etc.

Table 1.14 shows the current use of biomass and waste (2002), based on (De Jager *et al.*, 2003). The Table also shows two almost identical projections for 2020 as well as the technical potential of biomass, waste, and energy crops in 2050 (Internet source 22).

Table 1.14 *Tentative estimate of technical potential biomass, waste, and energy crops the Netherlands*

	Potential of biomass, waste, and energy crops [PJ]			
Reference	De Jager, 2003	De Noord *et al.*, 2004	Internet source 22	Internet source 22
	2002	2020	2020	2050
Industrial use of biomass (wood)	2.6			
Fuel wood in households	4.8	43	70	145
CHP (combined heat and power)	1.6			
Biogas (incl. sewage treatment, landfill gas)	5.4			
Co-combustion/gasification in power plants	9.7	72	45	55
Municipal solid waste	12.3			
Energy crops and reforestation	P.M.	6	5	50
Total	36.5[1]	121[2]	120[2]	250[2]

1 Figures based on avoided fossil fuel; 50% of waste is of organic origin (the balance is based on fossil fuel).
2 Figures based on energy content of biomass and waste, with correction for waste based on fossil fuels.

According to (De Noord *et al.*, 2004) biomass residues would be 43 PJ and biomass waste 72 PJ in 2020. The sum of biomass residues and biomass waste would be 115 PJ in 2020, which is equal to the estimate in the other column for the year 2020. Biomass residues refer to rest products from agriculture and forestry (like forestry residues, manure and straw) and mono-streams as a result of typical activities; biomass waste refers to residues of production processes (like roadside hay, wood, sludge and industrial waste).

In Table 1.14 it is assumed that 0.3 million ha is available for energy crops, short rotation forestry or reforestation (providing 50 PJ). This would imply that 15% of the agricultural land (1.97 million ha) would be used for energy crops etc. This is highly ambitious, but possibly achievable.

3.12 Portugal

3.12.1 Introduction

Biomass and waste have a significant potential, although they are not used to their full extent to date. §1.12.2 gives the technical potential of biomass, waste, and energy crops of Portugal.

3.12.2 Technical potential of biomass, waste, and energy crops

According to Almeida *et al.* (Internet source 23), in 1999 the main areas of biomass use were:

- Industrial use of wood and wood waste: 48 PJ (1.14 Mtoe).
- Residential use of wood: 23 PJ (0.53 Mtoe).
- Wood and wood waste - 70 PJ - accounted for 7% of the primary energy use in 1999.

Table 1.15 shows the use of biomass, waste, and energy crops, and its technical potential, which is estimated at 175 PJ - based on Almeida *et al.* and Spitzer (Internet source 23 and 11).

Table 1.15 *Technical potential of biomass, waste, and energy crops of Portugal*

	(Technical) potential of biomass, waste, and energy crops [PJ]	
	2000	2050
Forest residues, fuel wood, etc.	79	110
Biogas (agricultural residues, landfill gas)	P.M.	10
Municipal solid waste	7	10
Energy crops and reforestation (≤0.35 Mha)	P.M.	45
Total	86	175

According to (De Noord *et al.*, 2004), the potential of energy crops is 58 PJ, based on 0.72 million ha. The estimate of 45 PJ (Table 1.15) is based on an area of ≤0.35 million ha used for energy crops. This would imply that 9 percent of the agricultural area would be used for energy crops and reforestation. This seems to be rather ambitious, but probably achievable.

3.13 Spain

3.13.1 Introduction

Biomass has a large potential in Spain, but needs more investment and technological development. §1.13.2 gives an estimate of the potential of biomass, waste, and energy crops.

3.13.2 Technical potential of biomass, waste, and energy crops

Use of biomass and waste accounts for approximately 153 PJ (3.65 Mtoe), equivalent to 3% of the total primary energy use. Some 140 companies are involved in collecting, treating and storing agricultural waste for energy use in Spain. Another 130 companies work in the treatment of forest waste. Spain leads in the EU the production of electricity with biogas (including gas from sewage treatment plants and landfill gas), accounting for approximately 4.5 PJ (0.1 Mtoe).

Spain's total resources of biomass, waste, and energy crops have been estimated at approximately 620 PJ by (Internet source 24) (Table 1.16).

Table 1.16 *Technical potential of biomass, waste, and energy crops of Spain*

	(Technical) potential biomass, waste, and energy crops [PJ]	
	2000	2050
Forest residues	20.5	58.5
Black liquor	22.6	22.5
Industrial by-products (solid)	68	87.3
Wood wastes	P.M.	51.5
Domestic (residential) firewood	12.1	12.1
Other (including energy crops)	29.7	385.6
Total	153	~620

According to (De Noord *et al*., 2004), the potential of energy crops would be 482 PJ, based on an area of 5.646 million ha used for energy crops. This would imply that 19 percent of the agricultural land (29.97 million ha) would be available for energy crops. The aforementioned figure of 386 PJ (Table 1.16) would imply that approximately 2.8 million ha would be used for energy crops, equal to 9 percent of the total agricultural area. This seems to be ambitious, but probably achievable.

3.14 Sweden

3.14.1 Introduction

Sweden is one of the EU-15 countries with a high share of biomass in total primary energy use (largely based on wood). However, there is still remaining potential e.g. energy crops (§1.14.2).

3.14.2 Technical potential of biomass, waste, and energy crops

Biomass and waste account for approximately 15% of the primary energy use of Sweden. Until recently, wood residues and by-products were used by the wood industry to the tune of 120 PJ/a, 45 PJ/a of fuel wood by households, and approximately 100 PJ/a of wood for district heating.

Table 1.17 presents a tentative estimate of the technical potential of biomass, waste, and energy farming in Sweden - about 620 PJ - which is mainly based on (Internet sources 25-27).

Table 1.17 *Tentative estimate of technical potential biomass, waste, and energy crops of Sweden*

	(Technical) potential biomass, waste, and energy crops [PJ]		
	2000	Remaining potential	Technical potential
Forestry residues, fuel wood, etc.	330	140	470
Agricultural residues (e.g. straw)	P.M.	60	60
Anaerobic digestion	4	16	20
Municipal solid waste	17	8	25
Energy crops and reforestation (≤0.3 Mha)	<0.5	45	45
Total	351	274	620

The technical potential of fuel wood - 470 PJ - is in accordance with Spitzer (Internet source 11). According to (De Noord *et al*., 2004), the potential of energy crops would be 31 PJ, based on an area of 0.15 million ha. The figure of 45 PJ (Table 1.17) is based on an area of ≤0.3 million ha, or 9 percent of the agricultural land (3.272 million ha). This seems to be ambitious, but probably achievable.

3.15 United Kingdom

3.15.1 Introduction

In the UK, the use of biomass and waste is increasing, and there is a significant biomass potential. §1.11.2 gives a tentative estimate of the potential of biomass, waste, and energy crops.

3.15.2 Technical potential of biomass, waste, and energy crops

In 2002, the Inter-departmental Analysts Group (IAG) made an estimate of the potential of waste, biomass, and energy crops in the UK (Internet source 28). It made a distinction between:

- Municipal solid waste.
- Landfill gas.
- Agricultural and forestry residues.
- Energy crops.

Finally, a summary is presented of the potential of biomass, waste, and energy crops.

Municipal solid waste
The UK produces 27 Mt of municipal solid waste annually. According to (De Noord *et al*., 2004), a realistic estimate of the potential of municipal solid waste is 65 PJ.

Landfill gas
Landfill gas is used to a limited extent for electricity generation. The potential of landfill gas for energy production (mainly electricity generation) is estimated at approximately 50 PJ in 2025.

Agricultural and forestry residues
Agricultural and forestry residues fall into two main groups:

- Dry combustible materials such as forestry residues, straw, etc.
- Wet materials like green agricultural crop wastes (e.g. root vegetable tops) and farm slurry.

The first group can be combusted or converted by other thermal processes (gasification) to heat and/or power. The second group can be used to produce biogas through anaerobic digestion.

As the area of woodland – 2.8 million ha – is small compared to some other EU countries, most of the potential of dry combustible materials pertains to agricultural residues. The technical potential of dry combustible materials is estimated at 145 PJ. Farm slurries are the biggest potential of wet materials, with a potential of approximately 30 PJ.

Energy crops

According to (De Noord *et al.*, 2004), the potential of energy crops would be 156 PJ, based on 0.8 million ha. The figure of 330 PJ (Table 1.18) is based on an area of ≤2 million ha, which is ≤11 percent of the agricultural land (17.44 million ha). This seems to be ambitious, but possibly achievable.

Summary of biomass, waste, and energy crops
Table 1.18 shows the technical potential of biomass, waste, and energy crops of the UK.

Table 1.18 *Tentative estimate of technical potential biomass, waste, and energy crops of the UK*

	(Technical) potential biomass, waste, and energy crops [PJ]		
	2000	Remaining potential	Technical potential
Dry residues from forestry and agriculture	37	108	145
Biogas (agricultural residues, farm slurries)	34	31	65
Landfill gas	P.M.	-	-
Municipal solid waste[1]	12	53	65
Energy crops and reforestation (≤2 Mha)	P.M.	330	330
Total	82	520	605

1 Figures based on energy content of biomass and waste, with correction for waste based on fossil fuels.

3.16 Summary of EU-15 countries

The potential of biomass, waste, and energy crops of each of the EU-15 countries has been analysed to a certain extent. Figure 1.2 shows a possible development of biomass, waste, and energy crops by EU-15 country. Figure 1.2 is a summary of the data presented in this Chapter.

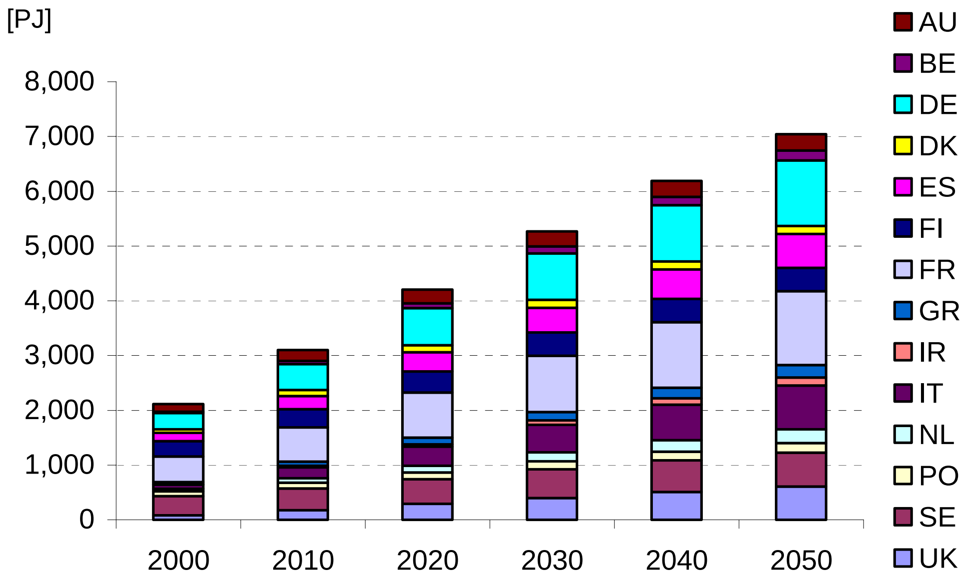


Figure 1.2 *Possible development of biomass, waste, and energy crops by EU-15 country*

Table 1.19 presents the data on biomass, waste, and energy crops that were used for Figure 1.2.

Table 1.19 *Deployment of biomass, waste, and energy crops in the EU-15, 2000-2050 [PJ]*

	2000	2010	2020	2030	2040	2050
AU	140	200	250	275	290	300
BE + LU	24	55	90	125	155	180

DE	295	475	675	850	1,025	1,200
DK	64	110	130	145	145	145
ES	153	240	350	450	540	620
FI	282	330	385	425	425	425
FR	468	625	825	1,025	1,200	1,350
GR	42	80	120	155	190	225
IR	6	25	45	80	115	150
IT	71	200	350	500	650	800
NL	50	80	120	165	210	250
PO	86	105	125	145	160	175
SE	351	400	450	525	575	620
UK	82	175	290	400	510	605
Total	2,114	3,100	4,205	5,265	6,190	7,045

Another cross-section is the development of the potential by category, viz. by-products from forestry and agriculture, waste, and energy crops (Figure 1.3). In the next few decades much of the growth will come from by-products and waste, as the production of energy crops is relatively costly. Around 2020, energy crops could provide a significant amount of energy, based on the estimates by country in this Chapter.

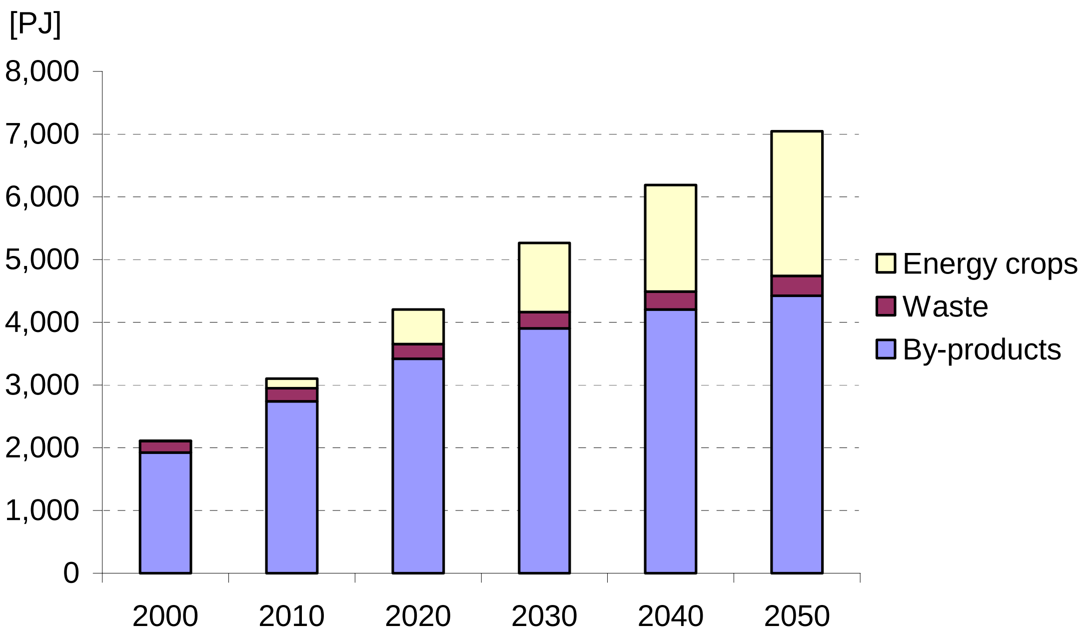


Figure 1.3 *Possible development of biomass by category (by-products, waste and energy crops)*

These estimates may be compared with those from Jorgensen *et al*. (Internet source 29). They expect a realistic potential of biomass (excluding digestion) in the EU-15 of approximately 4,200 PJ/a by 2010 and 5,000 PJ/a by 2030. However, such a booming scenario will probably not materialise. The higher figures for 2040 and 2050 in Table 2.19 (compared to Jorgensen *et al*.) may be explained by inclusion of biogas (anaerobic digestion), municipal solid waste, and energy crops.

Another comparison is the potential of energy crops in this study and that of (De Noord *et al*., 2004) for the EU-15 countries (Figure 1.4).

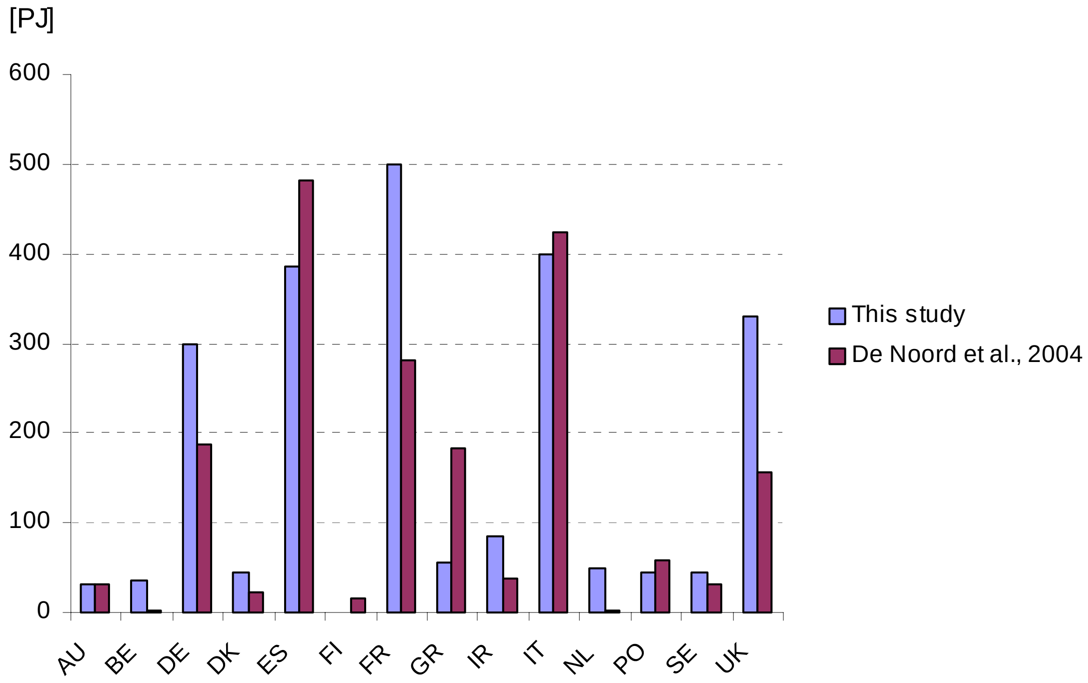


Figure 1.4 *Possible development of the potential of energy crops in the EU-15 according to this study and (De Noord et al., 2004)*

The potentials of different EU-15 countries may differ a lot. This may be due to the fact that the potentials of (De Noord *et al*., 2004) are based on the cost of land. However, the total potentials do not differ so much: 2,300 PJ in this study vis-à-vis 1,900 PJ according to De Noord *et al*.

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4 Biomass Technologies

4.1 Biomass – Pretreatment and First Conversion

Biomass shows a relatively low energy density (see table 7-4) leading to an extended supply area (see figure 7-10) and relatively high transport costs (see figure 7-11). These transport costs approximately double the raw biomass costs of 6 to 12 US$/MWh$_{biomass}$ /1/. Considering also the relatively low 20 % electrical efficiencies of biomass power technologies, biomass power generation units should be smaller and more dispersed than conventional thermal power generation units.

Table 7-4: Energy density of different fuels	
Fuel	Energy density in GJ/m³
Fuel oil	35-40
Hard coal	22-25
Wood chips	2.5-4
Wood pellets	10-14
Straw chipped	0.5-0.8
Straw pellets	6.5-10.5
Cattle excrements (liquid)	1.3-1.7

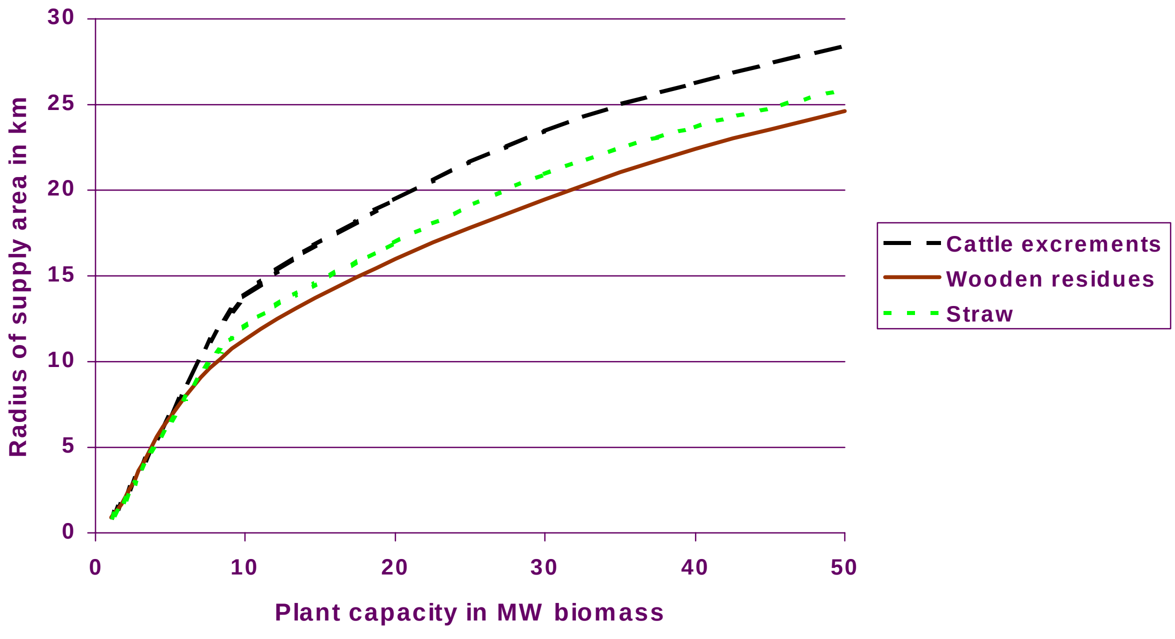

Figure 7-10: Radius of supply area over biomass plant capacity /1/

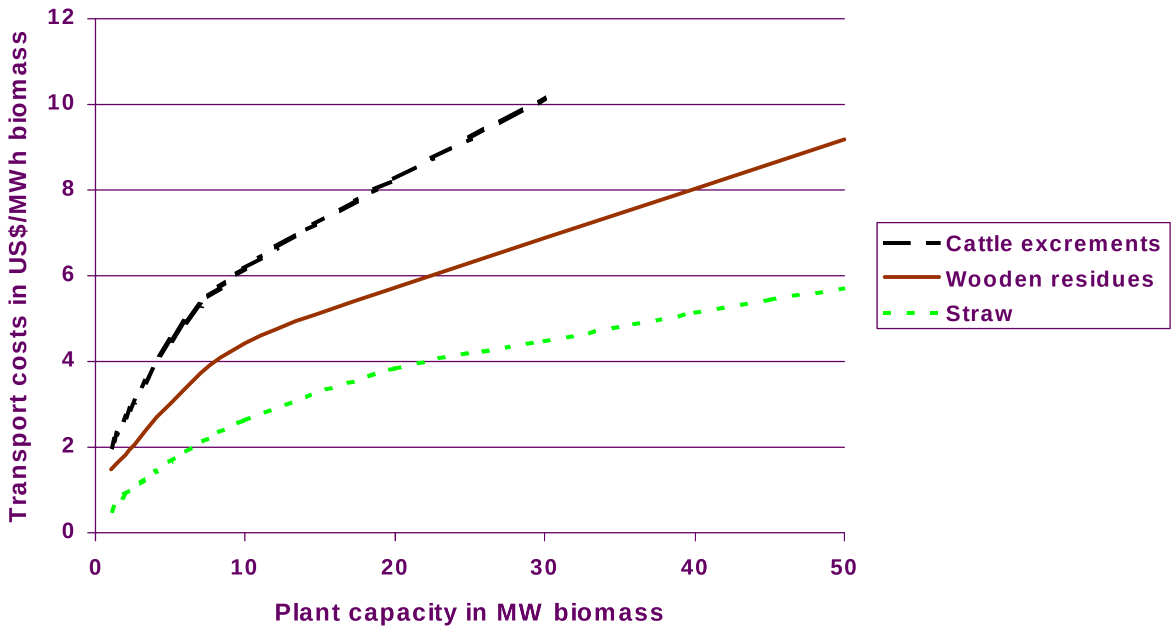

Figure 7-11: Transport costs in dependence of biomass plant capacity /1/

Table 7-5 shows further properties of wood and straw. Wood has a relatively low sulfur and chlorine content and is therefore relatively environmentally friendly. An economic combustion of straw at low environmental impact is a more challenging task. The ash of straw vitrifies below 1000 °C, causing corrosive chlorine, potassium oxide of magnesium oxide containing layers on the boiler walls and tubings. For protecting the burning chamber the walls can be covered with silicon carbide.

Table 7-5: Biomass properties

	Calorific value in MJ/kg	Ash softening in °C	Components in g/GJ			
			Ash	Sulfur	Nitrogen	Chlorine
Wood (tan)	18.7	1260	200	11	107	5
Straw	17.5	930	2600	57	229	194

In table 7-6 the development status of different biomass to power technologies is summarized. Figure 7-12 gives an overview of the technologies and energy conversion steps from biomass to heat and power which are discussed in the following.

Table 7-6: State of development of biomass to power technologies /1/

Technology	Research	Development	Demonstration	Commercially available
Steam turbine / steam engine				+
Stirling CHP	+			
Solid bed gasification + gas engine				+
Fluidized bed gasification + gas engine			+	
Hot air turbine	+			
Co-firing			+	+ (biomass grate)
Biomass-IGCC			+	

Biomass + fuel cell	+ (thermal gasification)		+ (biological gasification)	
Power from biogas				+

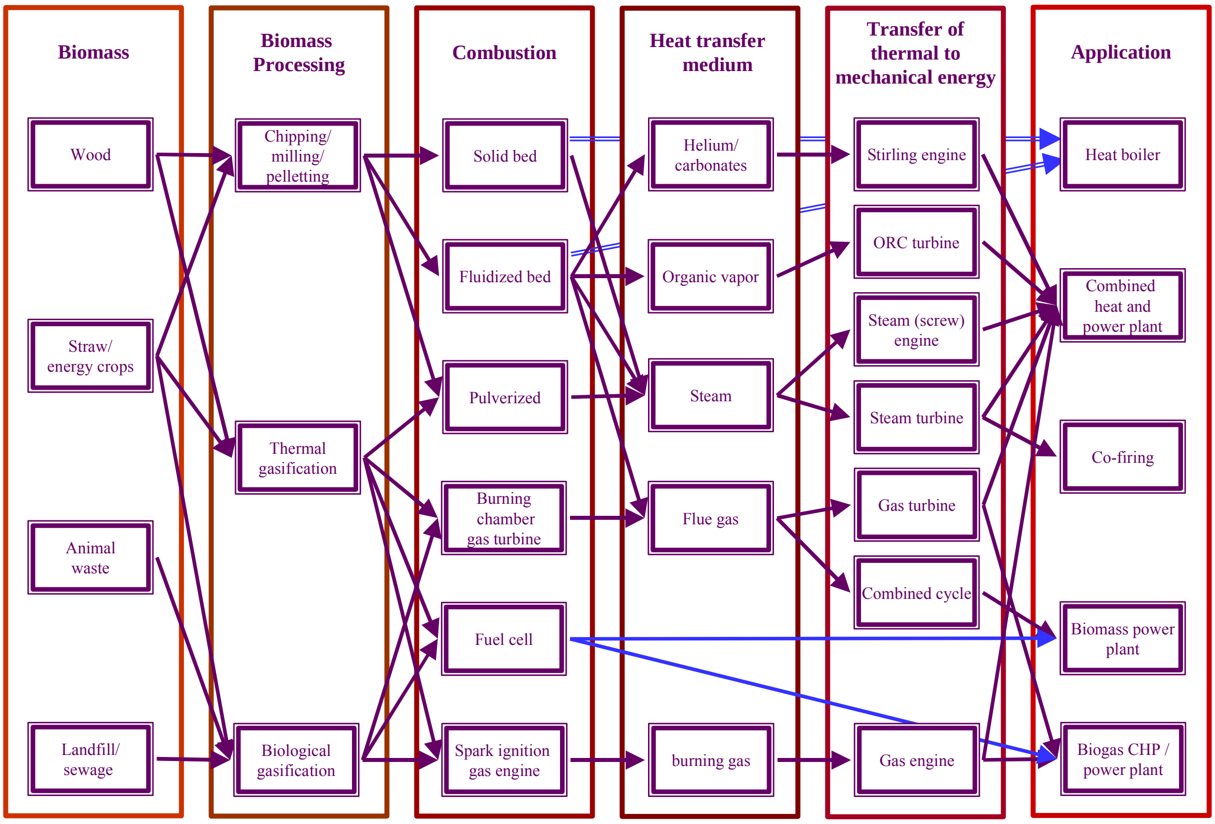

Figure 7-12: Conversion steps and technologies from biomass to heat and power

Prior to combustion solid biomass has to be processed. Wood and wooden residues are chipped shredded or milled, saw dust is pelletized, straw is compressed, in order to get the biomass into a form, which allows automated feed and incineration. Depending on the resulting particle size three solid biomass incineration technologies:

- Solid bed incineration
- Fluidized bed incineration
- Pulverized biomass incineration

or

- Biomass gasification

is applied.

4.1.1.1 Solid Bed Incineration

For incinerating relatively coarse biomass like wooden residues, straw and waste, solid bed firing is applied. Several technologies are in use:

- The spreader-stoker firing is shown in figure 7-13. A screw called “stoker” feeds a moving grate called “spreader”. This technology is applied for low-ash fine-grained biomass fuels like saw dust, pellets and fine wood chips up to 6 MW_{bio} /2/. By addition of magnesium oxide the formed slag stays in loose consistency.

- With feed grates, biomass transport is achieved by periodic movements of every second grate element. The grate is divided into a number of grate zones which can be regulated separately. Feed grates are used for capacities up to 50 MW_{th}.
- The travelling grate uses a revolving grate for moving the biomass through the burning chamber. The fuel bed is not overturned and thus fuel particles are not whirled up. Due to the even distribution of the fuel on the grate, the thermal stress is lower than with the feed grate. The travelling grate is especially appropriate for burning wood chips, pellets and old wood. The Travelling grate cannot be applied for combusting coarse-grained, inhomogeneous or very small grain fuels.
- Static sloped grates.
- Water cooled sloped vibration grates are used especially for fuels with a high tendency to slagging (e.g. straw). With vibration grates combustion control, however, is difficult.

Following flue gas cleaning techniques are applied with biomass combustion:
- feed of urea into the upper part of the incineration chamber in order to reduce NO_x formation;
- a combination of cyclones and electrostatic precipitators for dust removal ;
- textile filters for dust removal.

An advantage of solid bed incineration is its low costs, a disadvantage its low flexibility with respect to particle size. An irregular distribution of particle size can lead to temperature peaks and high CO or NO_x emissions.

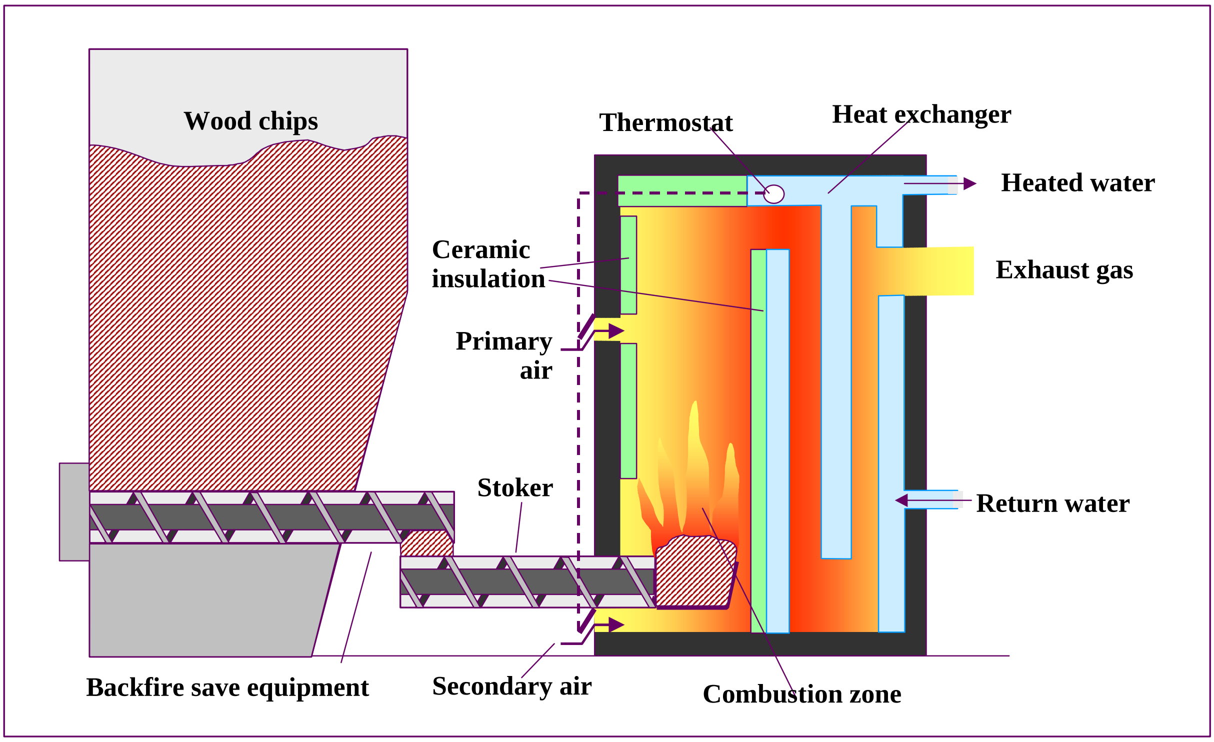

Figure 7-13: Scheme of “stoker” wood combustion technology

4.1.1.2 Fluidized Bed Incineration

The general scheme of a fluidized bed combustor for biomass incineration is the same as for coal incineration (see figure 7-15). Fluidized bed combustion can be done in one of three operating modes:
- with stationary beds (the bed material moves in a relatively small area of the combustion chamber);

- with internal circulating beds (coarse-grained bed material forms a stationary bed for the primary combustion zone, while fine-grained bed material circulates between the primary and a secondary combustion zone within the burning chamber);
- with external circulating beds (the bed material is blown out of the combustion chamber, separated from the flue gas in a cyclone and recycled).

Advantages of fluidized bed incineration are:
- a relatively low burning temperature is achieved (750 to 900 °C), leading to low NO_x and CO emissions;
- sulfur can be removed during combustion by addition of limestone;
- different materials can be burned over a wide spread of particle size;
- less area is needed than with solid bed incineration.

Disadvantages of fluidized bed incineration as compared to solid bed combustion are:
- higher investment costs;
- higher electricity consumption;
- longer start-up period.

Due to the high investment costs, stationary fluidized bed combustion is economic only for $MW_{th} \geq 20$, circulating fluidized bed combustion only for $MW_{th} \geq 30$.

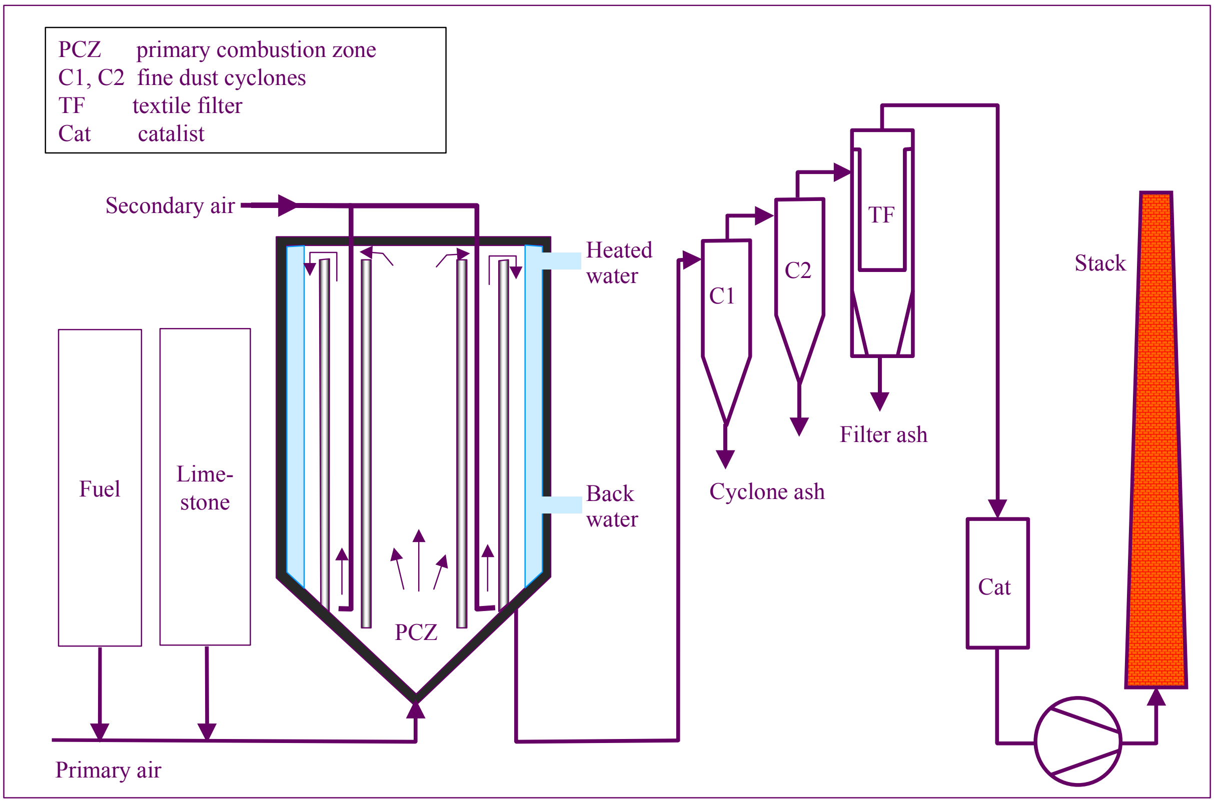

Figure 7-15: Scheme of a fluidized bed heat generator with advanced flue gas cleaning as used for combustion of raps seed extraction residues /3/

4.1.1.3 Pulverized Biomass Incineration

Biomass, like e.g. rise straw, is shredded and pulverized in hammer mills to particles smaller 20 mm, transported into the burning chamber utilizing a pneumatic conveyor and burned by powder burners. In order to keep the slag from vitryfying the burning temperature is kept low (860 °C) /4/.

4.1.1.4 Thermal Biomass Gasification

During thermal gasification at about 700 °C biomass reacts with air, oxygen or steam to form a mixture of CO, CO_2, water and methane. Utilizing air leads to a product gas with low calorific value of 4-6 MJ/Nm³. With oxygen or water the product gas has an energy contents of 10-14 MJ/Nm³ (as compared to 18-25 MJ/Nm³ for bio-, landfill-, or sewage-gas).

The reaction with the wood component cellulose as shown in equation (9) takes up energy:

$$C_6H_{10}O_5 + H_2O \rightarrow 6CO + 6\ H_2 + 3.34\ MJ/kg \qquad (9)$$

The reaction energy is provided

- either by burning part of the biomass in the reactor,
- or by recovering heat from the flue gas in a high temperature heat exchanger.

Three basic types of biomass gasifiers are in use:

- Co-current downdraft gasifiers with low tar emissions are utilized in the range of 10 kW_{bio} to 1 MW_{bio} (see figure 7-16).
- Counter current updraft gasifiers with high tar emissions are used in the range of 1 MW_{bio} to 10 MW_{bio} (see figure 7-16).
- Stationary or circulating fluidized bed gasifiers, with atmospheric or high pressure, leading to medium tar emissions are expected to be economic in the range of 10 MW_{bio} to above 100 MW_{bio} (see figure 7-17).

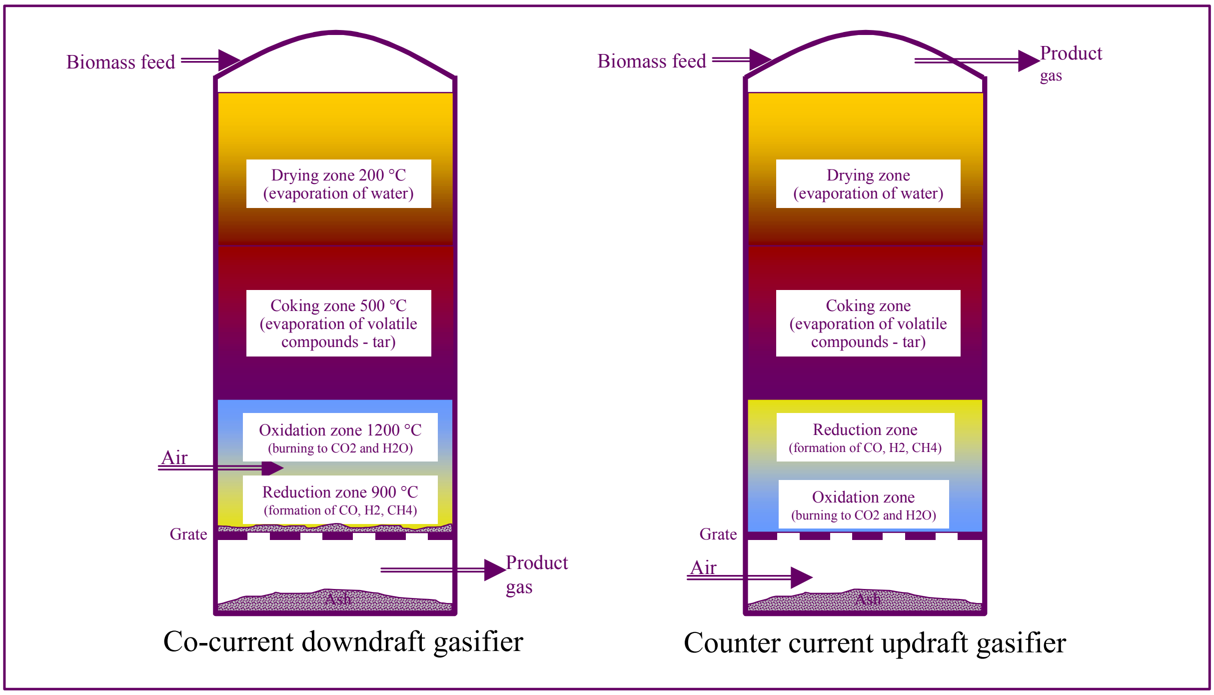

Figure 7-16: Scheme of solid bed gasifiers and reaction zones /1/

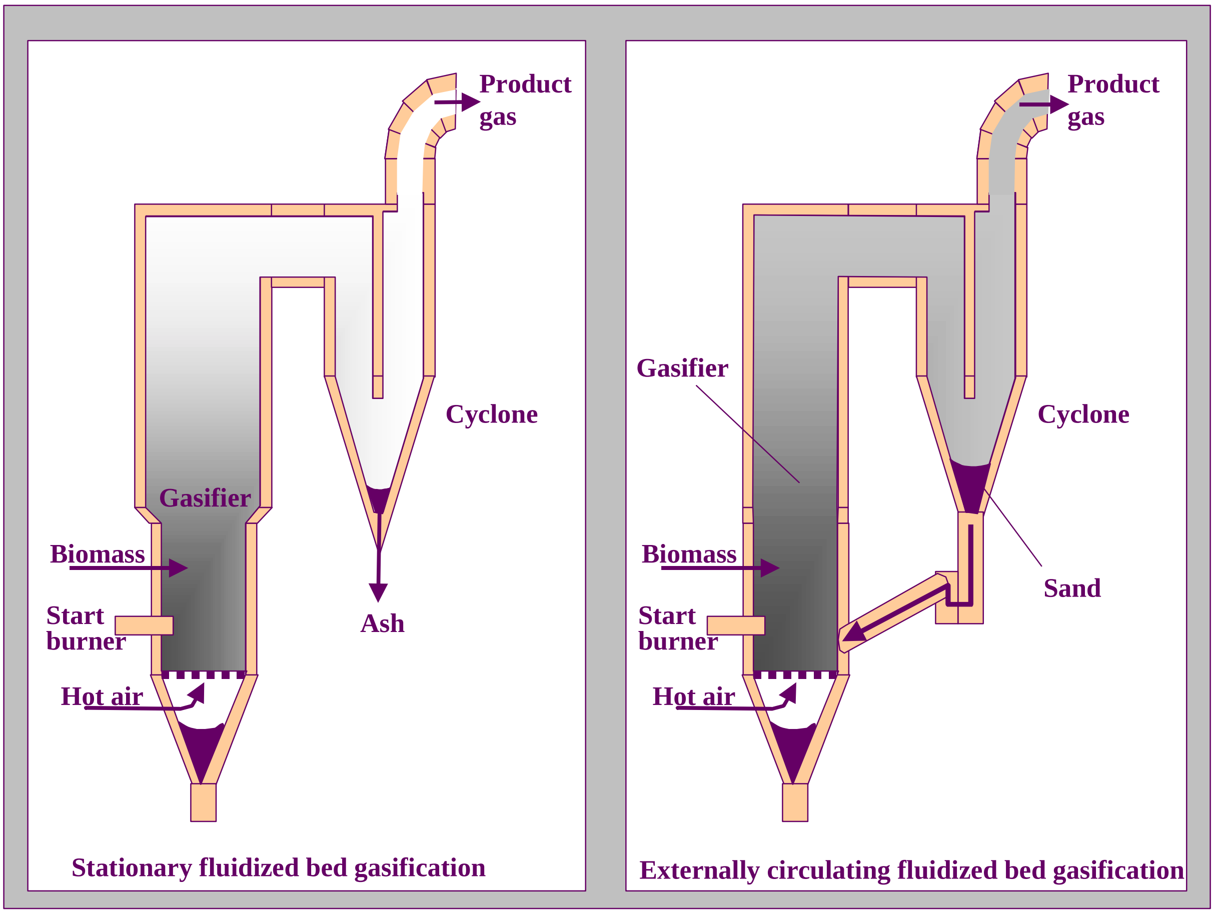

Figure 7-17: Scheme of fluidized bed gasifier

An advanced technology is the internal circulating fluidized bed gasifier, in which bigger sand particles make up a stationary fluidized bed for the gasification reaction, while a fraction of smaller sand circulates between the burning zone (= the oxidization zone) and the gasification zone (= reduction zone) and takes care of the heat exchange /1/.

Due to difficulties with high tar contents up to now biomass gasification is commercially available only for heat production. All thermal biomass gasification technologies which aim at power production are still in the demonstration phase.

Several processes for cleaning the biomass gas are under development:

- The tar can be adsorbed on active coal or char coal; the disadvantage of this option is that the biomass gas has to be cooled down to 300 °C prior to adsorption to avoid decomposition of the adsorbent.
- The tar can be cracked either thermally at1000 °C or catalytically with Ni- or dolomite catalysts at 800 to 900 °C. The disadvantage of the cracking option is that part of the energy contained in the biomass gas must be utilized for the tar cracking.
- The tar can be removed by wet processes like Venturi washers or wet electric precipitators. The disadvantages of this option are the high costs and the necessity to introduce a waste water cleaning system.

In addition to tar also dust has to be removed from the biomass gas. This is done by hot gas cleaning equipment like cyclones and/or textile filters.

4.2 Biomass Combined Heat and Power

4.2.1 Biomass CHP Technologies and Costs

A number of conventional and innovative technologies for a combined heat and power production from biomass is currently under investigation:

- The steam turbine process (STP),
- the steam engine process (SEP),
- the steam screw engine process (SSEP),
- the organic Rankine cycle (ORC) process,
- the Stirling engine process (StEP),
- the direct (inverse) gas turbine process (DGT),
- the indirect (hot air) gas turbine process (HAT),
- the solid bed gasification + gas engine or fuel cell (SBC+GE),
- the fluidized bed gasification + gas turbine (FBG+GT).

The development status of these technologies is summarized in table 7-6 (see above).

The Steam Turbine Process for Biomass CHP (STP)

The steam turbine process, shown in figure 7-18, can be described as follows: In the combustion zone biomass is burned. The resulting hot flue gases heat water to produce saturated steam, which can be further heated in an overheater (3). The flue gas flows into a feed water preheater (not shown), is cleaned and is emitted through a stack. The steam is expanded through a turbine (4) and condensed. The steam's condensing energy is utilized for producing end use steam or district heat. A pressure reduction valve provides a by-pass to the turbine for regulating the ratio of produced power to produced heat. The condensate is collected in a tank, gas and liquid phase are separated there. The condensate pump transports the liquid into the feed water tank (1). A small part of steam from the boiler is used for the thermal degasification of the feed water. The feed water pump provides the pressure for the boiler steam production (2).

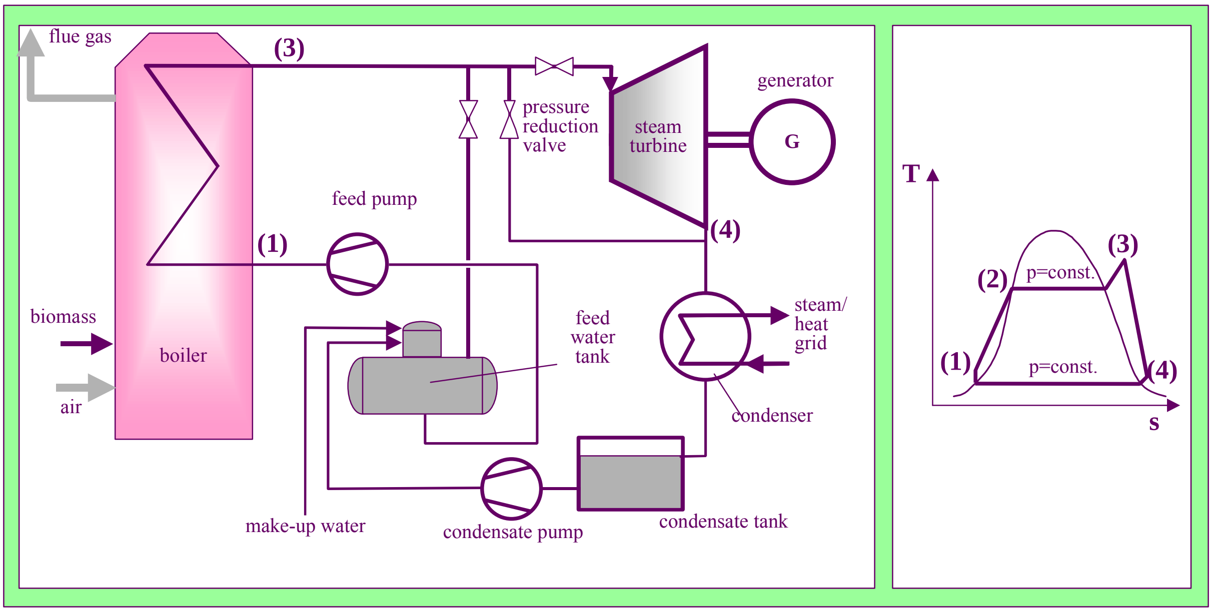

Figure 7-18: Scheme of steam turbine process for biomass CHP and T-s-diagram of this process

De-central biomass-steam processes show some specific features different from conventional steam processes:

- Usually single step steam turbines are used for the capacity range from 150 kW to 5 MW_{el}, together with a fire-tube boiler (multi-step turbines are economic only above 5 MW_{el}, water-tube boilers only above 2 MW_{el}) /5/.
- The steam usually has a lower pressure (30 to 40 bar) and temperature (400 °C).
- A back-pressure turbine is used with a by-pass for increasing the heat production (instead of an extraction-condensation turbine).

Small scale industrial steam turbines can be considered as mature technology and are in world wide use. In biomass plants the upper steam temperature is limited by the concentration of alkali metals, sulfur and chlorine in the fuel. These compounds lead to high temperature corrosion. With wood, the temperature ceiling lies at 500 °C, with straw at 460 °C. A limiting factor is also the relatively low part load efficiency (see figure 7-28). The electrical efficiency lies with 8 to 18 %. For a summary of the technical data see table 7-7. Investment costs for a 1 MW_{el} unit including only steam turbine, shift gear and generator lie at 420 US$/kW /6/. Investment costs for adding a whole 700 kW power generation system to an existing process/district heat scheme lie at 1600 US$/kW. The investment cost development in the 250 to 2000 kW range is shown in figure 7-29. /7/ reports power generation costs of 7.8 US¢/kWh_{el}, whereas other sources claim that at least 10 US¢/kWh are necessary to cover the power generation costs /8/. The difference might be related to governmental subsidies, which in Austria can be as high as 30 % of the investment costs.

Table 7-7: Technical / economic parameters of biomass-CHP processes /7/

Process	P_{el} in kW	electrical efficiency in %	total efficiency in %	electricity to useful heat ratio	Recom-mended operation	noise in dB_A	investment costs in US$/kW	power generation costs in US¢/kWh
STP	>150	8-18	80	0.11-0.29	h/p	91-94	1588	7.8
SEP	20-1200	8-20	78	0.11-0.34	h/p	95	1824	9.1
SSEP	25-2500	10-20	82	0.14-0.32	h/p	90	1885	8.3
ORC	200-1400	10-18	85	0.13-0.27	h/p	90	2654	10.5
StEP	10-150	6.5-28	63-86	0.08-0.8	h	silent	2716	14.7
DGT	200-1400	14-21	74-80	0.21-0.39	p		4112	17.1
HAT	200-1800	13-24	65-70	0.23-0.59	p	very loud	3373	16.6
SBC+GE	10-2000	15-30	75	0.25-0.67	h/p	loud	2521	13.4
FBG+GT	>1000	20-25	75-80	0.33-0.50	p	loud	3380	14.5

P_{el} electrical plant capacity,
total efficiency = (electricity + useful heat produced)/input energy;
recommended operation: h/p...heat or power driven, h....heat driven, p....power driven;
Investment costs are costs for converting a heat plant into a CHP plant;
Assumptions for power generation costs: fuel price = 1.2 USc/kWhbio, 4000 full load operation hours, 15 a life time, 6 % discount rate
STP = steam turbine process, SEP = steam engine process, SSEP = steam screw engine process, ORC = organic Rankine cycle process, StEP = Stirling engine process, DGT = direct gas turbine process, HAT = hot air turbine process, SBC+GE = solid bed gasification + gas engine, FBG+GT = fluidized bed gasification + gas turbine

Steam Engine Process (SEP)

As can be seen in figure 7-19, the steam engine process follows a similar scheme as the steam turbine process. The main difference is, that a lubricant has to be added to the steam before entering the steam engine, for cooling and lubrication. After leaving the engine, this lubricant is removed in two steps. The bulk of lubricant is separated directly after the steam engine in a phase separation tank, complemented by the removal of traces in a filter after the condensate pump.

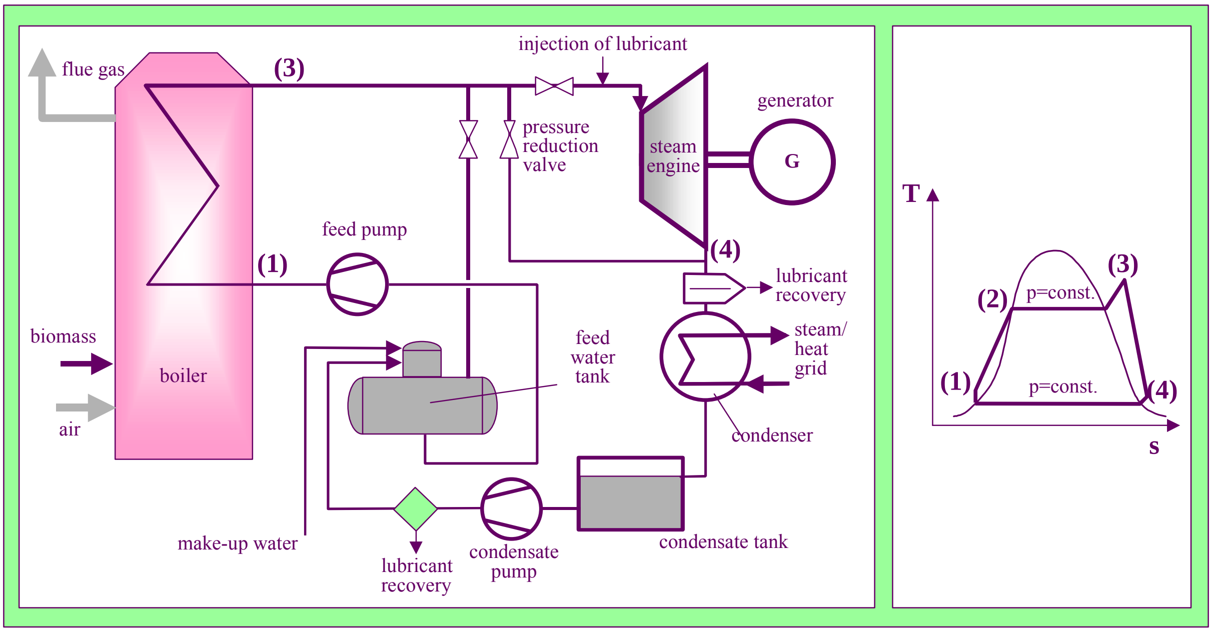

Figure 7-19: Scheme of steam engine process for biomass CHP and T-s-diagram of this process

The working process within the steam engine is shown in figure 7-20: While moving from state (a) to state (b) in the p-V-diagram, steam flows into the working cylinder till the regulation piston stops this flow. Between state (b) and state (c) the steam expands while moving the working cylinder and executing work. Between state (c) and state (d) the expanded steam is pushed out of the working cylinder. At state (d) the exit is closed, so that between (d) and (a) the remainder of the steam is compressed to the pressure of the new steam. As the working piston is moved by steam from both sides, the explained process takes place twice, however with 180 ° phase shift (see dotted line in the p-V-diagram). A steam engine consists of one to six working pistons with the respective number of regulation pistons.

As compared to the steam turbine, the steam engine is less sensitive to water formation during steam expansion and to impurities in the steam. Inlet steam pressures of 6 to 60 bar can be utilized as well as exit steam pressures of up to 25 bar. Steam flow can range from 0.2 to 20 t/h. Thus the steam engine is very flexible (see figure 7-28). Electric efficiency lies between 6 and 10 % with single step expansion and between 12 and 20 % with two step expansion. The life time of a steam engine usually exceeds 200.000 hours. For a summary of the technical data see table 7-7.
Steam engines bigger than 20 kW_{el} belong to the mature technologies. Investment costs with a 500 kW unit lie at 1800 US$/kW. The course of the investment cost development in the 150 to 1200 kW range is shown in figure 7-29.

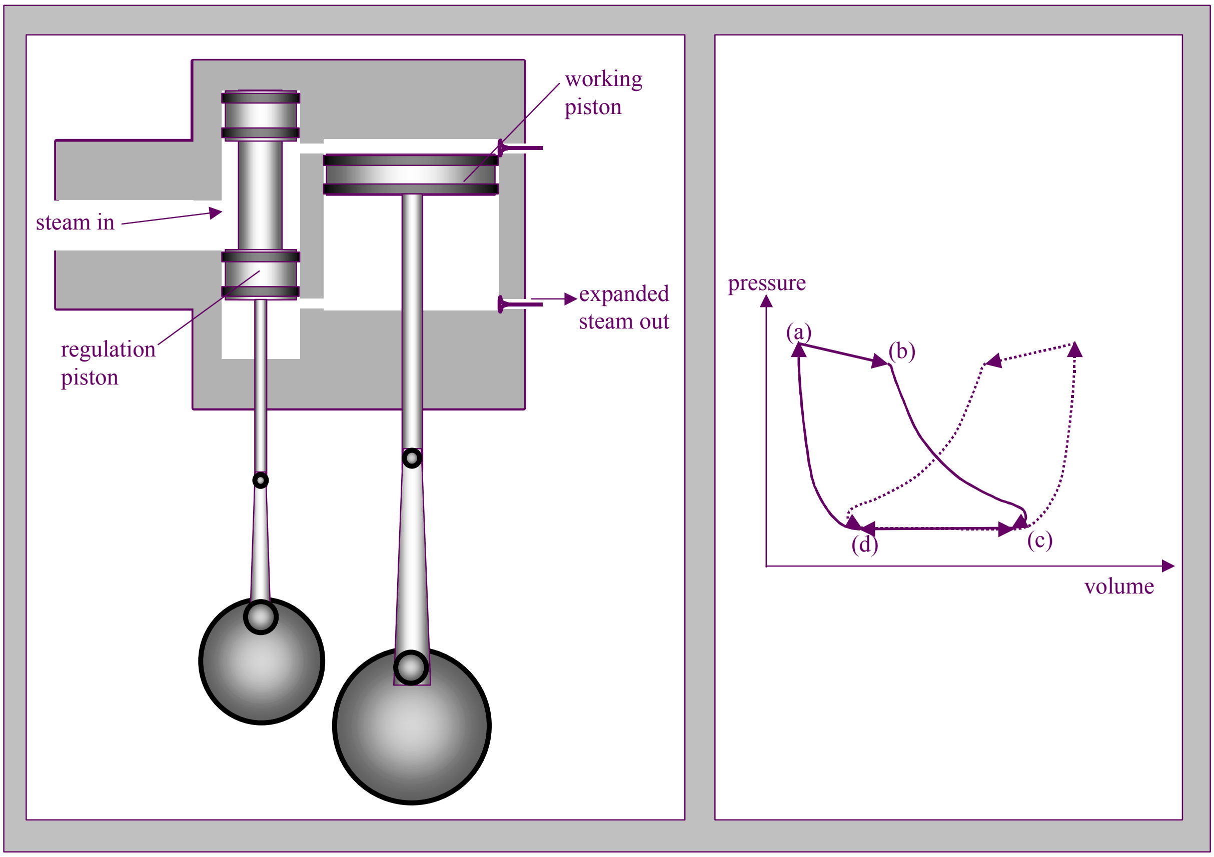

Figure 7-20: Scheme of a steam engine and p-V-diagram of the working process

Steam Screw Engine Process (SSEP)

Also the steam screw engine process is very similar to the steam turbine process. As compared to the steam engine process lubrication is not always necessary. The screw engine consists of two screw-like rotors which rotate by the released energy of expanding steam. In most cases screw engines are screw compressors used for producing mechanical work instead of compressing a medium. The rotors are synchronized by a special gear, so that they do not touch.

In contrast to steam turbines, through the screw engine also wet steam and pressurized hot water can expand without causing damage. At inlet pressures of 5 to 40 bar, single step pressure differences of up to 20 bar, and at a steam throughput of 0.2 to 25 t/h, up to 25.000 rotations per minute are achieved. A switch gear must connect the screw engine with the generator, which rotates at lower rate. The screw engine leads to an electrical efficiency of 10 to 20 % (super heated steam) and shows good part load efficiency (see figure 7-28). The capacity ranges from 100 to 2000 kW. A life time of more than 30 years can be expected. For a summary of the technical data see table 7-7.

Though steam screw engines have been available for 50 years, they show significant potential further development. Investment costs with a 500 kW unit lie at 1880 US$/kW. The course of the investment cost development in the 150 to 1900 kW range is shown in figure 7-29.

Organic Rankine Cycle (ORC) Process

Figure 7-21 shows the scheme of the ORC process for biomass CHP. In the combustion zone biomass is burned. The flue gas passes a boiler in which thermo-oil is heated. By a thermo-oil cycle heat is transferred to the evaporator of the organic Rankine cycle. The organic medium is evaporated (3). The organic steam reaches the turbine, where it expands and performs work (4). The expanded steam flows to the condenser, the deducted heat is used as process or district heat. The liquefied organic medium is brought from a pressure below 1 bar back to the operation pressure of about 10 bar (1) and flows into the boiler.
In an economizer the 300 °C hot off-flue gas additionally warms up the district or process heat.

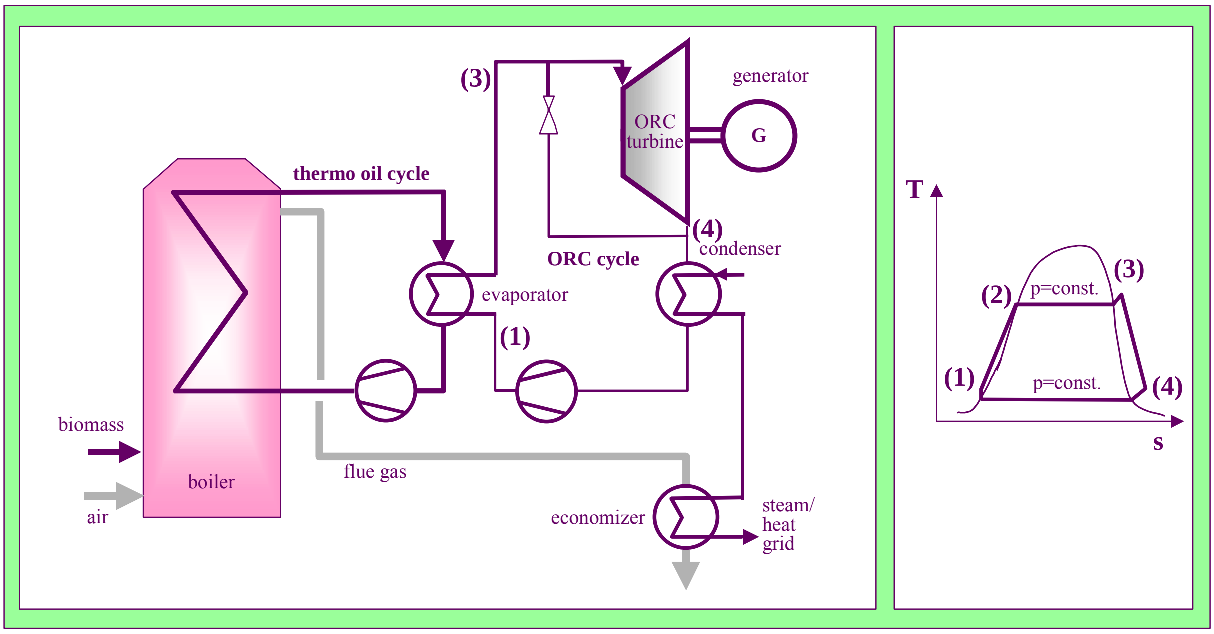

Figure 7-21: Scheme of ORC process for biomass CHP and T-s-diagram of this process

The thermo-oil circle is necessary as the organic medium would be destroyed by temperature peaks occuring in the boiler. The introduction of the thermo-oil cycle has the further advantages

- that heat transfer is better to control,
- that the boiler can be operated without high pressure parts,
- and that an expensive cleaning of the heat transfer media can be avoided.

As organic medium for the Rankine cycle iso-pentane, iso-octane, toluene or silicon-oil is in use. Turbines used in the ORC-process reach a turbine efficiency of 85 %, working at low rates of rotation. Thus long life times (20 years) can be achieved and a shift gear to the generator can be avoided. ORC-turbines are available in the range of 200 to 1400 kW_{el}.
The part load efficiency of the ORC process is relatively good (see figure 7-28). The electrical efficiency lies with 10 to 18 %. For a summary of the technical data see table 7-7.

The ORC process is technically mature. The application for biomass combustion is, however, still in the development phase. Investment costs with a 400 kW unit lie at 2650 US$/kW. The investment cost development in the 200 to 1400 kW range is shown in figure 7-29.

Stirling Engine Process (StEP)

Figure 7-22 shows the scheme of the Stirling engine process: In the combustion chamber biomass is burned. A part of the heat contained in the flue gas is utilized in the Stirling engine for producing work. Remaining heat in the flue gas is transferred to district/process heat in the down stream boiler. The return of the process/district heat scheme is used for cooling the Stirling engine.

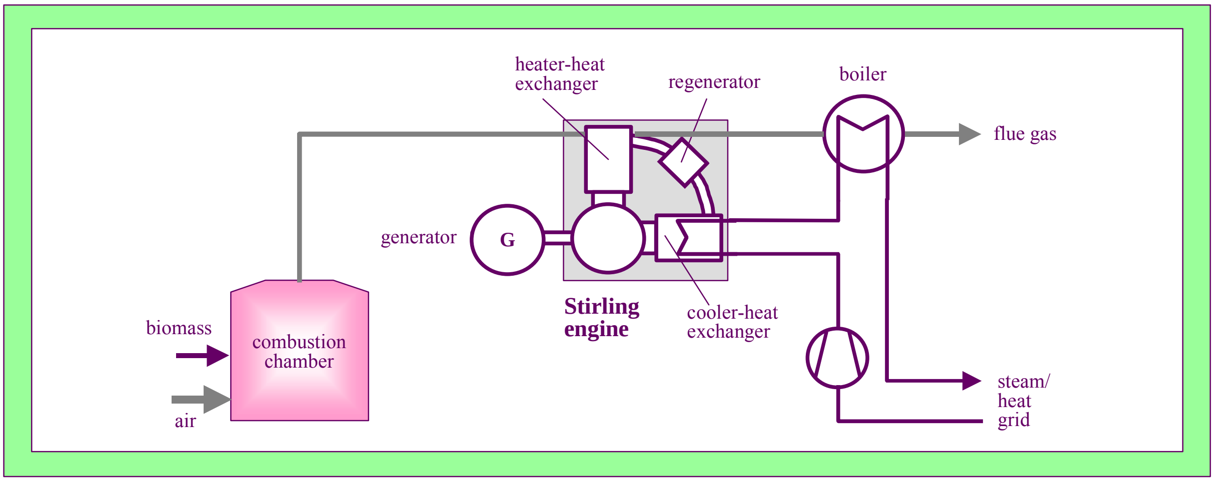

Figure 7-22: Scheme of a Stirling engine process for biomass CHP and T-s-diagram of this process

The highest thermodynamical efficiency possible in a heat driven engine, is the Carnot efficiency. It is achieved, when the heat uptake and work generation is at the highest possible temperature and the heat disposal, for closing the thermodynamic circle, is at the lowest possible temperature. A heat to work conversion with high efficiency is achieved in Stirling engines. Figure 7-23 shows the principle of this type of engine. The engine consists of two pistons, a heat storage device (the regenerator), a working fluid (helium, air, nitrogen or hydrogen), an external cooling system and an external heat source. In the first step of the process the compression piston compresses the working fuel, while cooling is applied, so that the temperature of the working fluid is kept constant (steps a to b in figure 7-23). In the next step, the working fluid takes up the energy QR stored in the regenerator while being kept at constant volume (steps b to c). Then the expansion piston is moved by the expanding working fluid (step c to d). In this step the temperature is kept constant by external heating of the system. In the last step the expansion piston pushes back the working fluid into the cold part of the engine, while the regeneration energy QR is stored in the regenerator (step d to a).

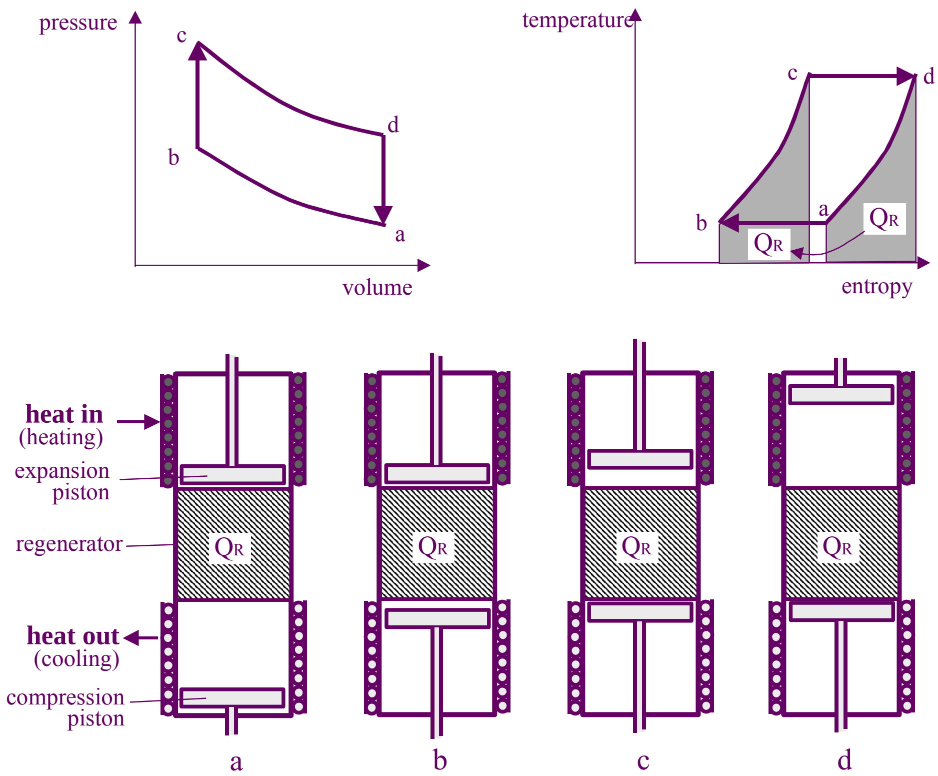

Figure 7-23: Scheme of a Stirling engine and p-V- as well as T-s-diagram of the working process

A number of Stirling engine types have been developed. These types can be grouped into - Stirling engines with 4 or more pistons which work alternately as compression and expansion piston (as in the Rinia engine), - and Stirling engines with a special power piston which does the compression and expansion and a special displacer piston which moves the working fluid between the cold and the hot part of the engine. An example for this technology is the Overdriven Ringbom Engine /9/.

With biomass combustion special construction developments are necessary for the heater's heat exchanger. A slagging of the heat exchanger walls needs to be prohibited. Special material is necessary to avoid high temperature corrosion induced by the metals and chlorine contained in the flue gas. The dust concentration in the flue gas needs to be lower than 300 mg/Nm³, thus requiring a low-dust combustion of the biomass. On the other hand Stirling engines can be added to already existing biomass-process/district-heat-schemes. They are also relatively silent.
A limiting factor for Stirling engines is the very low part load efficiency (see figure 7-28). The electrical efficiency lies between 6.5 and 28 %. Stirling engines are available in the 10 to 150 kW_{el} range. For a summary of the technical data see table 7-7.

The Stirling engine is still under development. Investment costs with a 40 kW_{el} unit lie at 2700 US$/kW.

Direct (Inverse) Gas Turbine Process (DGT)

Figure 7-24 shows the scheme of the direct or inverse gas turbine process. The inverse gas turbine process works similar to a conventional gas turbine process, however, not by expansion from high to ambient pressure, but by expansion from ambient pressure to low pressure. In the combustion chamber biomass is burned under atmospheric conditions. The flue gas (2) is cleaned by a high temperature filter and cooled by steam or water injection from 1000 to 700 °C. Then the flue gas expands in the gas turbine to 0.3-0.39 bar (3), performing work. The still hot flue gas (500-600 °C) is cooled in a series of heat exchangers. Process- or district heat is extracted. The flue gas exiting the condenser (4) is compressed to ambient pressure (5) while raising the temperature from 50 to 170 °C. Residual heat is utilized for pre-heating the combustion air to 130 °C.

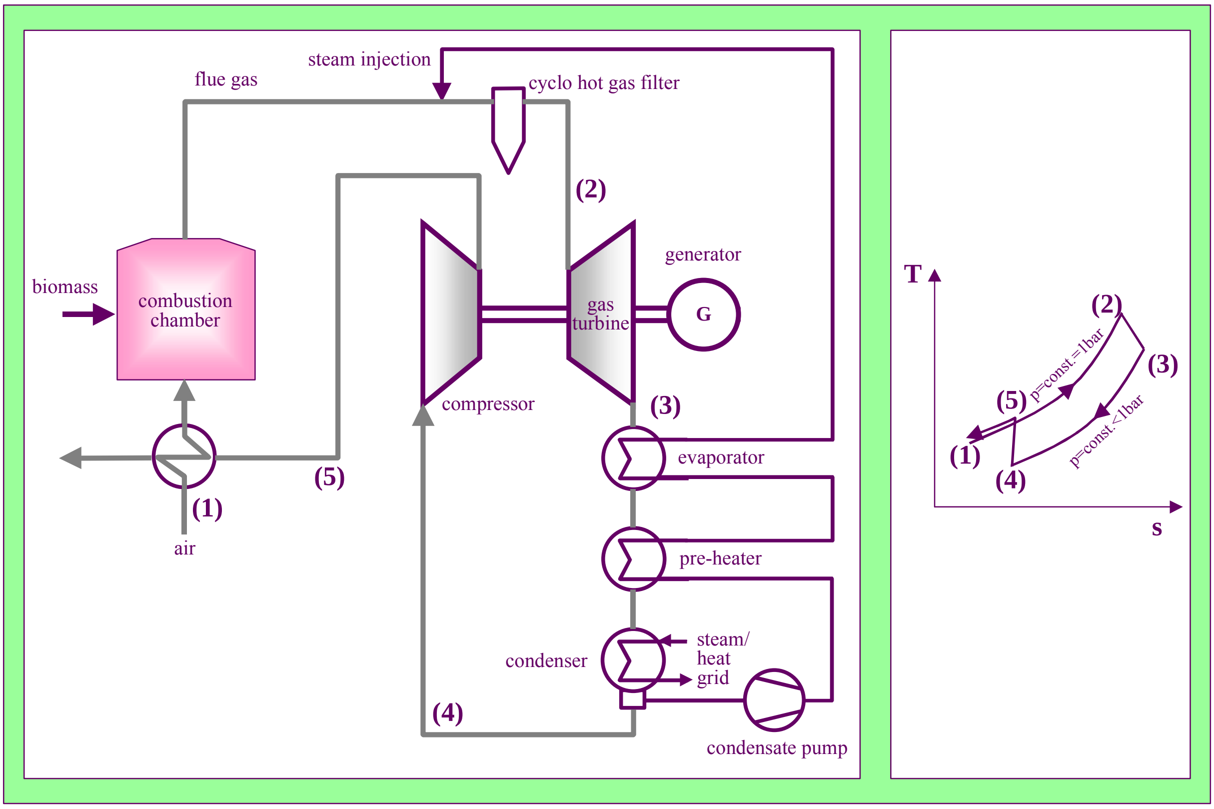

Figure 7-24: Scheme of direct (inverse) gas turbine process for biomass CHP and T-s-diagram of this process

The inverse gas turbine process shows a moderate part load efficiency (see figure 7-28). The electrical efficiency lies with 14 to 21 %. For a summary of the technical data see table 7-7.
The inverse gas turbine process is in its conceptual phase. Investment costs with a 500 kW unit lie at 4100 US$/kW, making the direct gas turbine process the currently most expensive option for biomass CHP. The investment cost development in the 200 to 1400 kW range is shown in figure 7-29.

Indirect (Hot Air) Gas Turbine Process (HAT)

Figure 7-25 shows the scheme of the hot air turbine process. In the combustion chamber biomass is burned. The hot flue gas is cleaned in a high temperature cyclone. Part of the heat is transferred to air in a high temperature heat exchanger (here the flue gas is cooled from 900 to 500 °C). Most of the residual heat is transferred to water (for steam injection) and district/process heat. In counter current ambient air (1) is compressed to 10 bar (2), cooled by injected steam and heated in the high temperature heat exchanger from 300 to 850 °C (3). Subsequently the hot air expands through a 1 step gas turbine (4). The expanded 500 °C air pre-heats the combustion air for the biomass burning.

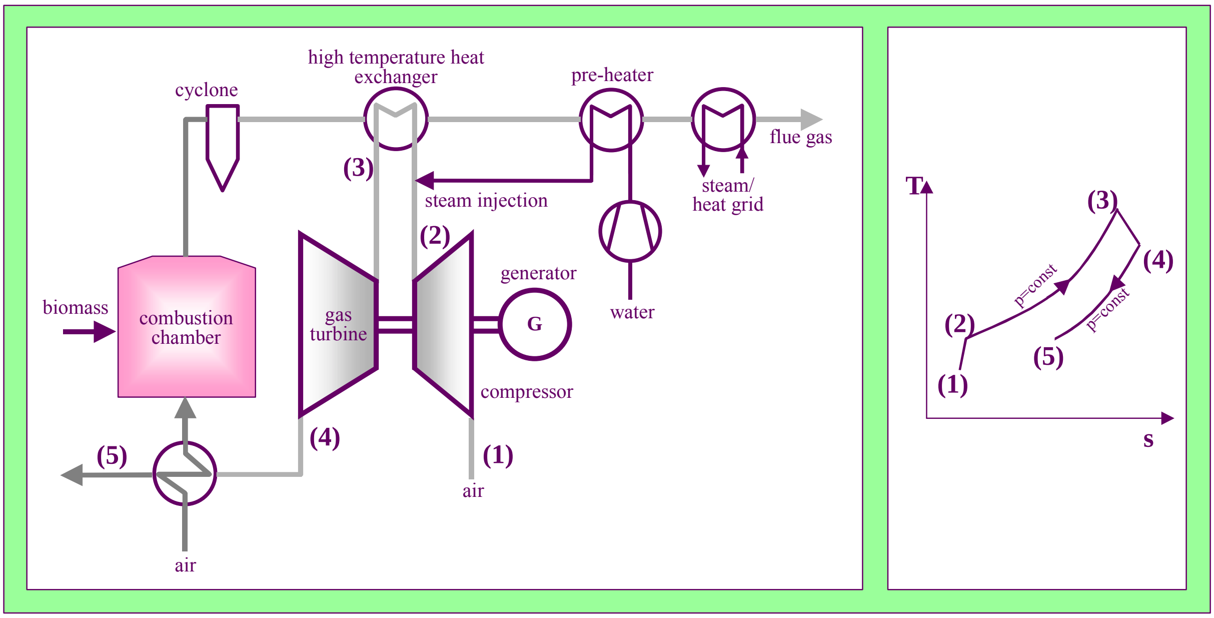

Figure 7-25: Scheme of indirect (hot air) gas turbine process for biomass CHP and T-s-diagram of this process

The critical part of the HOT process is the high temperature gas to gas heat exchanger. It takes up 17 % of the total investment costs. An extensive noise reduction equipment also is needed. A limiting factor for the process is the relatively low part load efficiency (see figure 7-28). The electrical efficiency lies between 13 and 24 %. For a summary of the technical data see table 7-7.
The HAT process is in its demonstration phase. Further applications might combine the HAT process with existing coal power plants leading to efficiencies of up to 50 %.
Investment costs with a 250 kW_{el} unit lie at 3400 US$/kW. The investment cost development in the 200 to 1800 kW_{el} range is shown in figure 7-29.

Solid Bed Gasification + Gas Engine or Fuel Cell (SBG+GE)

A gas engine has special requirements on the purity of the gas used as fuel (see table 7-8). These requirements can only be met by combining a co-current solid bed gasification with an extensive gas cleaning cleaning as discussed in chapter 6.2.3. A gas cleaning technology which is currently tested for the special application of biogas for gas engines is textile filters coated with removable calcium-oxide. This calcium-oxide adsorbs the tars. When it is depleted it can be removed from the carrier textiles and a new reactive layer is applied.

Table 7-8: Requirements of a gas engine on the product gas from biomass gasification (referred to a gas with 5 kWh/Nm^3 lower calorific value) /7/

Dust concentration in mg/Nm^3	Particle size in µm	Tar concentration in mg/Nm^3	Concentration of alkaline metals (Na, K) in mg/Nm^3
<25	<3	<10	unknown

The thermodynamic process of gas combustion in the gas engine is depicted in figure 7-26 as p-V and T-s-diagram: After mixing the cleaned product gas with combustion air, the mix flows into the gas engine (step (e) to (a)). The mix is compressed (b) and ignited. The chemical energy of the mix is released increasing pressure and temperature (c). The piston of the gas engine is allowed to move,

performing work, the combustion gases expand (d). At opened exit valve the expanded gases are pushed out of the gas engine (step (d) to (e)). The exit valve closes, the inlet valve opens and the cycle starts again.
The electrical generator is directly connected to the gas engine. No shift gear is necessary.

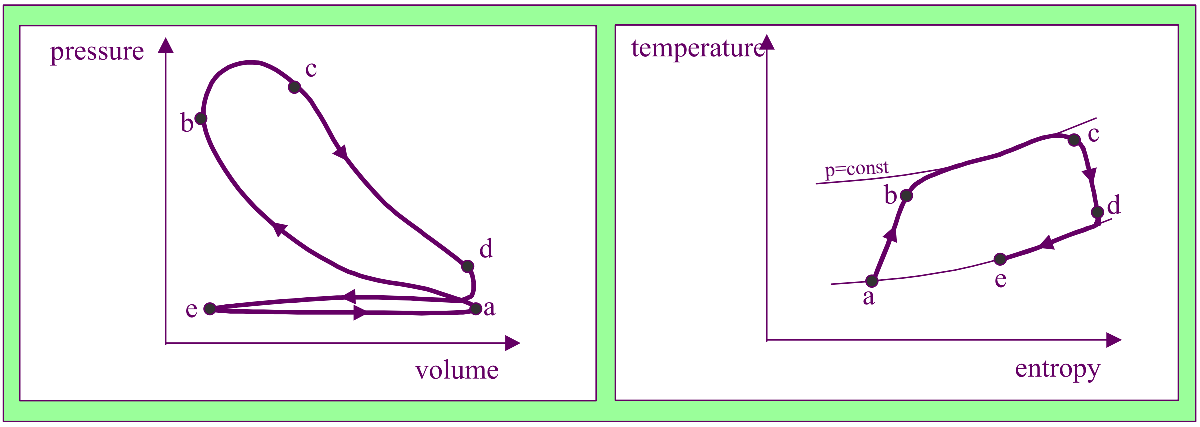

Figure 7-26: p-V and T-s-diagram of a gas engine

The product gas from thermal biomass gasification shows only limited pre ignition resistance, reducing the engine efficiency to 30-37 % /1/. The product gas has a low heat content (approximately 5 MJ/Nm³). Thus the product gas must be compressed. Additionally the gas cooled is below 30 °C allowing water removal and gas cleaning. Table 7-9 shows the German limits for pollutants in exhaust gas of stationary engines. Biomass gas engines have difficulties to stay below the limit for CO. An option for solving this problem is the application of an oxidation catalyst, which, however, only can be introduced when the product gas is free of heavy metals. It is not yet clear if this requirement can be fulfilled.

Table 7-9: Exhaust gas limits from stationary motors according to TA-Luft /7/ referred to 5 % O_2 contents in the dry exhaust gas

Concentration of hydro carbons in mg/Nm³	Concentration of NO_x in mg/Nm³	Concentration of CO in mg/Nm³
<150	<500	<650

Gas engines show an excellent part load efficiency (see figure 7-28). The electrical efficiency of the total biomass gas engine process lies between 15 and 30 %. For a summary of the technical data see table 7-7. Investment costs with a 200 kW unit lie at 1600 US$/kW. The investment cost development in the 50 to 2000 kW range is shown in figure 7-29.

Research is under way to prove the feasibility of power production from biomass using fuel cells. The requirements on gas cleanness are even higher than with gas engines (see table 7-10). A gas cleaning process consisting of 3 steps:

- tar removal by thermal or catalytic cracking
- CO to CO_2 shift reaction
- fine purification with
  - a palladium membrane which is only permeable for hydrogen,
  - an iron sponge reactor in which iron-oxide is reduced by the product gas to iron, which then reduces pure water to hydrogen,
  - or CO_2 scrubbing and methanization of CO,

is currently investigated in Germany and Austria /10/. It, however, will take some years till such a process can achieve industrial maturity.

A drawback for the combination of thermally gasified biomass with fuel cells is the high share of inert components in the product gas which leads to low power densities in the fuel cell.

Table 7-10: Requirements of fuel cells on product gas quality /1/			
	PAFC	MCFC	SOFC
CO	< 1 Vol%	-	-
H_2S	< 6 ppm	< 0.1-1 ppm	< 0.1-1 ppm
Chlorine	< 0.05 ppm	< 1 ppm	< 1 ppm
Nitrogen	< 1 ppm	?	< 5000 ppm
Dust	< 1 mg/Nm³		
Tar	?		

Fluidized Bed Gasification + Gas Turbine (FBG+GT)

The requirements of a gas turbine on the purity of product gas from biomass gasification are less strict than the requirements of a gas engine (see table 7-11). As a consequence gas turbines can be combined with fluidized bed gasification to a process as shown in figure 7-27.

Table 7-11: Requirements of a gas turbine on the product gas from biomass gasification /7/			
Dust concentration in mg/Nm³	Particle size in µm	Tar concentration in mg/Nm³	Concentration of alkaline metals (Na, K) in mg/Nm³
<30	<5	Unknown	<0.24

The process shown in figure 7-27 features fluidized bed gasification with internal circulation. The gasifier consists of two compartments, the gasifying part with stationary fluidized bed and the combustion part with circulating fluidized bed. The two chambers are connected by a channel through which the bed material (sand and catalyst) and solid biomass residues (char coal) flow from the gasification chamber to the combustion chamber. In the burning chamber the bed material is fluidized and the char coal is burned by preheated air. 850 to 900 °C are reached. The bed material leaves the burning chamber together with the flue gas, is separated from the flue gas in a cyclone and brought back to the gasification chamber. In the gasification chamber a temperature of 800 °C is maintained in order to crack tar in the product gas.
The bed material is the main heat exchange medium for transferring energy from the combustion chamber to the gasification chamber. A part of the product gas is used for fluidizing the gasification chamber. This leads to an increased calorific value of the resulting product gas and to reduced nitrogen oxide formation.
At a biomass water content of 35 % about 80 % of the biomass is gasified and 20 % is burned in the above described process.

After leaving the gasification chamber the product gas is cleaned by hot gas filtration at 350 to 500 °C. The product gas and air (1) is compressed (2) and burned together in the gas turbine combustor (3). The hot flue gas enters the gas turbine and expands (4). In a heat exchanger energy is transferred from the off-gas to district/process heat.

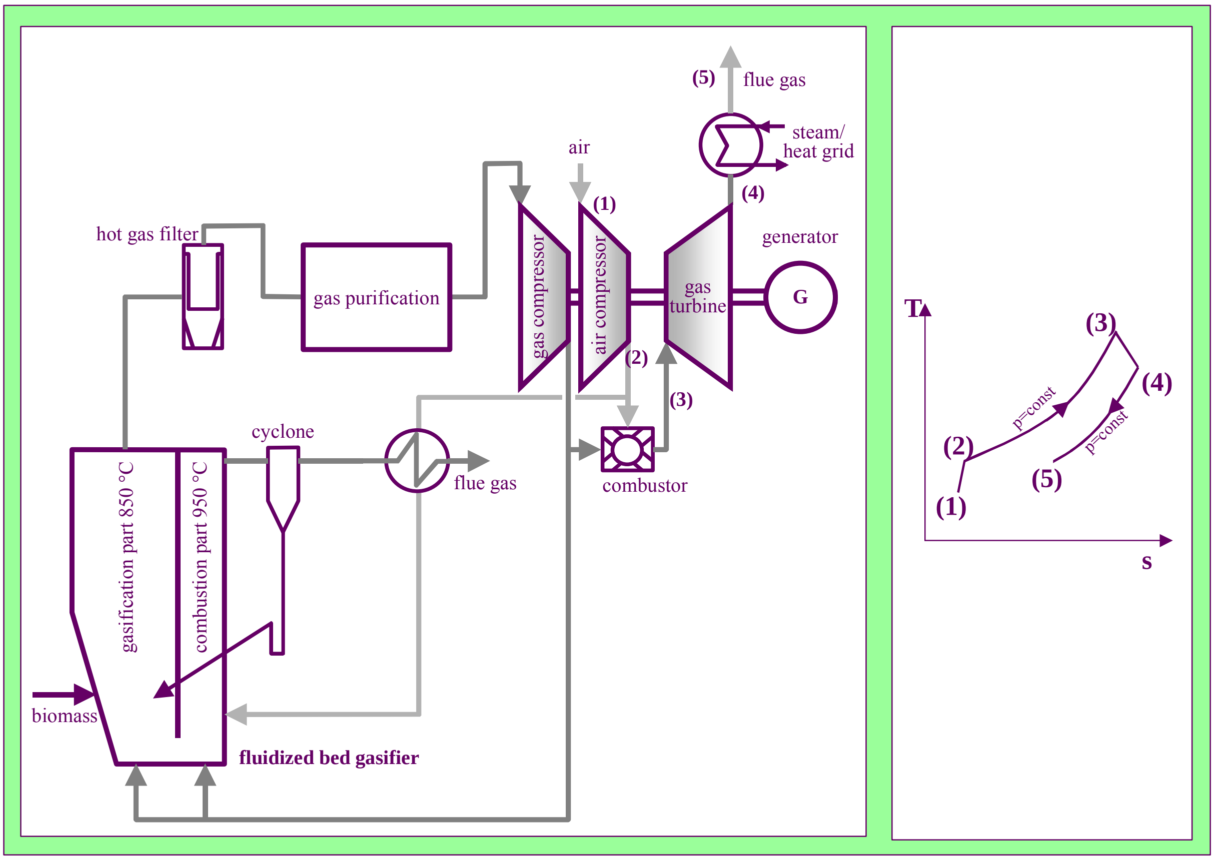

Figure 7-27: Scheme fluidized bed gasification + gas turbine process for biomass CHP and T-s-diagram of this process

Disadvantages of the process are a long start up phase of 8 to 9 hours and the low flexibility. Minimum operation capacity is 70 % of full capacity (see figure 7-28). The electrical efficiency lies between 20 and 25 %. The process is available for electrical capacities bigger than 1 MW. For a summary of the technical data see table 7-7.
The LM2500 aeroderivative gas turbine by General Electrics has shown its applicability for thermal biogas combustion /11/. A 8 MW_{el} demonstration project is currently under construction in Guessing/Austria by TU-Wien and Austrian Energy /12/.
Investment costs with a 1 MW unit lie at 3400 US$/kW. The investment cost development in the 1 to 2 MW range is shown in figure 7-29.

Comparison of Biomass CHP Technologies

Figure 7-28 shows the part load efficiency of the discussed biomass CHP technologies. It can be seen that especially steam and gas engines maintain their full load efficiency over a wide range of load variation. Small steam turbines and Stirling engines show relatively low part load efficiency. Gas turbines in combination with fluidized bed gasification have a very restricted load flexibility.

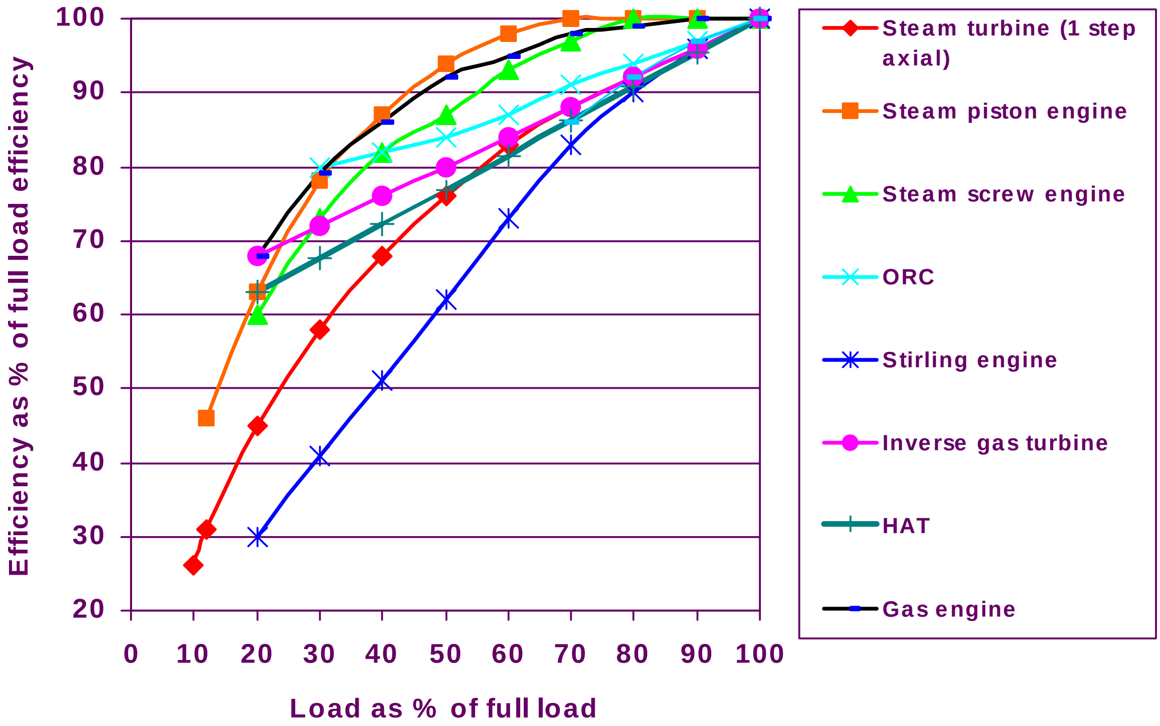

Figure 7-28: Comparison of part load efficiency of biomass CHP technologies /7/

Figure 7-29 shows the investment costs for complementing an existing heat production plant by a biomass-power generation technology over the capacity range which is typical for de-central biomass CHP. It can be seen that especially steam turbines and steam screw engines provide the lowest investment costs over a wide capacity range. This is reflected in typical power generation costs as shown in table 7-7. Table 7-7 gives also a summary of the technical/economic parameters of the discussed biomass-CHP processes. Advantages and disadvantages, status of development and technical milestones of these technologies are summarized in table 7-12.

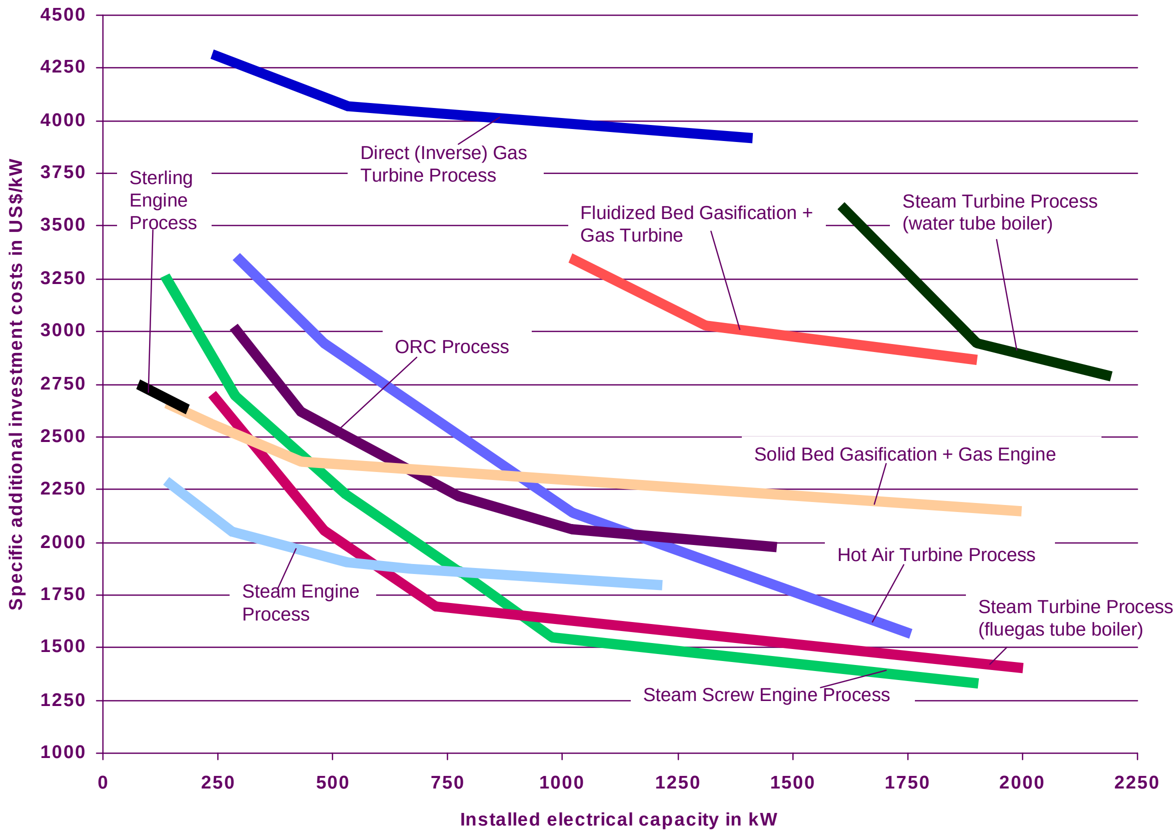

Figure 7-29: Investment costs of adding a power generation technology to an existing heat plant /7/

Table 7-12: Status of biomass-CHP processes /7/					
Process	Milestones	Strength	Weaknesses	Application	Develop-ment status
STP	mature technology	wide capacity range, mature, low investment costs	low efficiency, especially in part load, sensitive to water condensation	industrial CHP	mature
SEP	mature technology, regular maintenance decisive	Very good part load efficiency, low investment costs	low electrical efficiency, high maintenance demand, lubricant emission	CHP and small and medium sized enterprises (saw, wood industry)	mature
SSEP	even low energy level can be utilized as technology can also work with wet steam	Good part load efficiency, low maintenance demand, utilization of wet steam possible	Little experience, limited steam pressure	CHP and small and medium sized enterprises	develop-ment phase

ORC	mature technology, biomass ORC new, working medium decisive	good part load efficiency, easy to automatize	no experience with biomass, thermo-oil cycle necessary	CHP and small and medium sized enterprises	demon-stration phase
StEP	very compact, critical is the heater heat exchanger	Compact, simple addition to existing heat plants, low maintenance requirements, low noise level	heater-heat exchanger, leakages, low part load efficiency, limited unit capacity	Addition to biomass heat plants for covering own power consumption	develop-ment phase
DGT	expansion into vacuum, no experience with biomass effects on turbine	good efficiency, low pressure, possibility of combined cycle	expensive, little experience, complicated	Industrial CHP with constant heat demand	concep-tual phase
HAT	very complex technology, critical high temperature heat exchanger	high electrical efficiency, big capacities possible	complex process, difficult start-up, low availability	Industrial heat production with heat extraction	demon-stration phase
SBC+ GE	high electrical efficiency, gas cleaning needs to be improved	high electrical efficiency, very good part load efficiency, wide capacity range	cleaning of product gas difficult, low total efficiency, not mature	in biomass CHP and small and medium sized enterprises	develop-ment phase
FBG+ GT	relative complex, no part load flexibility	high electrical efficiency	Cleaning of product gas necessary, nearly no part load flexibility, not mature	base load CHP in bigger district heat schemes and wood industries	develop-ment phase
STP = steam turbine process, SEP = steam engine process, SSEP = steam screw engine process, ORC = organic Rankine cycle process, StEP = Stirling engine process, DGT = direct gas turbine process, HAT = hot air turbine process, SBC+GE = solid bed gasification + gas engine, FBG+GT = fluidized bed gasification + gas turbine					

4.3 Biomass Cofiring

4.3.1 Cofiring Technologies

Co-firing is the simultaneous combustion of biomass and fossil fuels. The advantages of co-firing are:

- leveling of (seasonal) fluctuations in biomass supply;
- stabilization of fuel heat value;
- increase of power plant capacity /1/;
- the low additional investment costs of about 400 US$/kW /13/;
- biomass with a water content of up to 69 % can be utilized without drying;
- the product gas does not need to be purified prior to combustion;
- the gasifier can be operated down to 50 % of full capacity;

- an electrical efficiency for the biomass to power conversion of 38 to 40 % is achieved.

Co-firing of wood with coal, peat and fuel oil in special co-firing plants is an established technology. Recent pilot projects feature the co-firing of biomass in existing pulverized coal power plants. As shown in figure 7-30 the principle possibilities for combining biomass combustion with pulverized coal combustion are:

- combustion of biomass in an additional combustion chamber and feed of the flue gas into the boiler of the coal power plant;
- application of an own biomass grate for biomass combustion below the burning zone of the coal (an example for this option is installed in the coal power plant St. Andrae, where bark and wood chips are burned on a countercurrent stair grate);
- pulverization of biomass (< 6 mm) and feed together with pulverized coal;
- thermal biomass gasification and feed of the produced gas (lower heating value = 2.5-5 MJ/Nm³) / char coal powder (< 0.2 mm) into the coal boiler. The scheme of such a kind of plant as installed with the coal power plant Zeltweg is shown in figure 7-31.

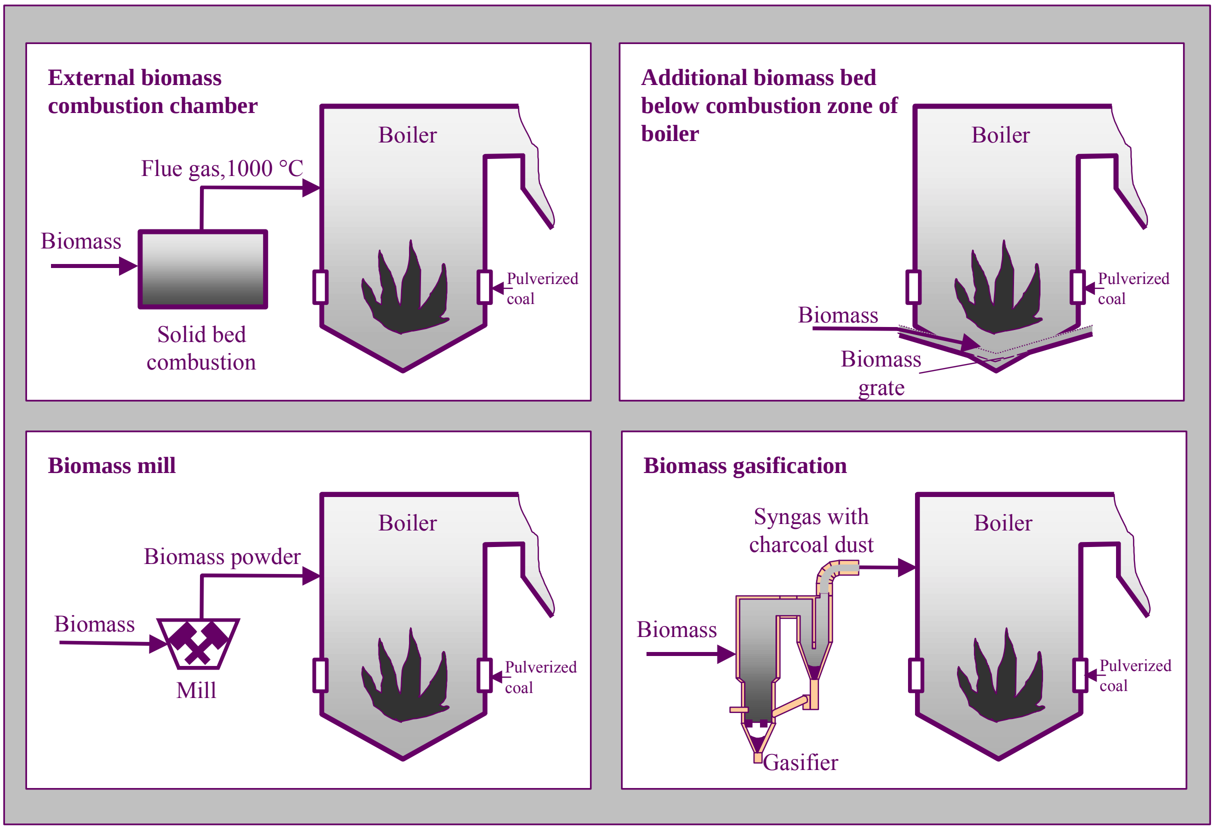

Figure 7-30: Methods for co-firing biomass with pulverized coal /14/

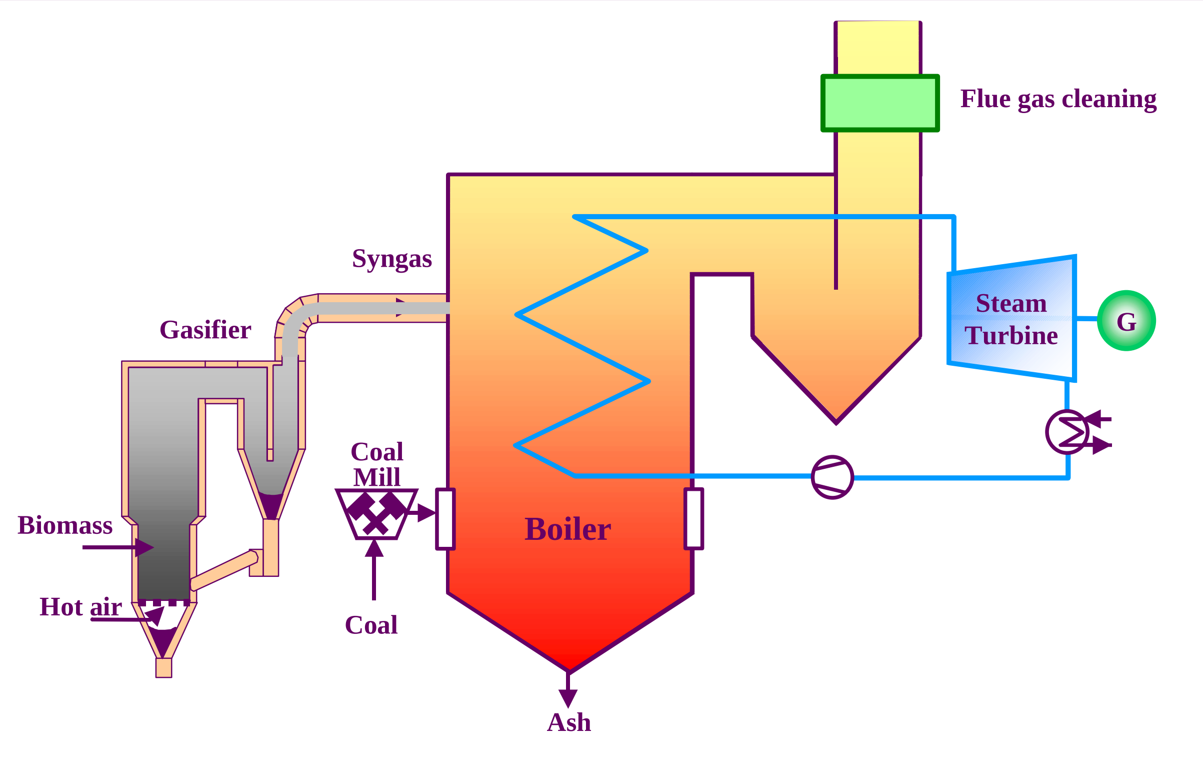

Figure 7-31: Scheme of biomass co-firing in Zeltweg coal power plant /15/.

4.4 Biomass Power Plants

4.4.1 Technology Description

The focus of developments for large scale biomass power plants lies with improvements of the IGCC process. One design concept of biomass IGCC, the TPS-process, is shown in figure 7.32. This process is based on two circulating fluidized bed reactors (a biomass-gasifier and a tar-cracker). A 8 MW_{el} TPS plant is currently constructed in Yorkshire/UK. Other concepts, like the VEGA process of Vattenfall or the Värnamo plant of Sydkraft AB feature pressurized gasification. Further demonstration plants are under operation in Hawaii (the fuel is sugar cane residues) and in Vermont (with wooden residues as fuel) funded by the US department of energy Biomass Power Program, and in Brazil funded by the World Bank /16/.

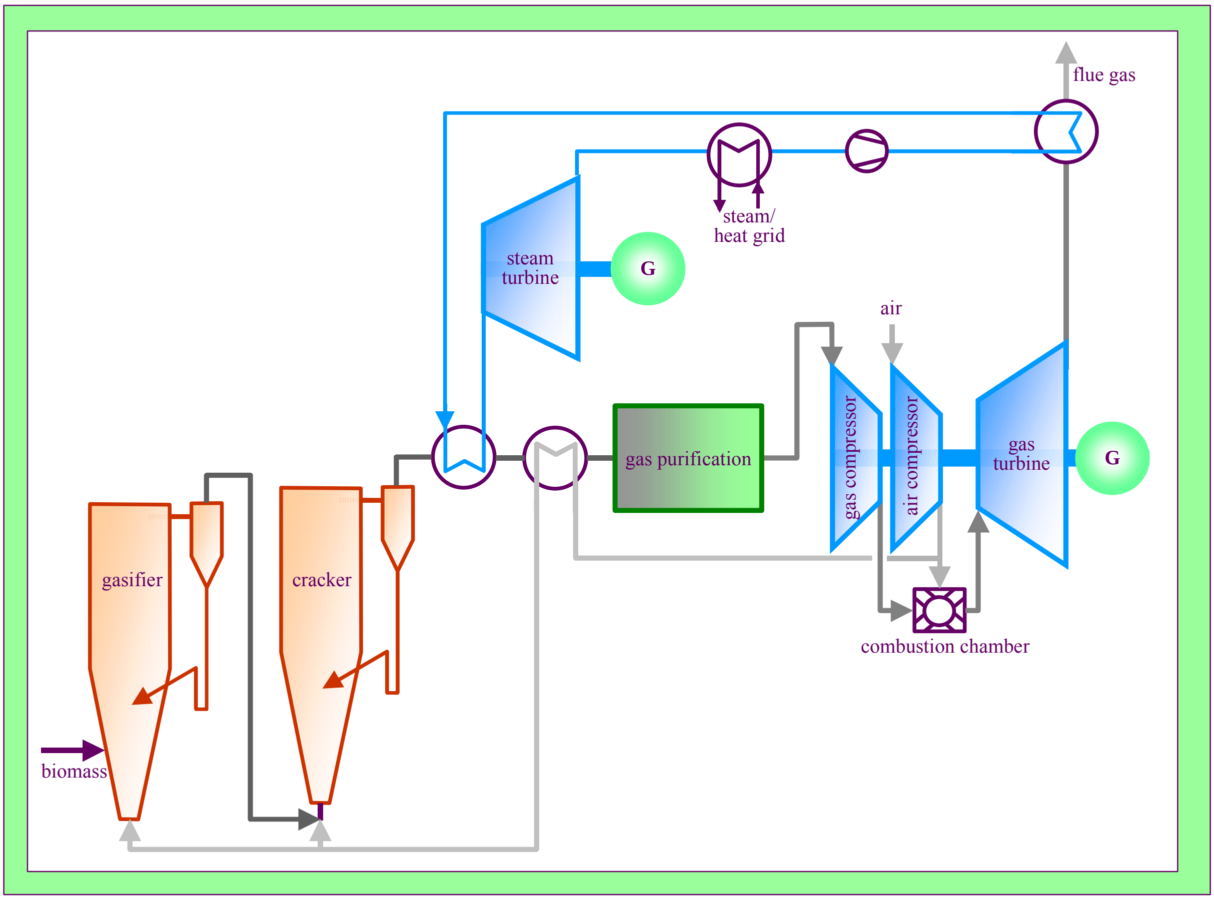

Figure 7.32: Scheme of a biomass IGCC (integrated gasification combined cycle) plant

4.4.2 Market Potentials and Costs

Development goals for biomass gasification power plants are capital costs <1900 $/kW for 2005 and <1500 $/kW for 2010 /17/.
Figure 7-33 shows the expected contribution of different technologies to power production capacity from biomass in the United States. It can be seen that for IGCC the biggest future market is anticipated.

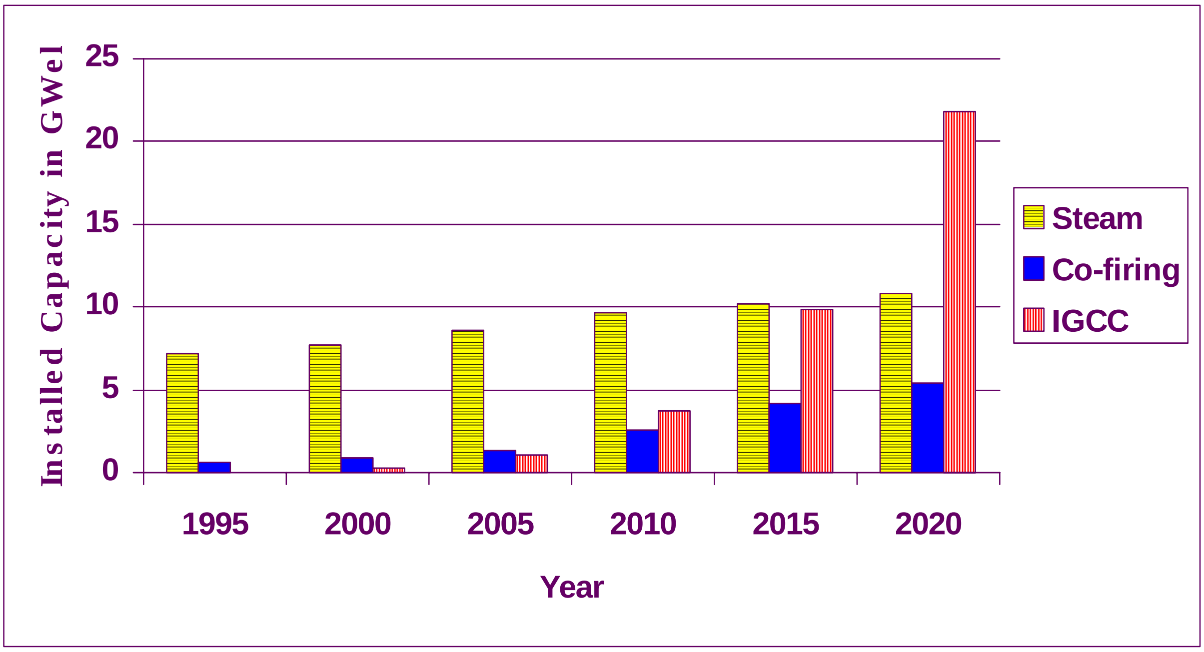

Figure 7-33: US power generation capacity from biomass /18/

4.5 Biogas

4.5.1 Biogas Technologies

Anaerobic fermentation is the wet conversion of agricultural or communal residues by certain bacteria to biogas, a mixture mainly of methane and carbon dioxide. Solid biomass like wood or straw show a very slow biodegradation rate. That is why biofermentation of this kind of biomass is not economic.

Different fermenter types are commercially available. Usually fermentation is performed in a totally mixed reactor as shown in figure 7-34. Mesophilic bacteria achieve maximum conversion rate at temperatures of 30 to 40 °C, thermophilic bacteria at 50 to 60 °C. As heat source for keeping the fermenter at the optimal temperature, 15 to 30 % of the produced biogas is used. For the generation of 1 kWh power and 1.24 kWh heat 5-7 kg bio-waste, 5-15 kg municipal waste, 8 to 12 kg cattle waste or 4-7 m^3 organic waste is required.

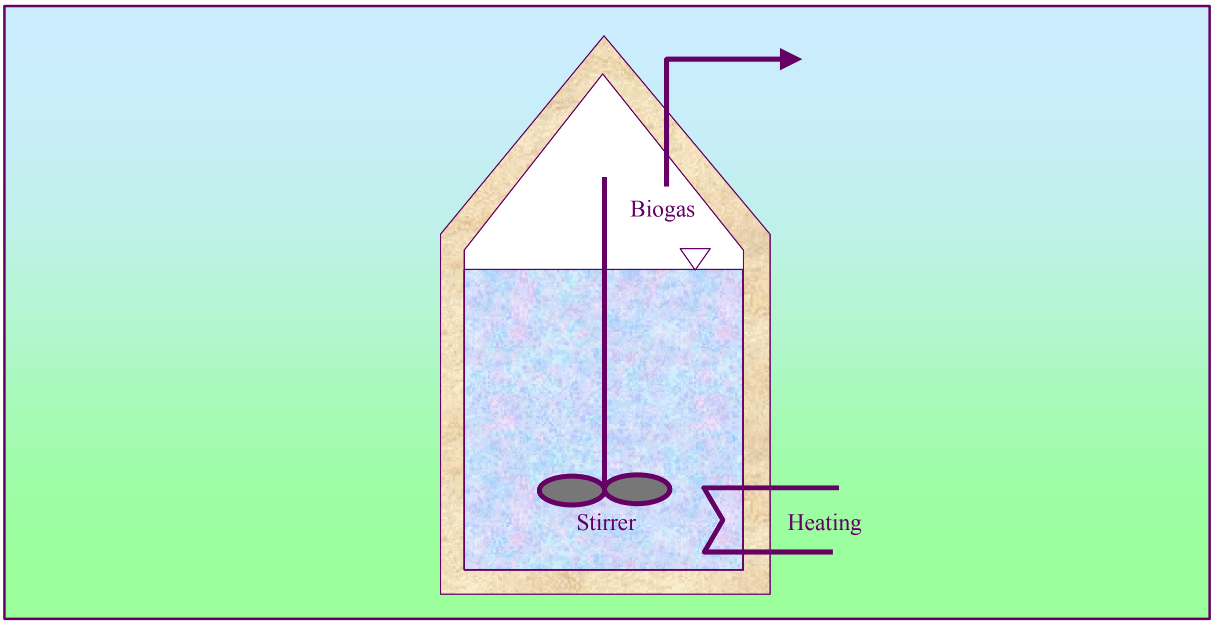

Figure 7-34: Scheme of a biomass fermenter /7/

The high share of carbon dioxide in biogas, sewage gas and landfill gas (>30 %) give these gases a high pre ignition resistance. That is why these gases are appropriate for combustion in stationary engines. The conversion of biogas to mechanical energy is usually performed by gas engines. Gas engines are sensitive to biogas impurities (see table 7-13). That is why gas cleaning frequently is necessary. For further details on gas engines see chapters 5.5 and 6.2.4.

Table 7-13: Requirements of a gas engine on biogas composition /7/

H_2S concentration in mg/m³CH_4	Chlorine concentration in mg/m³CH_4	Fluor concentration in mg/m³CH_4
<1500	<100	<50

In the range from 1 to 5 MW_{el} also gas turbines are in use. Figure 7-35 shows the development of the gas turbine efficiency over this capacity range.

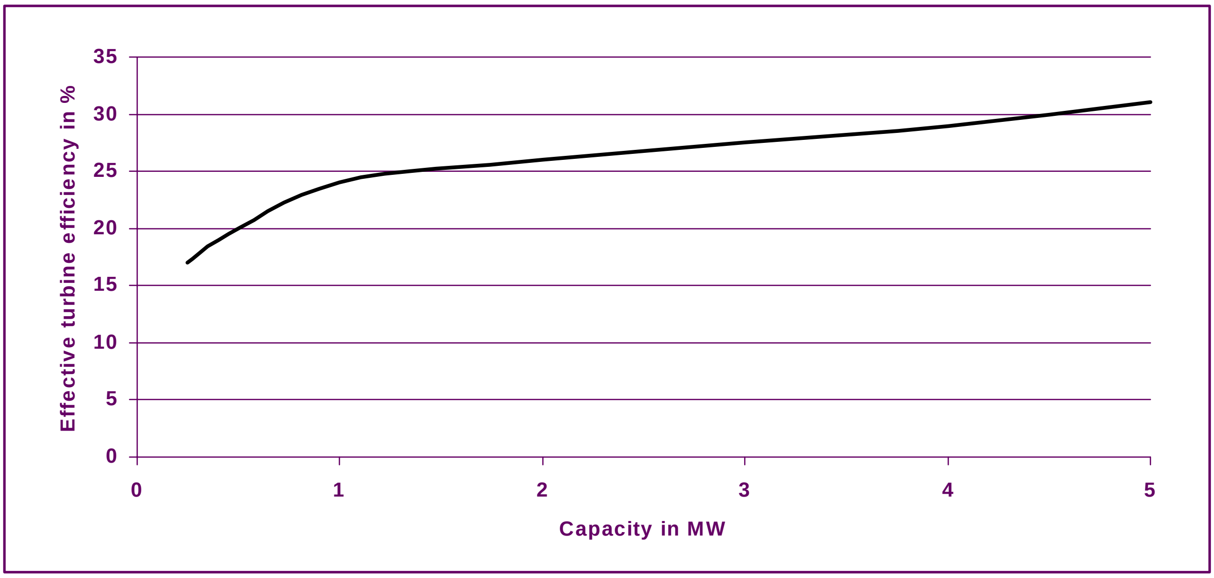

Figure 7-35: Gas turbine efficiency with biogas combustion /7/

The combination of biogas with fuel cells is in the demonstration phase. The 200 kW_{el} – PAFC landfill gas plant Penrose in Sun Valley California shows promising test results /19/.

4.5.2 Current Market Penetration and Costs

The highest penetration of biogas plants is found in threshold countries like China or India, where biogas is mainly used for cooking /7/.

Table 7-14 shows the number of biogas based plants in Austria as of 1996.

Table 7-14: Total number of biogas installations in Austria (1996) /20/

Installations	Number
Agricultural installations	58
Anaerobic digesters	3
Industrial installations	6
Municipal sludge digesters	118
Landfill gas recovery	11
Total	196

4.5.3 Future Market Potentials

The potential for biogas from cattle in Austria is estimated to be 1130 GWh/a for electricity production plus 1170 GWh/a for heat production /21/. The typical Austrian farm with an average 18 cattle per farm can only produce 25 m^3 biogas or 50 kWh power per day, which corresponds to the consumption of 4 households. According to /22/ biogas fired combined heat and power plants are economic at a demand of 70 kW_{el} upwards. This capacity could, however, only be achieved by the cooperation of 11 average Austrian farmers or by one farmer who grows 200 cattle.
In Denmark where farms with big numbers of cattle are more frequent than in Austria, 20 biogas plants with a total biogas production of 140.000 m^3/d are installed. These plants can produce 100 GWh/a of electric power.

5 Conclusions

The amount of biomass utilisation as an energy source varies considerably between developing, transition, and industrialised countries. Whereas biomass is a significant energy source in developing countries, in transition or industrialised countries it does not play such a large role – ranging from almost no utilisation to about 3-4%.

The role of biomass in the next century is projected to increase significantly. Estimates of the technical potential of biomass energies are much larger than the present world energy consumption. In fact, several different scientific studies predict the future contribution of biomass to the global energy supply to range from 11-46%, whereas today it is approximately 11%.

Modernisation of biomass technologies will make them both environmentally friendly and economically competitive. If agriculture is modernized up to reasonable standards in various regions of the world, several billions of hectares may be available for biomass energy production well into this century. This land would comprise degraded and unproductive lands or excess cropland, and preserve the world's nature areas and quality cropland.

The development of modern biomass technologies depends on various factors. There is no doubt that the world energy use will continue to increase steadily in the next century. The share of renewable energy will also rise slowly, especially as a result of new technologies that will be developed in industrialised nations where renewable energies receive financial and regulatory support from governments in their efforts to reduce dependence on fossil fuels. Thus, one major driving factor will be the fossil fuel market. Other driving factors will be social and environmental concerns, such as greenhouse gas emissions. A key issue is also developing the natural resources that are used in biomass technologies – be it crops on degraded lands, wooden residues, animal matter, agricultural biomass, and other biomass fuels – the optimal land development patterns for biomass energies need yet to be researched.

6 List of Abbreviations

CC	Combined Cycle
CEE	Central And Eastern Europe
CGH_2	Compressed gaseous hydrogen
CHP	Combined Heat And Power
CNG	Compressed Natural Gas
CO	Carbon-Monoxide
CO + H2	Syngas, Gasification Product Gas
CO2	Carbon-Dioxide
DG	Distributed Generation
DGT	Direct (Inverse) Gas Turbine Process
DMFC	Direct Methanol Fuel Cell
DOE	U.S. Department Of Energy
EPRI	U.S: Electric Power Research Institute
FBC	Fluidized Bed Combustion
FBG+GT	Fluidized Bed Gasification + Gas Turbine
FC	Fuel Cells
FGD	Flue Gas Desulfurization
GE	Gas Engines
GT	Gas Turbines
H2	Hydrogen
HVAC	High Voltage Amplifying Current
HVDC	High Voltage Direct Current
IGCC	Integrated Gasification Combined Cycle
IT	Information Technology
LFC	Liquids From Coal
LH_2	Liquefied hydrogen
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MCFC	Molten Carbonate Fuel Cell
MH_2	Metal hydrides
NGCC	Natural Gas Fired Combined Cycle
NGCCC	Natural Gas/Coal Fired Combined Cycle
NGICC	Natural Gas Fired Turbine Integrated With Existing Plant
NGST	Natural Gas Fired Steam Turbine
NH3	Ammonia
NOx	Nitrogen Oxide
O&M	Operation And Maintenance
OECD	Organization For Economic Co-Operation And Development
ORC	Organic Rankine Cycle
p	Pressure
PAFC	Phosphoric Acid Fuel Cell
PEFC	Polymer Electrolyte Fuel Cell
R&D	Research & Development
R/P ratio	Reserve to Production ratio in years

s	Entropy
SBC+GE	Solid Bed Gasification + Gas Engine Or Fuel Cell
SEP	Steam Engine Process
SO2	Sulfur Dioxide
SOFC	Solid Oxide Fuel Cell
SSEP	Steam Screw Engine Process
StEP	Stirling Engine Process
STP	Steam Turbine Process
T	Temperature
ZEV	Zero Emission Vehicles

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