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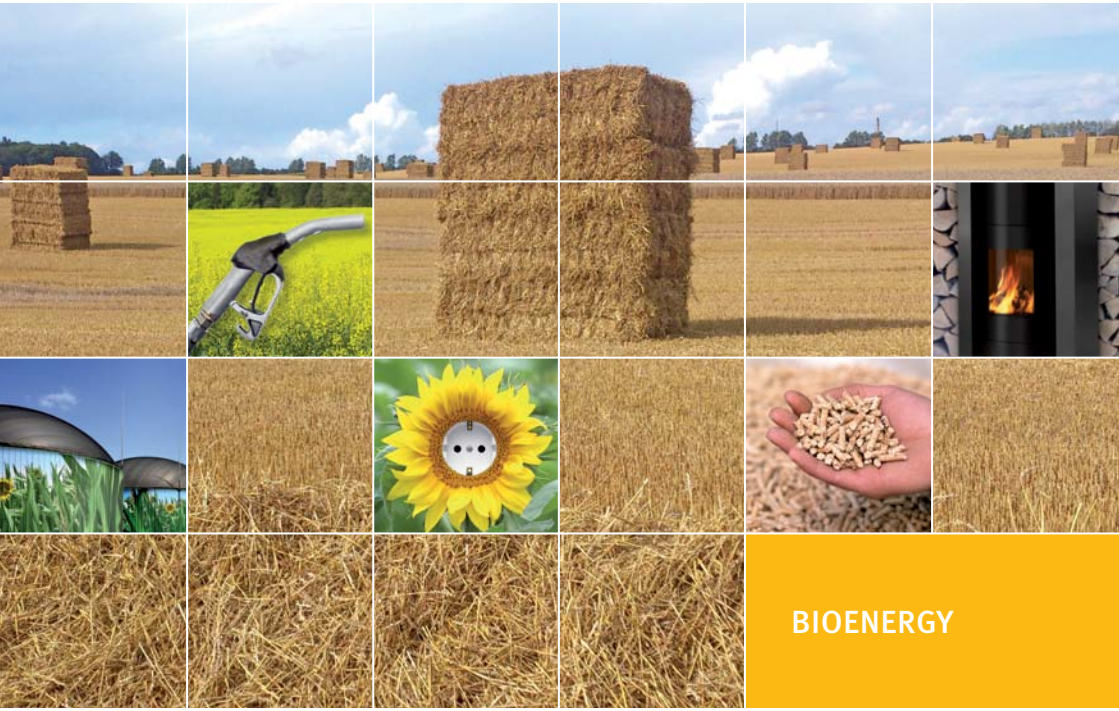
BIOENERGY

the multifaceted renewable energy



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FOREWORD

Bioenergy is Germany's most significant renewable energy source and will remain so for the foreseeable future. At roughly two thirds, bioenergy makes the largest contribution to the supply of energy from renewable sources. Up to now biomass has been the only renewable energy source in the fuel sector while in heat generation, with around 90 percent share, it is the predominant one. In generating renewable electricity, bioenergy is in second place after wind power and before photovoltaics. Bioenergy thereby makes a substantial contribution to the efforts to conserve fossil-based resources, reduce dependence on petroleum, protect the environment and create economic value and employment in rural areas.

Against a background of finite fossil-based resources and advancing climate change, Europe faces the urgent task of structuring the supply of energy in a way that is more efficient and more compatible with the environment. Energy sourced from sustainably produced biomass is a very important element in this. Thus the EU and also Germany's Federal Government are planning to further expand the use of bioenergy. The objectives are established in various directives and plans. In these documents, the governments also highlight opportunities and potentials for a sustainable use of biomass; they indicate the measures with which bioenergy – as an integral part of the overall energy-supply concept – should be developed.

The goal is to raise bioenergy's market share significantly, roughly doubling it in relation to the current status. It is also the objective to further improve the results attained in the reduction of greenhouse gases and in the energy efficiency of bioenergy. Particular importance is attached to the use of sustainably produced biomass. Within this, the German Government's plans include the improved development; of organic residues and the expanded use of energy crops.

This brochure aims to provide you with an overview of this great variety of possibilities, advantages and opportunities presented by biomass and bioenergy.

Dr.-Ing. Andreas Schütte,
Chief Executive Officer
Agency for Renewable Resources

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1 BIOMASS – THE MULTIFACETED RENEWABLE ENERGY SOURCE

A variety of terms and definitions are used when referring to biomass. Defining the term broadly, biomass denotes the totality of all living entities, of the present or the past, including the dead matter that remains from organisms that once lived. In the context of renewable energies, all organic matter of plant or animal origin that can be used as an energy source is characterised as biomass.

In its Renewable Energy Directive, the European Union defines biomass as follows: biomass is the biologically decomposable part of products, waste and residual material based on agriculture and of biological origin (including animal-based and plant-based substances), from forestry, and from associated sectors of business, including fishing and aquaculture. According to this definition, the biologically degradable part of waste matter from industry and households also counts as biomass.

Thus, biomass is (among other things)

- plants, constituent parts of plants, and the energy sources produced from plants and their constituent parts;
- waste and by-products (of plant and animal origin) from agriculture, forestry and fisheries and the respective downstream processing operations;
- waste wood from the forest-based industry;
- material from landscape conservation and various organic matter obtained by maintenance of water bodies, including their banks;
- waste wood and
- municipal organic waste.

The term biomass does not encompass biogenic fossil fuels such as petroleum, coal, natural gas and peat, as these do not replenish anytime soon, so they do not fulfil the criteria of renewability.

Wood, with its various points of origin, is currently the most significant energy source from biomass. Wood does not solely come from the forest. Apart from forest waste wood, the following should be mentioned as significant providers of wood (among others): waste/used wood from industry, wood from landscape conservation activities and from agriculture (like agroforestry or short-rotation coppice).

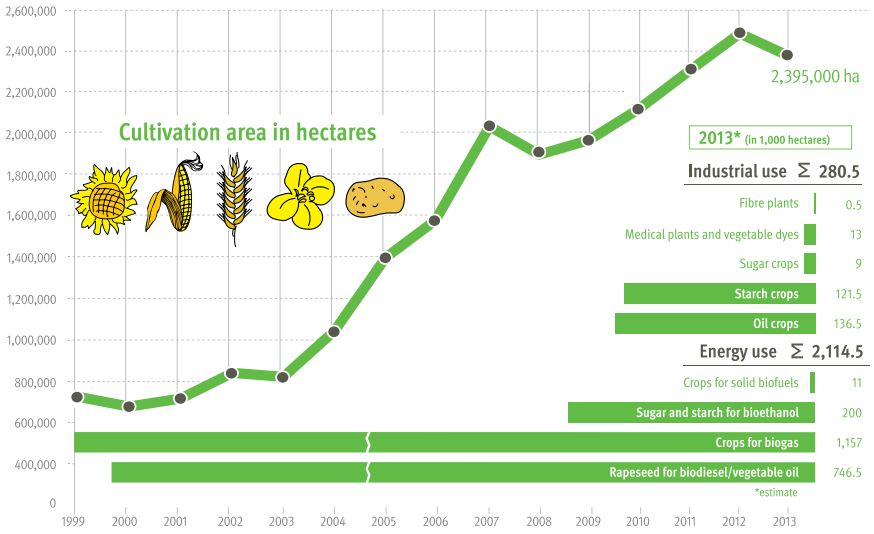
Viewing the possibilities and potentials, energy crops will have the largest contribution to make in the planned expansion of energy generation from biomass. Energy crops are cultivated specifically as an energy source and, according to choice, provide

- substrates for biogas production (cultivation of maize, grass, grain, sorghum, sugar beets and other crops);
- woody biomass or biomass containing lignocellulose for use as a solid fuel (e.g. rapidly growing trees, miscanthus and other tall grasses) and/or
- sugar, starch, or plant oils for biofuels (e.g. cultivation of rapeseed, grain, maize or sugar beets).

Energy crops generate regular and sustainable yields of biomass, as one-year and multi-year crops. One particular advantage of biomass distinguishes it from the other renewable energies: biomass is storable over longer periods (many months or years) and can be made available or used for energy generation, according to demand.

Energy crops are part of renewable resources. The current significance and the scope of agricultural cultivation is shown in the graphic below:

CULTIVATION OF RENEWABLE RESOURCES IN GERMANY



Source: FNR 2013

However, not only the resource base is diverse – the energy sources obtained from it, the processes of conversion and the forms of final energy are also characterised by a wide variety: biomass is available in solid, liquid and gaseous form, for heat, electricity and biofuels. Energy can be sourced from biomass, using the most diverse range of technologies and processes and spanning the broadest spectrum of energy-output categories. Bioenergy in the form of heat is supplied, for instance, by stoves and pellet boilers in private homes. Biogenic heat is also produced by steam generators in industry and businesses, fired by wood chips sourced from forest waste wood, as well as wood-fuelled heating plants used to supply heating to villages and towns/cities. Bioenergy is produced by electricity generation from used wood and industrial waste wood in biomass power plants, and also by co-firing of biomass pellets in coal-fired power stations. Bioenergy is biogas from agricultural biogas plants: it is very versatile in its use for heat and electricity, direct at the plant or distributed via the natural gas grid, or used as fuel – depending on the mode of processing and the conversion procedure. Rapeseed oil pressed at farms and used as fuel for tractors is also bioenergy, as are biodiesel and bioethanol, proportionally admixed to diesel fuels and petroleum by the petroleum industry. Not least, energy generated from municipal organic waste, sewage gas and landfill gas is included in the bioenergy category.

Classification of wood chips according to application

2 BIOMASS IS STORED SOLAR ENERGY – THE BIOCHEMICAL BASICS

In essence, biomass emerges through photosynthesis by plants. By means of solar energy, the carbon dioxide of the air, water and various nutrients combine to form biomasses which can be subdivided into the following groups of substance:

- wood and stalk-materials (lignin, hemicellulose and cellulose)
- sugar, starch and cellulose (carbohydrates)
- oils and fats
- proteins

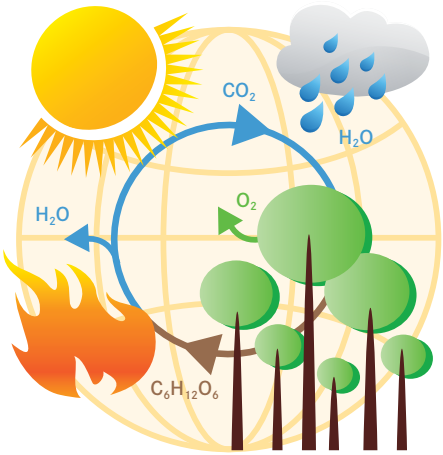
Photosynthesis takes place with oxygen being released in the process. The biomass produced as a result mainly consists of carbon, hydrogen and oxygen. Solar energy is thus stored as chemical energy, e.g. in the form of wood, sugar, oils and fats. Photosynthesis is often displayed with a simplified formula, using sugar as an example.

$$6\ CO_2 + 6\ H_2O + \text{light} = C_6H_{12}O_6 + 6\ O_2$$

If biomass is used as energy, depending on the type of use, the carbon dioxide cycle remains closed to a large degree. Thus the CO_2 balance is decidedly positive compared to fossil-based fuels, because the CO_2 re-released at the time of use was removed from the atmosphere at the time when the plant grew and formed chemical bonds. However, the CO_2 calculation should include the additional energy expended in harvesting, transporting, processing and converting the organic matter (into heat, electricity or fuel), in so far as this use of energy is not covered by renewable sources. For wood fuels such as firewood (typically logs), wood chips or wooden pellets, this additional expenditure of energy is particularly low, accounting for less than 5 percent of the fuels' energy content.

If fossil-based fuels such as coal or petroleum are substituted by biogenic energy sources, this makes an important contribution to avoiding additional CO_2 emissions.

CO_2 CYCLE AND PHOTOSYNTHESIS



Source: FNR

Admittedly, the origin of fossil-based natural resources is likewise nothing other than biomass: they emerged from dead plants and animals, in a process lasting millions of years. Yet humankind is using up the global reserves of oil, gas and coal at phenomenal speed, within just a few centuries. Therefore, the CO_2 balance from the use of fossil-based resources is not in balance, especially because the new formation of fossil-based resources is only taking place on an extremely limited scale. By contrast – on the precondition of sustainable use – plants can grow back again on the same scale on which they are consumed.

The CO_2 balance improves further still in the case of wood burning. Waste wood previously used for many decades in construction or other wood products, is first used as a material and only subsequently used as an energy source (so-called "cascading"). This wood initially withdrew CO_2 from the atmosphere and stored it for a long period of time. It is then burned on a CO_2-neutral basis. The difference in comparison to fossil-based fuels is that not all wood used as a material is burned simultaneously in a short period; moreover, in the period of its use as a material, new trees in the forest replace it on the same scale. In addition: if the wood rots in the forest, it releases the same quantity of energy and CO_2 as it does when it is burned, because in terms of energy the process of biological decomposition operates on more or less the same basis.

Among the biomass formed globally by photosynthesis on land and in the seas, only a very small part is used in feeding humans and animals, in serving as a material, or as an energy source. The global theoretical potential of biomass as an energy source is estimated to be 2,400 exajoule (EJ), yet the sustainably-usable proportion of this is estimated to be merely 100 EJ. In 2008, global primary energy consumption amounted to around 500 EJ. Thus in approximate terms it becomes evident that about 20 percent of current worldwide energy consumption can be provided by biomass.

Since humankind's earliest beginnings, humans have influenced the characteristics and the performance capabilities of plants by means of selection and cultivation, in terms of the plants' role as a supplier of natural resources for food, energy and material products. As part of this, many plants, whether they are trees in the forest or grain, root crops or oil plants on arable fields, cover a variety of needs with their principal products, by-products and residual material. The growing significance of bioenergy leads to plants being cultivated with optimised characteristics and qualities for this segment of use; accordingly, in recent years new terms have entered our language, such as energy beet and biogas maize. These serve to emphasise that beet and maize with especially advantageous and high-performance characteristics are being cultivated for use in biogas plants.

3 POLITICAL GOALS AND LEGAL FRAMEWORK

The background for public support of renewable energy and bioenergy, both by the German Government and by the EU, is the finite nature of fossil-based resources and the growth of the greenhouse effect, caused by use of such resources. Accordingly, the strategies for securing the energy supply and for protecting the environment respectively include energy savings and the increase of energy efficiency, but also focus on the use of renewable energies.

The German Government's goals and measures aimed at expanding the use of biomass, and taking as their foundation the Renewable Energy Directive[1] issued by the European Union in 2009 are anchored in the following:

- the "Action Plan for Renewable Energies" (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety [BMU], August 2010),
- the "National Biomass Action Plan for Germany" (Federal Ministry of Food, Agriculture and Consumer Protection [BMELV], BMU, September 2010) and
- the "Energy Concept for a reliable, affordable energy supply that spares the environment" (Federal Ministry of Economics and Technology [BMWi], BMU, 28 September 2010).

The Biomass Action Plan highlights the areas of potential for bioenergy in Germany, what proportion of this is already being used, and which reserves can still be opened up. Building upon this, it presents the strategies which the German Government is pursuing for the expansion of the use of bioenergy in the areas of heat, electricity and fuel, and what measures are envisaged in this context. Likewise, in its Energy Concept, in which bioenergy is an integral part of Germany's overall concept for energy supply in the future, the German Government

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German Bundestag

[1] *"Directive 2009/28/EC of the European Parliament and of the Council on the promotion of the use of energy from renewable sources"*

declares its commitment to the expansion of the three areas – heat, electricity and fuel from sustainable use of biomass. The Energy Concept formulates guidelines for an energy supply that is reliable and affordable and environmentally friendly. As part of this, a long-term strategy, looking as far into the future as 2050, maps out the path for the far-reaching conversion to energy supply from renewable sources. As a result of the Fukushima catastrophe in the spring of 2011, the intention is to implement the Energy Concept even faster than was originally planned.

Important measurable criteria of the Energy Concept:

- the reduction of greenhouse-gas emissions,
- renewable energies' share in gross final energy consumption,
- the proportion of electricity generation from renewable energies in gross electricity consumption and
- primary energy consumption.

The development paths for these criteria are indicated in Table 1:

TABLE 1: PATHS OF DEVELOPMENT IN THE ENERGY CONCEPT

	Reduction of greenhouse-gas emissions (base year: 1990)	Renewable energies' share of gross final energy consumption	Share of electricity generation from renewable energies in gross electricity consumption	Primary energy consumption (base year: 2008)
2020	–40 %	18 %	35 %	–20 %
2030	–55 %	30 %	50 %	
2040	–70 %	45 %	65 %	
2050	–80 % to –95 %	60 %	80 %	–50 %

Beyond this, the aim is to double the rate of refurbishment of the building stock from ‹ 1 percent at present to 2 percent, in order to improve the efficiency of energy supply for/in buildings. In transport, the goal is for final energy consumption to be reduced by around 10 percent by the year 2020, and around 40 percent by 2050 (base year: 2005). Expansion measures and restrictions on bioenergy are described as follows in the Energy Concept:

1. Improved utilisation of domestic bioenergy potentials, subject to avoiding competition between uses, by means of strengthening the use of organic residues and waste material, agricultural co-products, material from landscape conservation and wood sourced from short-rotation plantations;
2. Enhancing energy and land use efficiency by means of improved management, process development, strengthening the use

of biomass in combined heat-and-power installations, expansion of need-based electricity production from biomass, as a way of supplementing other fluctuating renewable energies, as well as the further development of integrated concepts for the use of biomass, i. e. the innovative combination of installations and processes;

3. Expanded use of biomethane by creating further opportunities for the feed-in into the natural gas grid, in order to make energy available and
4. Supplementing the supply of bioenergy by imports of sustainably generated biomass.

A particular concern in this regard is to avoid competition between these uses and the demands of food and animal feed production, as well as to maintain sustainable and efficient agriculture and forestry that is compatible with nature's needs.

Aside from the political directives and concepts mentioned in the context of future expansion of bioenergy, numerous state legislative rulings are decisive in terms of flanking the current areas of use and also giving support to the attainment of the further goals of expansion. This includes laws, ordinances and directives that determine the requirements, prohibitions, obligations to use, tax incentives, financial support given to investment aid and levels of remuneration.

The following statutory rulings that relate to bioenergy are of particular interest, also for the end-user:


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Federal Immission Control Act (1. BImSchV)

The so-called Small Firing Installations Ordinance determines the fuels permissible for use in boilers and stoves, as well as technical and emission-related requirements and the demands for their supervision by the district chimney sweep. The amendment to this legislation in 2010 issued significantly more demanding requirements regarding efficiency and emission levels for newly-installed heating units. Rules were also set up with regard to installations already in use which must be given a retrofit at a certain point in time or be taken out of service. A variety of solid biofuels, such as grain and renewable resources, were newly designated to be standard fuels – subject to meeting specific stipulations – and more specific requirements were established with regard to the properties of fuels sourced from wood. Fitting into this, the aim behind stricter requirements with regard to emissions of particles and CO, as well as provision of advice to the public in the case of manually-fed biomass installations, is to reduce emission levels and nuisance to neighbours, especially in the case of stoves. Further information is available from the district chimney sweep.

The Energy Saving Ordinance (EnEV)
Via the Heat Protection Ordinance (Wärmeschutzverordnung) of 1995 and the Energy Saving Ordinance, which has already been amended several times, sustained emphasis and effort are being directed to the improvement of heat insulation and the reduction of buildings' energy consumption. The Energy Saving Ordinance 2009 establishes requirements for buildings that are to be newly built and also to existing buildings and installations. It also establishes requirements regarding installations for heating, ventilation, and air-conditioning units, as well as water-processing facilities.

The Energy Saving Ordinance stipulates the issue of energy certificates that indicate and make transparent the buildings' energy consumption for the respective owner of the property and for tenants in residential units.

The Renewable Energy Sources Act (EEG)
The most important legislative instrument available to promote the generation of electricity from renewable sources is the Renewable Energy Sources Act (EEG). It first entered into force in 2000, with later amendments taking market developments into account in mid-2004 and then at the start of 2009 and 2012 respectively. This Act obliges the grid operators to connect installations generating electricity from renewable energies to their grid on a priority basis, as well as to purchase the electricity generated, at fixed rates of remuneration. The legislature has thereby immensely improved the regulatory framework for the generation of electricity from renewable energies. The level of remuneration differs depending on the type of installation and its capacity level. The remuneration period is 20 years plus the year in which the installation enters into service. The basic remuneration and the bonuses are subject to an annual degression: this amounts to 1 percent for installations entering service until 31.12.2011 (EEG 2009), and 2 percent for installations entering service from 2012 onwards (EEG 2012).

For biogas and biomass installations coming into service from 2012 there is an extra input substrate tariff; this is apart from the graduated basic remuneration and it is subdivided into two classes: input substrate tariff class 1 includes energy crops such as maize or beets; input substrate tariff class 2 includes ecologically-advantageous substrates like slurry, material from landscape conservation or new energy crops such as wild flowers. The input substrates in class 2 receives a somewhat higher remuneration than at in class 1. The additional remunerations for both classes do not come within the scope of the annual degression. Bonuses are granted for biowaste fermentation plants and also for biogas upgrading. There is also a special remuneration for so-called small slurry plants, with a maximum electrical capacity of 75 kW. New elements introduced with the EEG amendment of 2012 are a binding minimum use of the produced heat and a limit on the input of maize and grain kernels. Operators' obligation to present documentary proof within the framework of the EEG encompasses documentation on the input substrates used and the checking of these data by the environmental auditor. In order to bring the renewable

energies to the market, as well as to initiate electricity generation that corresponds with demand, a market premium and a flexibility premium were introduced on an optional basis.

For new installations, from 2012 onwards, generating electricity from plant oil or waste wood, the EEG remuneration does not apply.

Renewable Energies Heat Act (EEWärmeG)

The purpose of the Renewable Energies Heat Act is to support the further development of technologies for the generation of heat and cold from renewable energies. The intention of the Act is to contribute – subject to maintaining economic viability – to raising to 14 percent the renewable energies' share of final energy consumption for heat and cold, by the year 2020. The Renewable Energies Heat Act explicitly takes as an orientation point the role-model function that public buildings have, establishing usage requirements for new buildings in terms of sourcing their heating from renewable energies. Owners of buildings about to be constructed must cover their needs for heating and cooling energy by using renewable energies for a specified proportion of the total. In the case of public buildings, obligations governing use also apply with regard to fundamental renovations of these.

Aside from this, the Energy Tax Act (Energiesteuergesetz), Sustainability Ordinances (Nachhaltigkeitsverordnungen), the Biomass Ordinance (Biomasseverordnung) and other ordinances establish rules for the generation and use of bioenergy.

Biogas plant

4 BIOMASS POTENTIALS

In 2008 global primary energy consumption amounted to approx. 500 exajoules (EJ). Renewable energies supplied 64 EJ; of this, biomass (50.4 EJ) accounts for almost 80 percent of the regenerative sources. The German Government's Advisory Council on Global Change (WBGU) estimates the global sustainable bioenergy potential to be 80–170 EJ per year (of this, 30–120 EJ from energy crops and 50 EJ from waste material and organic residual material).

The potential offered by renewable energies is enormous and is sufficient to cover the world's energy needs. The use of biomass, mainly sourced from wood, is already economically viable today in many instances; it has a correspondingly large share. In order to take into account food supply and nature conservation aspects, the areas of potential for sustainably-usable biomass are subject to certain restrictions.

In the conversion from fossil-based energy sources to renewables, biomass has particular significance in Germany and elsewhere. In the framework of an estimate of potential, the Fachagentur Nachwachsende Rohstoffe (FNR) – Germany's Agency for Renewable Resources – has produced the following results: 23 percent of our primary energy can be made available from domestic biomass in 2050! One of the factors underlying this estimate is the assumption that primary energy demand in Germany will reduce by half by 2050 in relation to the base year 2008, from around 14,000 PJ to 7,000 PJ (source: Energy

TABLE 2: THEORETICAL, TECHNICAL AND SUSTAINABLY-USABLE POTENTIALS FOR RENEWABLE ENERGIES (WORLDWIDE)

	Theoretical potential (EJ/year)	Technical potential (EJ/year)	Sustainably-usable potential (EJ/year)	Production 2008 (EJ)
Biomass	2,400	800	100	50.3
Geothermal	41,700,000	720	22	0.4
Hydropower	504,000	160	12	11.6
Solar energy	3,900,000	280,000	10,000	0.5
Wind energy	110,000	1,700	>1,000	0.8
Total Renewable energy	**46,000,000**	**283,500**	**>11,000**	**64.0**

Source: German Advisory Council on Climate Change (WBGU), 2011

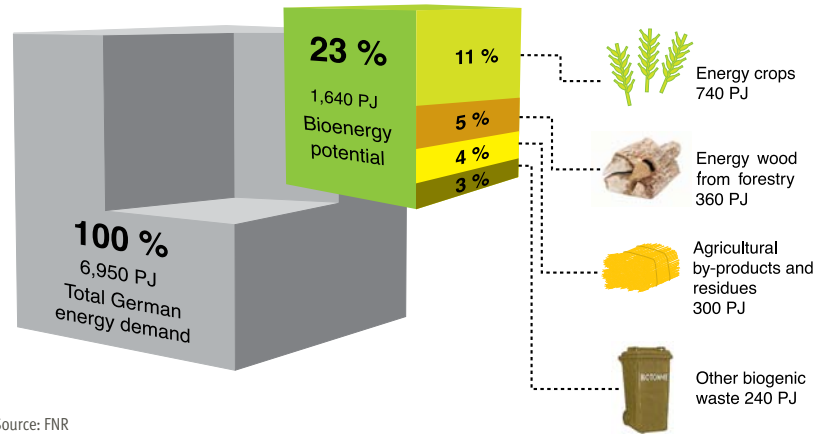
Harvesting of energy wood

Scenarios for a German Government Energy Concept – 2010). The reasons for this are attributable to demographic and technological developments, among other factors. Around 2,200 of the total 7,000 PJ could be supplied by biomass by that date; of this, in turn, around 1,640 PJ (or around 23 percent of the total primary energy demand) would be able to be supplied by domestic sources. The energy needed would be supplied by energy crops from arable lands, energy wood from the forest, co-products and biogenic residual material. The remainder, around 600 PJ of biomass, would have to be covered by imports.

Energy crops provide the largest domestic potential for biomass. Taking into account restrictions due to nature conservation, in the year 2050 energy crops will be able to be grown on up to 4 million hectares of arable land (2012: around 2.1 million hectares). Assuming a biomass yield of 10 tonnes per hectare (calculated as dry mass, water content: 0 percent) and a calorific value of 18.5 GJ per tonne, it would be possible to produce 185 GJ on one hectare and 740 PJ on 4 million hectares. In 2050, the various residual materials, co-products and energy wood from the forest are projected to contribute 900 PJ to primary energy consumption.

The assumption underlying the FNR estimate of potential is that the share accounted for by imports of food and animal feed will not substantially change and that the current level of domestic supply of food and animal-feed requirements will remain constant. It is also expected that so-called cascading use will establish itself; i. e. renewable resources will initially first be used as materials and then only at the end of their life cycle will they be used energetic.

DOMESTIC BIOENERGY: WHAT CAN ITS OUTPUT BE IN 2050?



Source: FNR

The segments for biomass, referred to in the graphic, are comprised as follows:

1. **Energy crops:** Maize, rapeseed, grain, grasses and new energy crops, as well as agroforestry (fast-growing tree species), providing biogas, biofuels and solid fuels
2. **Agricultural by-products and residues:** straw and other harvest residues, slurry and manure, material from landscape conservation, etc.
3. **Energy wood from the forest:** wood from thinning operations, wood of low calorific value, residues of tree crowns, etc.
4. **Other biogenic waste:** waste wood from industry, used wood, sewage sludge, organic waste from households, industry and commerce, landfill gas and sewage gas, etc.

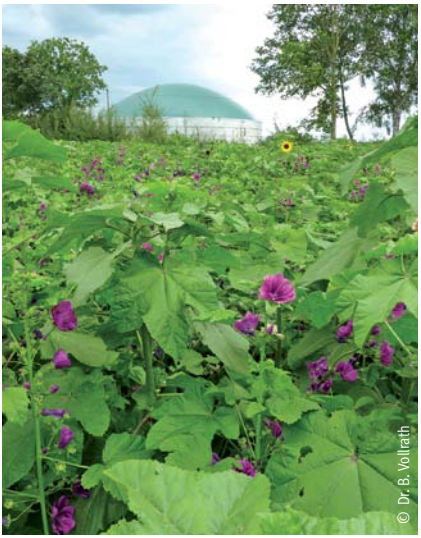
5 BIOMASS AND SUSTAINABILITY

Sustainability includes more than one level, as is made clear in the definition of the "three-column model": this indicates that sustainability has an environmental, an economic and a social component. Putting it simply, the best environmental concept cannot be sustainable if it is unaffordable and/or it cannot be harmonised with the social needs of the parties involved. In that case there would be no overall sustainability. Accordingly, many facets need to be taken into account when considering the sustainability of bioenergy. What is initially in the focus is

ENVIRONMENTAL SUSTAINABILITY OF BIOENERGY

This in turn is subdivided into various levels:
Climate protection: The use of biomass for obtaining energy has a large sustainability potential, because in principle it is beneficial to the reduction of greenhouse gas emissions, in particular CO_2 emissions. The reasons for this are to be found, quite literally, "in the nature of things" – their basis are the biochemical connections underlying the emergence of biomass and its transformation in terms of energy, as examined in Chapter 2. However, these principles are sometimes undermined if generating and processing the biomass itself entails a major expenditure of energy (covered by fossil-based sources) or if, in order to create space for the cultivation of the biomass, jungles are cleared and swamps are drained, thereby releasing large quantities of greenhouse gases. Under some circumstances these quantities are greater than the savings of no longer using fossil-based fuels. As a consequence, the use of bioenergy must match certain framework conditions that need to be critically challenged and monitored continuously.

Diversity of species: The same applies here – subject to having the right framework conditions, bioenergy has the potential to contribute to the diversity of species. After all, the wide range of energy crops and other renewable natural resources is significantly greater than the current, rather limited spectrum of plants used for food and



Wild flowers as energy crops

animal feed production. This range is by no means fully tapped; on the contrary, up to now most "energy farmers" are concentrating on high-yield crops that they know well and for which they have the suitable cultivation and harvesting techniques: maize, rapeseed, grain. And yet the change has begun: for instance, the Renewable Energy Sources Act (EEG) has stipulated that farmers in Germany are not permitted to use only maize in their biogas plants, brought into service in or after 2012, if they wish to continue to get the remuneration established in the EEG (EEG: cf. Chapter 3). Much urgent effort is being directed into research work on new energy crops. And many farmers are already interested in trying out new things on their arable land. One thing is clear: the use of bioenergy needs legislative framework conditions, research and development, a functioning transfer of knowledge from research into practice, and farmers who implement new findings from research – then there is nothing more standing in the way of a diverse agricultural landscape, which apart from producing food and animal feed, also generates other raw materials and energy.

Substances hazardous to the environment: A wood heating system emits more particulate matter than a gas-powered heating system does, but biodiesel is less hazardous to water than fossil-based diesel. A non-covered post-digester used in a biogas plant releases ammonia, but so does a conventional slurry container. Other examples could be listed making the same point. Conclusion: again, reality is not a black-and-white matter. As a general observation, biomass is less toxic and hazardous to the environment than fossil-based natural resources, but in a particular situation the issue is always HOW it is being used. Yet here also, through technical development and appropriate framework conditions, sustainability can constantly be further enhanced, step-by-step – thus, for example, modern wood-fuelled heating systems are emitting much less particulate matter and due to what by now is the legally-binding obligation to seal the post-digester gas-tight, the ammonia emissions from biogas plants are prevented to a large degree.

ECONOMIC SUSTAINABILITY OF BIOENERGY

Use of biomass needs to be economically viable because otherwise it has no prospect of long-term success. Yet this does not mean that it is not possible for higher costs to arise during the development phase. Nevertheless, over the medium to long-term, bioenergy needs to be able to assert itself economically, also in comparison to other renewable energies. Above all, the most economically-viable options for conversion must be pursued. The imperative of economic viability is closely related with that of efficiency – often the most efficient processes are also the most economically viable. In addition, careful use of biomass as a resource is a basic prerequisite for sustainability – after all, the potential is great but it is not infinite.

Another economic aspect is also that of regional development through bioenergy – the creation of jobs and economic value, particularly in what so far have been rather structurally-weak rural areas. If the use of bioenergy can be linked to economic development in this way, this enhances the sustainability because, in turn, more affluence creates the opportunity to boost training and investment in modern technologies on an environmentally sound basis.

SOCIAL SUSTAINABILITY OF BIOENERGY

The transitions to economic sustainability are fluid, not firmly fixed, particularly from the regional-development aspect. Bioenergy brings with it a high degree of potential for social sustainability, especially for rural areas. Pure "dormitory villages", whose inhabitants commute to work in urban centres and leave their energy supply to major companies and energy suppliers from distant countries, become self-sufficient regional producers. Localities gain new vitality, new jobs emerge in small and medium-sized companies as well as in agriculture and forestry. Private individuals, companies and municipalities get involved in an economic sense, and consequently social cohesion grows. All of this leads to a sense of having a greater stake in society and to peaceful social relations, without which there cannot be sustainability in the long term.

CERTIFICATION OF BIOMASS

Mention has already been made of the significance of the legislator's "guiding hand" in securing sustainability in bioenergy. Among the ways in which the German Government has taken this into account are the following: the Biomass Electricity Sustainability Ordinance (Biomassestrom-Nachhaltigkeitsverordnung) of July 2009 and the Sustainability Ordinance for Biofuels (Biokraftstoff-Nachhaltigkeitsverordnung) of September 2009 are two ordinances devoted exclusively to sustainability in the use of biomass. With these, the German Government made Germany the first country in Europe to implement the requirements of the EU's Renewable Energies Directive. The ordinances require strict controls of the generation of

biomass and also of trade in liquid sources of bioenergy for electricity generation and for fuel production in Germany; state funding is given solely to biomass that is certified accordingly. Biomass imported from abroad needs to be certified as well. The German Government is also considering whether to extend the biomass certification so as to include solid and gaseous sources of energy.

Within the framework of support for bioenergy, the core requirements of the sustainability ordinances are

- no use of biomass sourced from areas with a high nature conservation value (e.g. pasture with a high level of biological diversity, nature conservation areas, certain forested areas);
- no use of biomass from areas with a high carbon content (e.g. moorlands, marshlands);
- no use of biomass from peat bogs;
- the reference date for the named areas designated for protection is 1 January 2008;
- biomass must be cultivated in the EU according to good farming practices, which is also binding for food production, sanctions can be imposed for non-compliance with this requirement and
- the potential for greenhouse-gas-reduction must amount to at least 35 percent, rising to at least 50 percent from 2017 and at least 60 percent from 2018.

Compliance with these criteria is monitored by authorised certification centres, which after corresponding checks have been satisfactorily completed, issue certificates to all central links in the production chain of biofuel or bioelectricity. It is the Federal Office for Agriculture and Food (BLE) that is responsible for granting recognition and monitoring the certification systems and certification centres.

A problem that is currently being much discussed is the inherent limits to the certification system, constraining its effectiveness, particularly outside Europe: it is not possible to transpose European environmental laws and inspections to Asian and South American agriculture. There, cultivation of organic matter for food and animal feed or for technical purposes does not always take place according to sustainable conditions. It is solely for biofuel production for the European market that there has been a sustainability check for some years. This means: while sustainability of the biofuel production can be proven via the certification, there is the possibility that cultivation of land for other types of use is transferred unhindered onto environmentally valuable lands, e.g. areas of high biodiversity not used for agricultural purposes so far (savannas, bush land, rain forest). Biomass certification processes are not currently in a position to record this phenomenon termed “iluc” – indirect land use change. It is possible to solve this problem solely if the certification process globally, or at least in the most important biomass producing countries, were to be extended to encompass all types of agricultural use of natural resources. Indeed, declarations of intent consistent with this aim have been issued in Germany and at European level.

6 PRODUCTION OF BIOMASS BY CULTIVATING ENERGY CROPS

For plants that are cultivated, wholly or predominantly for use as an energy source, the term "energy crops" has established itself. Alongside it, the superordinate term "renewable resources" also encompasses wood from the forest, a variety of organic residual materials and by-products, as well as all forms of biomass designated for technical use or use as a material.

In 2012, renewable resources were grown on approx. 2.4 million of the roughly 12 million hectares of arable land in Germany Of this, energy crops account for around 2,1 million hectares. The biomass generated from forestry activity in more than 11 million hectares of woods can be added to this. The latter comprises the largest share of renewable resources.

TABLE 3: CULTIVATION OF RENEWABLE RESOURCES IN GERMANY 2012 AND 2013 (IN HECTARES)

Plants	Resource	2012	2013*
Industrial crops	Industrial starch	121,500	121,500
	Industrial sugar	10,000	9,000
	Technical rapeseed oil	125,000	125,000
	Technical sunflower oil	7,500	7,500
	Technical linseed oil	4,000	4,000
	Plant fibres	500	500
	Medical crops and vegetable dyes	13,000	13,000
	Industrial crops, total	**281,500**	**280,500**
Energy crops	Rapeseed and biodiesel/vegetable oil	786,000	746,500
	Crops for bioethanol	201,000	200,000
	Crops for biogas	1,158,000	1,157,000
	Crops for solid fuels (among others: agroforestry, miscanthus)	11,000	11,000
	Energy crops, total	**2,156,000**	**2,114,500**
Cultivation of renewable resources, total		**2,437,500**	**2,395,000**

Source: FNR (2013)

** Numbers for 2013 estimated*

Short rotation coppice with poplars

Various crops that are known from food and animal feed production are gaining significance as energy crops, such as maize, rapeseed, beet, and different types of grain. They are grown as one-year crops, i. e. each year they require tilling of the soil and new seeding. For the most part, they are cultivated in crop-rotation schemes consisting of several elements, i. e. a given area of land grows various crops, switching the crop once per year. Yet some species, such as maize, are "compatible with themselves" (in crop-rotation terms), and can be grown on the same area of land for several years in succession; for others such as rapeseed, there needs to be a 3–4 year break before cultivating it again on a given piece of land.

Multi-year crops are also cultivated as energy plants. Once they are sown or planted, these can be used for a long period, spanning up to 30 years. For instance, these include perennials such as cup plant *(silphium perfoliatum)* or tall grasses such as miscanthus: both of these are harvested each year. By contrast, short-rotation coppice operations grow species of trees, such as poplars and willows: they are planted in rows and harvested once every 3–5 years. After that, the fast-growing trees sprout from the rhizome once again. In the intervening years, the land on the area in question is more or less not worked; to a very great extent the trees develop without fertiliser or chemical plant-protection products. Accordingly, they are also very well suited for cultivation in drinking-water conservation areas and reservoirs. Initially, all multi-year energy crops are cultivated on a relatively small scale, unlike the one-year crops, but the level of interest in them is rising significantly.

What is new among the one-year energy crops are innovative systems of cultivation: e. g. the cultivation of mixed crops, in which various plant species – such as maize and sunflowers, or grain and false flax *(camelina sativa)* – are being grown on the same field; another example is the use of two-crop systems that makes two harvests possible in one year. An example of a crop rotation for the latter is to harvest the winter-grain crop rye in May/June, as whole-plant silage, and then planting sorghum or maize, harvesting it in October. These cultivation systems offer interesting options with regard to a diversified and environmentally-sound strategy for cultivating energy crops, in which (for instance) they provide year-round vegetative cover and prevent erosion.

An interesting combination of cultivating one-year and multi-year species in one system is presented by what is called agro-

forestry. In this, fast-growing species of trees are planted in rows; one-year crops are planted in the blocks of land between those rows (the width allocated to them is adapted to modern seeding and harvesting techniques, at 36 or 48 metres). In systems like this, the rows of trees contribute importantly in reducing soil erosion caused by wind and water (heavy rain). These cultivation processes also have yield-securing and yield-enhancing effects attributed to them; this is due to an improvement in the micro-climate and to more favourable conditions for beneficial organisms.

You can obtain extensive information on energy crops on the Internet, at:
http://energiepflanzen.fnr.de

EXTENSIVE CULTIVATION OF ENERGY CROPS AND CHANGES IN THE RULING ON COMPENSATORY MEASURES – SYNERGIES BETWEEN NATURE CONSERVATION, AGRICULTURE AND BIOENERGY?

According to the ruling that requires compensatory measures for encroachments, interventions in the balance of nature are required to be balanced out again by actions fostering nature conservation: this applies to construction work, e.g. commercial operations, new residential developments, or new roads. It is the property developer who must finance this, purchasing areas of land from farmers for that purpose. While the individual farmer earns money on this sale, agriculture must cede land twice: once for the construction project itself, and then for the compensation areas that are usually no longer available for agricultural production purposes. This loss of land is by no means an insignificant problem in Germany: the increase in area for commercial or residential development and for transport development still amounts to around 87 hectares each day (Federal Statistical Office, period 2007–2010); the compensation areas need to be added to this. That is why a model project is now examining whether energy-crop areas being used in extensive production, such as short-rotation coppice, could serve as a solution for both sides: the areas have a greater value from the perspective of nature conservation than they did with the previous, intensive agriculture use; yet the farmer continues to cultivate them and get an income from them. For nature conservation also, extensive energy-crop areas would be advantageous. In contrast to current compensation projects, which in many instances are small in scale, these projects could be on a substantially larger scale. Property developers, for instance municipalities, who find it increasingly difficult to acquire compensation areas amid rising land prices, would also benefit from the new ruling: it would mean that the areas remain the property of the farmers.

Information on the model projects is available at: www.landnutzungsstrategie.de

The expected yields and the energy value act as an important foundation when planning to cultivate energy crops. Table 4 provides a comparative overview based on the heating-oil equivalent.

TABLE 4: BIOENERGY SOURCES, TYPICAL CONVERSION PROCESSES THAT THEY USE, AND YIELDS, STATED AS HEATING-OIL EQUIVALENT IN LITRES PER HECTARE AND YEAR

Energy source	**Conversion process**	**Yield Heating-oil equivalent l/(ha • a)**
Residues		
Forest waste wood	Combustion	434
Straw	Combustion	2,390
Energy crops		
Maize silage	Anaerobic digestion into biogas	5,280
Rapeseed oil	Combustion/ transesterification into biodiesel	1,528
Short-rotation coppice (e. g. poplars, willows)	Combustion	5,120
Whole-plant grain silage	Anaerobic digestion into biogas	4,013
Grain kernels	Combustion/ anaerobic digestion into biogas/ anaerobic digestion into ethanol	2,232
Grass silage (e. g. *festuca arundinacea*)	Anaerobic digestion into biogas	3,016
Miscanthus (*miscanthus sinensis*, from the 3rd year)	Combustion	6,081

Source: Leitfaden Bioenergie, FNR (2007) (Guide to Bioenergy) and own calculations

7 BIOENERGY SOURCES AND THEIR USE

7.1 Solid sources of bioenergy

At present, the most important bioenergy source is wood. Wood has been used for heating since the dawn of humankind and Germany has a long tradition in this field. Nowadays, once again, every fourth German household is heated using wood. Each year, around 34 million cubic metres of wood are burned for heating, in the form of firewood (typically logs), wood chips, pellets and briquettes, in a total of approx. 16 million domestic fire units. The most significant wood-based fuel is firewood from the forest, at over 22 million cubic metres – often sourced and collected by the end-users directly. Yet wood from one's own garden or from landscape conservation activity also merits mention, as do untreated used wood, remnants of logs from saw-mills, wooden briquettes and wood chips sourced from forest wood.

HEATING WITH WOOD IN PRIVATE HOUSEHOLDS

In private households, it is predominantly single-room fire units, such as stoves, masonry heaters and tile stoves etc. that are used to heat single domestic rooms or living areas. In most cases they supplement the central heating system and are often only used occasionally. A good one million households in Germany have a wood-burning central heating facility (log gasification boiler, pellet heating, wood-chip heating, etc.), supplying all rooms with heating via the water-operated central heating system, and usually simultaneously heating the water used for other domestic purposes.

Today, thanks to technical progress, modern biomass installations – such as pellet stoves/pellet boilers, log gasification boilers, and wood chip heating – achieve efficiency grades that in many cases are already significantly over 90 percent. The technical development is remarkable: accordingly, modern installations are achieving efficiency grades around 20 percent higher than wood-burning boilers installed 20–30 years ago! By now, several manufacturers have also brought condensing technology to market readiness with regard to wood-burning heating units. Boilers with condensing technology use the fuel's energy content almost in its entirety, by also making use of the condensation heat of the water vapour in the flue gas. This makes them particularly efficient.


© FNR/Dr. H. Hansen

Wood-gasification boiler for domestic spaces

Yet the further development and optimisation of combustion chambers and combustion systems, as well as of the control and adjustment of the combustion process used in stoves and boilers, has not solely led to greater efficiency in wood burning. Integrated with this – emission performance has also been much improved. Modern wood-burning systems are characterised by very low emissions of particulate matter, carbon monoxide and nitrogen oxides. In 2010, an amendment was made to the 1st Ordinance on the Implementation of the Federal Immission Control Act (1. Bundes-Immissionsschutz-Verordnung), also known as the Small Firing Installations Ordinance (Kleinfeuerungsanlagenverordnung). This establishes minimum efficiency grades and significantly stricter emission requirements for single-room or single-area fire units.

The ruling also encompasses installations already in service. Requirements are placed upon installations still yet to be built, and also rulings are established regarding retrofit on old firing installations or respectively their withdrawal from service: this legislation makes an important contribution to keeping the air clean and to reducing nuisance caused by particulate matter.

Financial backing is given to the installation of low-emission pellet stoves and wood-burning central heating systems, sourced from the so-called market incentive programme of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. The "Guidelines to promote Measures aimed at the Use of Renewable Energies in the Heating Sector" – "Richtlinien zur Förderung von Maßnahmen zur Nutzung Erneuerbarer Energien im Wärmebereich" – have brought about a very substantial expansion of the market for efficient and low-emission biomass installations.

The next section describes and characterises certain types of biomass installation:

STOVES AND BOILER STOVES

Stoves and boiler stoves, but also other single-room fireplaces such as masonry heaters, clay stoves, tile stoves, wood-fuelled cookers etc. are highly popular; nowadays hardly any new house does not feature such a single-room firing installation. They lend the living space a certain ambience, a cosy radiant warmth, and convey a sense of security just in case the central heating system is ever out of action. With high fuel prices for oil and gas they can make a substantial reduction to heating costs.

In quantity terms, it is single-room fire units that are of greatest market significance, such as stoves and boiler-stoves, which are increasingly also offered and in demand as a water-operating model that supports the home's heating operation. In households of working people, stoves and boiler stoves are the first choice, because shortly after they are

started up they provide a beautiful interplay of flames and also cosy warmth.

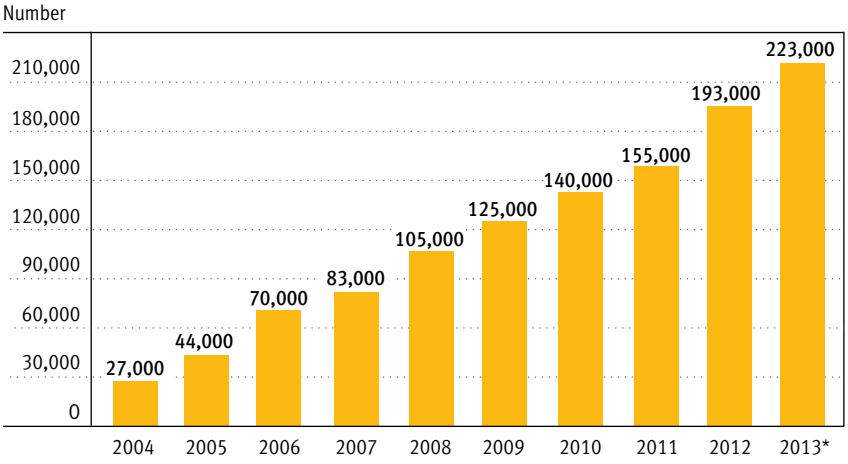
For houses occupied all day, e. g. homes occupied by two or more family generations, the spectrum on offer includes masonry heaters, clay stoves, heavy tile stoves and soapstone stoves, as well as other thermal-storage heating systems. Ignited in the morning and supplied with a good pile of wood, it takes a certain amount of time before the stove mass heats up, but then it exudes a pleasant radiant warmth the whole day.

The total quantity of single-room fire units currently amounts to approx. 15 million installations; over the last years, annual sales of stoves have been approx. 300,000–500,000 units. There is a wide spectrum of prices for single-room fire units, with the points of difference usually being in the selection of material and the design rather than in technological aspects such as efficiency and emission levels. Apart from pellet stoves, single-room fire units are fuelled by firewood (typically logs) or wood briquettes.

PELLET BOILERS

Thanks to wood pellets, there has now been a new fuel on the market for about 15 years: it has given a powerful impetus to product development of highly efficient and particularly low-emission wood-fuelled heating units. There is a diverse product offering of pellet-fuelled heating units and of

TOTAL INSTALLED CAPACITY OF PELLET BOILERS IN GERMANY



** Outlook*

Source: DEPI (Deutsches Pelletinstitut/Pellet Fuel Institut of Germany), according to ZIV, HKI (January 2013)

Wood-pellet stove

pellet stoves for households, operating on water-based and air-based systems. Cookers fuelled by wood pellets are available, as are stoves with pellet modules: according to choice, these can be fired by hand, using firewood and wooden briquettes or – e.g. if the home occupant is away during times of absence – automatically supplied with wood pellets. With the pellet heaters, wood-fuelled condensing boilers were created for wood fuels for the first time.

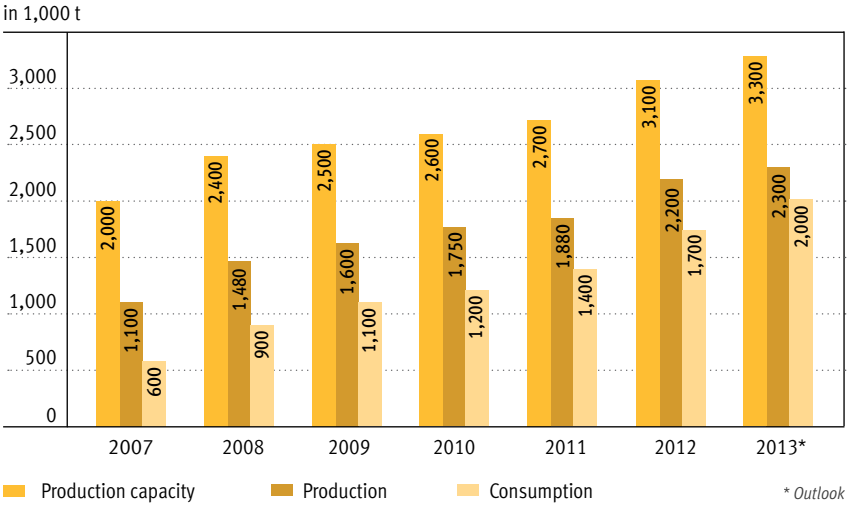
Pellet heaters are also offered at very low heat-capacity levels, making them the ideal heating option for modern passive houses or low-energy houses. Here in many instances it is enough to have water-operating pellet stoves – mostly used in combination with solar thermal installations – to completely take over heating the home and also heating the water used for the home's other needs.

Pellet stoves and pellet boilers are also equipped with electronic control and adjustment, managing the supply of heating in accordance with needs and providing optimum, low-emission combustion at every stage in the spectrum of capacity use. In most instances, the control elements are arranged so as to serve several heating circuits in a targeted way, as well as bringing other heat generators into the system, e.g. solar thermal units and buffer storage units. Also available are pellet-heating units with low-temperature capability: these are for buildings with floor-heating systems and wall-surface heating systems. In a comparison among wood-fuelled heating systems, pellet-burning systems are characterised by a very high degree of comfort and low space requirements for heating and storage. Space-saving pellet heating systems are available installed on the wall, standing or hanging.

Pellet stoves have a supply container with 15–25 kg capacity. Depending on the season and on heating requirements, the fuel should be refilled by hand, at intervals ranging from daily to weekly. Wood pellets can also be obtained in sacks – handy 15 kg sacks – from regional fuel dealers or in do-it-yourself construction stores. Via shipping pellet manufacturers and dealers supply pellets in sacks, free house, based on a quantity of pallets, with one tonne of wood pellets per pallet.

For private households, the storage units for pellet-fuelled boilers are typically dimensioned in such a way that they can house the whole year's wood-pellet requirement. In that case, wood pellets are supplied in tank trucks and the vehicle blows them into the storage areas. In the case of large pellet-heating installations, the storage capacities are arranged in such a way that they can take receipt of a truck's whole supply load. The wood pellets are sent to the pellet-fuelled heating boiler from the stor-

WOOD PELLETS – PRODUCTION AND CONSUMPTION IN GERMANY



Source: DEPI (Deutsches Pelletinstitut/Pellet Fuel Institut of Germany), FNR (2013)

age room or the silo container: this is done fully automatically by a conveyor spiral or a pneumatic conveyor system.

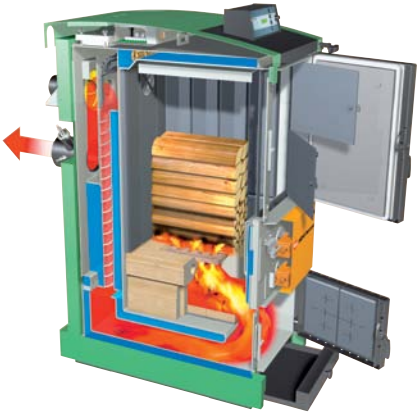
CARBON MONOXIDE IN PELLET STORAGE AREAS: VENTILATE BEFORE ENTERING!

This gas, that can cause deadly carbon-monoxide poisoning under certain circumstances, is colourless and has no smell; indications are that it emerges through natural decomposition processes in the dry wood. It is therefore essential to ventilate pellet storage areas thoroughly before entering them!

LOG GASIFICATION BOILERS

In buildings currently in use, especially in rural areas, log gasification boilers are highly popular. For consumers with their own wood supply and favourable access to firewood – such as farmers and foresters, business owners with quantities of waste wood left in its natural state, or those directly obtaining the wood and working it in some way – heat can be provided, rather laboriously but at a low price. Operators of log gasification boilers also need to have the necessary storage area, because what one really should do is to maintain (and keep protected from rain) a stock of firewood (logs) to cover at least 2–3 years' need, for drying the wood off and for balancing out weather-related fluctuations in demand for wood.

By now, log gasification boilers are close behind pellet heaters in terms of efficiency and emission levels, thanks to huge progress in development in recent years. They are absolutely not comparable anymore with the traditional boiler stoves for wood and coal, with their low levels of effectiveness and the nuisance caused to neighbours. There are modern log gasification boilers in the capacity range from 5 kW up to several 100 kW. The most modern firing and regulation technology provides efficient and clean combustion; the result is that many types of boilers already offer levels well below the stricter threshold values for emissions as required by the 2010 amendment to the Small Firing Installations Ordinance. By means of controlling the firing function via a smoke-gas temperature sensor and a lambda probe, the unit constantly provides the quantity of air or oxygen that is required for a complete combustion.



Scheme of a log gasification boiler

In the case of log gasification boilers, what is needed is to start them up in the mornings, putting plenty of wood in the filling space. The wood outgas over a period of many hours and is fully burned out in an afterburning chamber set up below or behind the grill. Control of output and adjustment of the firing operation guarantee best combustion and make it possible to operate the heating circuits directly. Surplus heat is stored in the buffer storage unit. Priority circuits take care of the supply of warm water for everyday domestic needs, but in many instances it is combined with solar heating.

WOOD-CHIP HEATING UNITS

Wood-chip heating units are available for single-family and multi-family residential buildings, from approx. 15 kW heat output. Yet wood-chip heating units are particularly worthwhile if the capacity level is above 50 kW or indeed 100 kW. In many cases, wood-chip heating units are used to supply heat to individual buildings or groups of buildings close to one another (micro heat networks). “Wood-chip heating plants” and “biomass heating plants” are the terms referring to larger wood-chip heating units, employing local heating networks or district heating networks to supply villages or whole streets and neighbourhoods of a city with heat sourced from biomass.

Many operators of wood-chip heating systems have wood available to them: they get it processed into wood chips, with their own chopping equipment or using an agricultural/forestry contractor. Yet there is also

growth in the number of biomass stations specialising in the provision of wood fuels of all kinds; in addition, in many instances composting facilities and recycling companies are extending their field of operations to include solid biofuels, marketing wood chips and shredded wood. Thus the option is on offer, also for companies without their own wood resources (particularly those with high fuel consumption), to say goodbye to high and volatile costs for fossil fuels and switch over to a sustainable, stable-priced supply of heating.

BIOMASS COMBINED HEAT AND POWER (CHP) STATIONS

If the firing output is of dimensions that make it worthwhile to generate electricity by a steam turbine, an ORC (organic-rankine cycle) turbine or a steam motor, then wood-fuelled or respectively biomass-fuelled stations are set up as a combined heat and power (CHP) installation.

Wood-fuelled CHP plants are frequently in service at wood-processing industry sites – e.g. saw-mills and wood-pellet producers, at manufacturing sites for wood chips, OSB panels, parquet and laminate, as well as production sites for paper, mechanical wood pulp and cellulose. Wood-based residual material not usable in the production processes or better used elsewhere is placed in the biomass installations, to produce electricity, heat and process steam. Surplus electricity is fed into the public power grid. Energy supply companies, cities and municipalities or their respective municipal utility companies have set up numerous wood-fuelled CHP plants in recent years. It is mostly waste/used wood that is burned in the energy supply companies' installations, which in many cases are set up to have electrical capacity levels between 10 and 20 MW. Conversely, in cities' and municipalities' installations are set up for a capacity of < 5 MW_{el} in most cases, what is used for energy is mostly assortments of forest waste wood and also wood from landscape conservation areas in the region, as well as wood material from municipal properties. Via local and district heating networks, the biomass installations' heat is made available to manufacturing, trade and service companies, as well as to housing cooperatives, private households and public buildings.

Wood-chip heating system

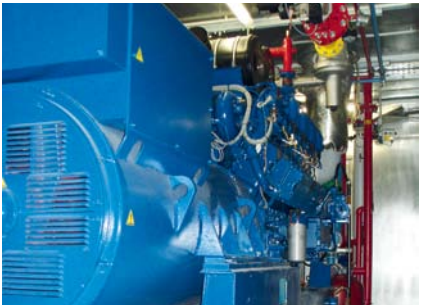
Conveyor belt and bale opener at the straw-fired heating plant in Gülzow

STRAW-FIRED HEATING PLANTS

In Denmark, straw-fired heating plants are widely spread. In agriculture for example, they generate heat for poultry and pig barns. In many instances, farmers also deliver surplus straw to large municipal heating plants that supply local and district heating networks. Even in a coal-fired power station, straw is burned to generate electricity for Copenhagen. By contrast, in Germany there are only a few straw-fired heating plants in service, but there is a growing level of interest in these installations. One manufacturer in Mecklenburg-Vorpommern is producing gasification boilers for straw bales, in which whole round bales can be fired; apart from that, there are straw-fired installations that bring large rectangular bales to a mechanism that breaks them down and chops them up; then the chopped straw is transported in the air stream for burning, in dosed amounts. Likewise, at capacities of approx. 400 kW–1,000 kW, several German straw-fired heating plants use the surplus of straw available locally to provide the main input fuel for price-competitive heating: this heating is used in municipal heating plants or larger livestock facilities. Since August 2013, a 1,000 kW straw-fired heating plant supplies heat to the FNR-office building, and to further sites in Gülzow.

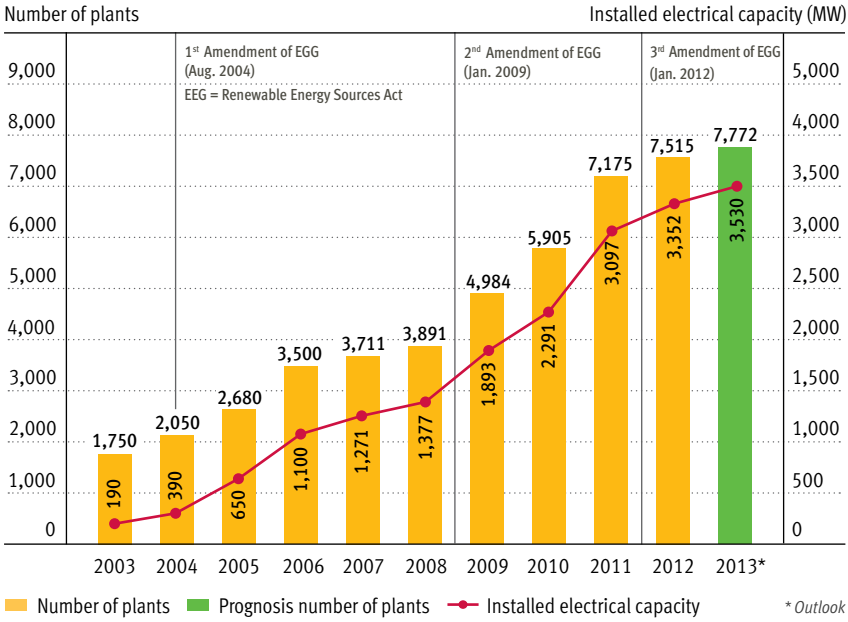
7.2 Biogas

Whether it is in bogs and swamps or in the ruminants' stomachs: biogas forms anywhere that organic material is decomposing in a moist environment in the absence of oxygen. A variety of bacteria, including methane bacteria, do the main work here. A biogas plant reproduces this process by technical means. The output and composition of the biogas vary depending on the composition of the input material and also the process technology. Ultimately the energy content of the biogas is directly dependent on the methane content. Thus one cubic meter (m^3) of methane has an energy content of approx. 10 kilowatt hours (9.97 kWh).



Combined heat and power (CHP) unit of a biogas plant

DEVELOPMENT OF BIOGAS PLANTS IN GERMANY



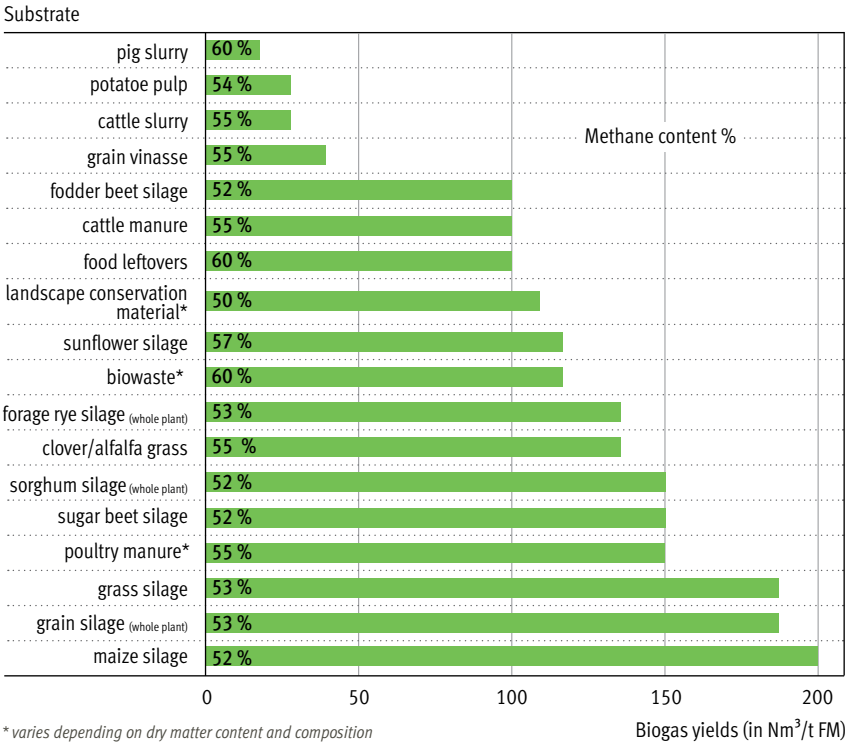
Source: FNR, according to FvB (German Biogas Association) (2013)

The coming into force of the Renewable Energy Sources Act (EEG) prompted a major rise in the number of biogas plants in Germany (see graphic above). At the end of 2012, there were more than 7,500 biogas plants in operation, with an electrical capacity totalling almost 3,352 MW, supplying as much electricity as five medium-sized coal-fired power stations.

THE INPUT MATERIALS

Biogas can be sourced from numerous organic starting materials. In agricultural biogas plants these are mostly energy crops grown specifically for this purpose, and also animal excrement (slurry and manure), that serve as substrates. The use of slurry and other farm fertilisers is of major significance, not solely from the perspective of climate protection (reduction of emissions); it also plays a part in stabilising the process. Crops for use as renewable resources include maize, grain, grasses, and sugar beets, among many others; however, maize currently accounts for the largest share, as a crop with high mass and gas yield, as well as offering the lowest specific costs. In some regions, however, the large amount of maize cultivation can have

BIOGAS YIELDS



** varies depending on dry matter content and composition*

Source: KTBL (The Association for Technology and Structures in Agriculture) (2010)

adverse effects on soil fertility and on biodiversity. As public discussion of this topic gains momentum, a lot of pressure is being applied to the search for alternatives. The aim is to structure the cultivation of energy crops in a way which is as sustainable and as environmentally friendly as possible. Accordingly, new energy crops such as cup plant *(silphium perfoliatum)*, sorghum, wild flowers or special grasses are now the focus of attention.

As the graphic above shows, the various substrates achieve very different biogas yields; the methane-content levels of the respective biogas also differ. As a result, depending on the composition of the input substrate, the gas output and the methane content also fluctuate.

Aside from renewable resources, agricultural by-products and residues, there are also certain non-agricultural substrates suitable for

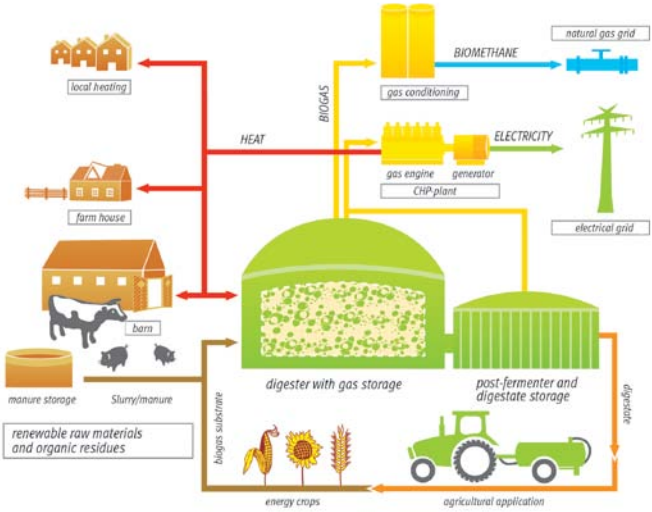
biogas production: these include residual material from the food industry (e.g. pomace, stillage, residues from grease traps), vegetable waste from wholesale markets, food waste, grass cuttings, material from landscape conservation, or organic waste from municipal waste disposal.

STRUCTURE OF A BIOGAS PLANT

For biogas production a diverse range of installation concepts is applied. They differ according to the process characteristics, such as the dry matter content, the way in which material is fed in or the number of process phases. Accordingly, depending on the dry matter content, a distinction is made between dry and wet anaerobic digestion. Almost all agricultural biogas plants work in a wet-anaerobic-digestion procedure, at an operating temperature in the mesophilic range (32–42 °C), with the familiar round containers and gas hoods. When using slurry, only wet anaerobic digestion is an option; the solid biomass which is introduced needs to be well broken down and has to make pumpable and stirrable.

By contrast, dry anaerobic digestion is particularly of interest for farms without either slurry or any other liquid base substrates at their disposal. Unlike with wet anaerobic digestion, in the case of dry anaerobic digestion it is not possible either to pump the material to be anaerobically digested or to make it flow; nor is it constantly being stirred or mixed up. However, as is the case with wet anaerobic digestion, a moist medium is necessary for

SCHEME OF A FARM-BASED BIOGAS PLANT



Source: FNR

the biological anaerobic-digestion process. This is produced by mixing the material with process fluid before the anaerobic digestion or by constantly spraying it with fermentation fluid during the process of anaerobic digestion.

The scheme on page 35 shows how an agricultural biogas plant operates and how the basic elements are arranged – preliminary tank/substrate input, the digester with the stirring unit, the gas storage, the post-digester and the utilisation of the biogas (options: biogas upgrading, CHP unit, or other). In the preliminary tank, the substrates are stored on an interim basis, chopped, thinned and mixed; from there, they are then sent into the insulated and heated digester. This is the core element of the plant: it has to be water-tight, gas-tight, and impermeable to light. Appropriate stirring technology guarantees the homogeneity of the substrate and supports the gas production. The biogas comes into the gas storage, while the digested substrate is transported into the digestate storage tank, the latter usually also serves as a secondary digestion container.

If the mix is also anaerobically digesting any substrates that justify concern in terms of disease prevention – e.g. slaughterhouse waste or other food waste – the material must be sanitised and heated to over 70 °C for at least one hour, to kill off germs.

The fluid or solid residue of the process is characterised as (wet or dry) digestate or biogas slurry; farmers mostly use it as organic fertiliser, because of its high nutrient content. In relation to raw slurry, digestates have essential advantages, e.g. reduced intensity of smell and a reduced corrosivity to crops. In terms of nutrients, the composition fluctuates depending on the input substrates used.

THE PROCESSES IN THE DIGESTER

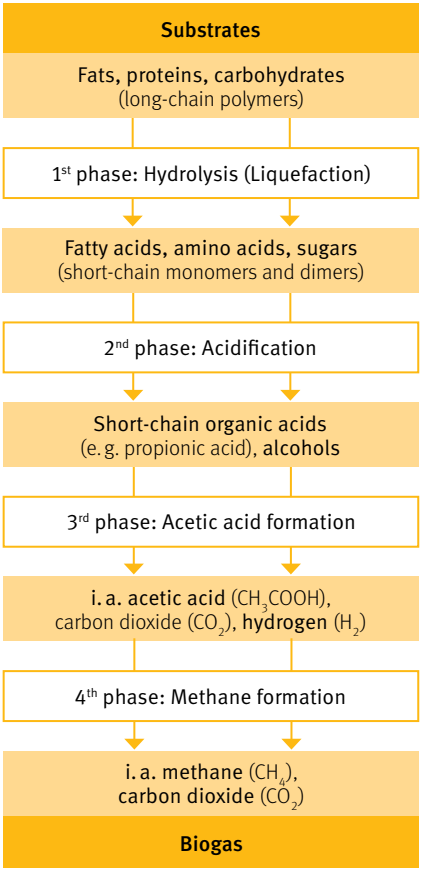
In principle, the anaerobic digestion process in the digester involves four steps that are mutually dependent, requiring anaerobic conditions (i.e. without oxygen), with each step using different groups of microorganisms. In the liquefaction phase (hydrolysis), the complex organic compounds are broken down into simpler compounds. In the following acidification phase, these products are then reduced to organic acids. As part of this, alcohols, hydrogen and carbon dioxide also emerge as starting materials for methane production. In the next phase – acetic acid formation – the organic acids and alcohols become acetic acid, water and carbon dioxide. In the subsequent methane formation phase, the products of the preceding phases are then converted into methane, carbon dioxide and water.

The gas mixture formed in this way predominantly consists of the following

- 50–75 % methane (CH_4),
- 25–45 % carbon dioxide (CH_2),
- 2–7 % water vapour (H_2O),
- < 2 % oxygen (O_2),
- < 2 % nitrogen (O_2),
- < 1 % hydrogen sulphide (H_2S) and
- < 2 % trace gases.

As a matter of principle, the four phases take place simultaneously and in parallel. Due to the various milieu conditions for the different microorganisms, there is a need to find a compromise between the optimum parameters, such as the anaerobic-digestion temperature, pH value, or supply of nutrients.

SCHEMATIC DIAGRAM OF THE ANAEROBIC DIGESTION PROCESS



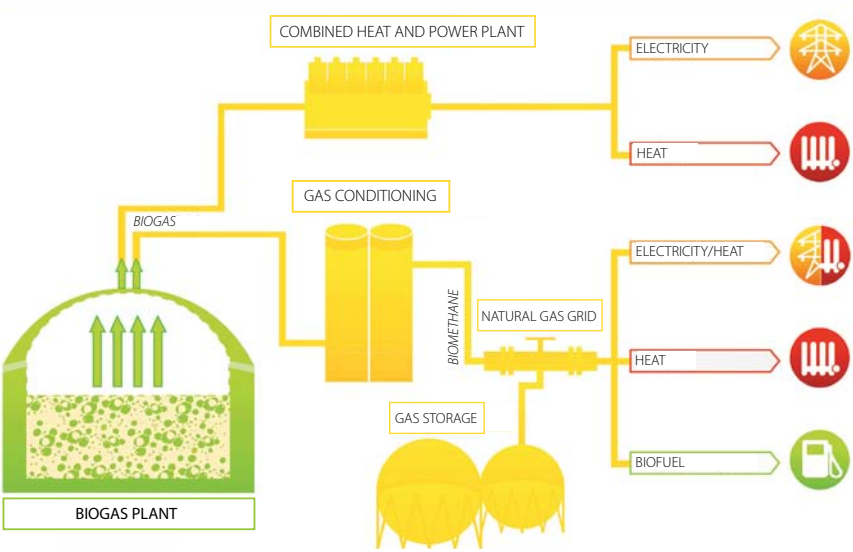
UPGRADING AND UTILISATION

Biogas offers many options for use. It can be used both for generating electricity and heat and also as a fuel and a natural gas substitute. Biogas is storeable and can be transported via the natural gas grid; by this it is available at any time, independent of the place of its origin. Energy production from biogas is not subject to any fluctuations according to the time of the day or year, or weather factors; thus it can take place continuously in accordance with demand.

Thanks to fixed remuneration rates for conversion into electricity, the generation of electricity and heat, in close proximity to the biogas plant, is currently the primary way in which biogas is used. The energy is converted in combined heat and power (CHP) units: electricity and heat are produced simultaneously. The CHP unit consists of an internal combustion engine powered by biogas, driving a generator for the production of electrical energy.

Apart from the electrical energy, the CHP unit generates heating as a coupled product. The biogas plant itself uses 20–40 percent of the waste heat for heating the digester, depending on the type of installation and the time of year. From the environmental viewpoint, and for economically viable operation of the unit, it is imperative that the remaining heat generated is used purposefully. One option is to use the heat of the CHP unit for heating domestic and farm buildings. If it is not possible

VARIOUS UTILISATION OF BIOGAS



Source: FNR

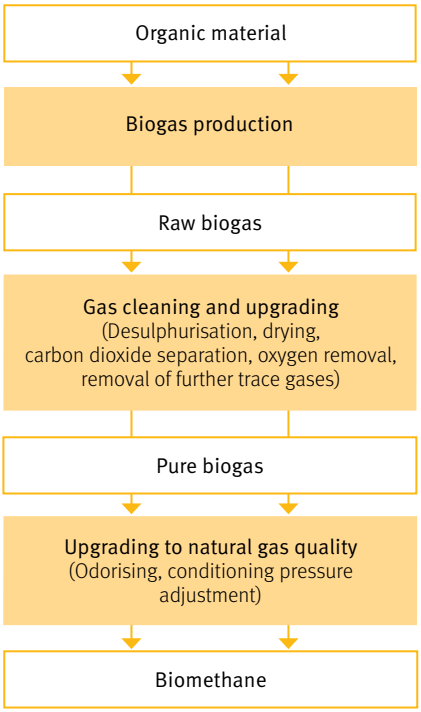
to use the heat in the immediate area of the biogas plant, it can be brought to the consumers with the help of decentralised heating networks. That way, besides supplying residential buildings, one can also supply municipal facilities such as swimming pools or hospitals, and business enterprises. In the case of larger distances, the biogas itself can be transported via gas pipelines to a so-called "satellite" CHP plant, producing electricity and heat at the place of demand.

In principle, biogas is also suitable as an energy source for fuel cells, Stirling engines and micro gas turbines. At present, the advantages of these technologies – such as greater efficiency or lower operating costs – are still outweighed by the higher investment costs. A further possibility for efficient use is offered by ORC technology. This produces additional energy from waste heat.

Over the last years, it has become an increasingly established practice to upgrade biogas to gas quality and feed it into the natural gas grid. By the end of 2012, 117 biogas upgrading plants were producing approx. 73,000 norm cubic metres of biomethane per hour. This quantity corresponds to an overall capacity of approx. 6 billion kWh per year. Upgrading technologies currently used for biomethane are: pressurised water scrubbing, pressure swing adsorption, and physical and

chemical scrubbing processes, as well as membrane technology. These separate the biogas, dividing off the desired methane from the other accompanying gases. In this way, by separating off carbon dioxide, and other trace gases (where applicable), the proportion of methane in the biogas is raised from around 50 percent to the level necessary for the respective gas grid, namely 85–98 percent. The following figure presents the generally applicable steps in the process of cleaning and upgrading biogas to form biomethane.

PROCESS STEPS IN THE UPGRADING OF BIOGAS



The upgraded biogas, now called "biomethane" and in effect identical with natural gas in chemical terms, can be transported by the available infrastructure of the natural gas grid, across any distance, to locations with high demand for heating all year round. The gas grid commands a huge transport and storage potential and is thus able to decouple the generation of energy from the demand for it. At the same time, the use of the gas grid reduces the need to expand the high-voltage power grids. Many gas suppliers offer biomethane/natural gas mixed products with various proportions of biomethane (5, 10 or 20 percent biomethane), which are also available for private users. 100 percent biomethane products are rather rare and are usually substantially more expensive than pure natural gas products with the same energy content. Any natural gas customer can use these products, without needing to substitute their existing heating system in order to do so. Conventional household appliances, such as gas-powered cookers or gas-powered driers, can be operated using biomethane.

Because of the higher investment costs and operating costs involved, it is primarily for larger enterprises that it is worthwhile to make the upgrade and feed-in, but technical progress is allowing smaller and smaller installations to take part in this market directly.

Biomethane is also used as a fuel in natural gas vehicles. Natural gas burns comparatively cleanly but as a fossil fuel it does

emit additional CO_2; by contrast, due to being plant-based, biomethane provides a high potential for saving CO_2, one that also compares extremely well among the options for biofuels. Accordingly, a 25 percent share of biomethane in natural gas reduces the CO_2 emissions by 20 percent. In the European countries that lead the field in this – Sweden and Switzerland – biogas has already been used for years in cars, buses and trucks. Conversely, Germany is still only starting with this form of use. Despite the technology being operationally ready, the potential is far from being fully used up. At present there are only a few service stations at which the customer can get pure biomethane. But about a third of the 900 natural gas service stations in Germany already offer mixtures of biomethane and natural gas.

WHAT NEEDS TO BE TAKEN INTO ACCOUNT?

When setting up and then operating biogas plants, as well as for applying the digestates onto soil, a large number of laws and ordinances need to be taken into account. These requirements encompass planning law, construction law, water law, nature conservation law, and waste law; the provisions of immission control, fertilisers and hygiene law are also relevant.

Biogas is flammable; in mixtures with 6–12 percent air it is explosive. For this reason, the safety rulings for agricultural biogas plants and the corresponding general regulations need to be taken into account. It is a matter of principle that the emergence and escape of dangerous gases must be avoided. The operators need to provide a large number of items of proof and to conduct checks that guarantee safe operation. Subject to compliance with the statutory requirements and recommendations, dealing with biogas involves no greater risk than natural gas does.

For commercial success the challenge is to use all areas of potential for lowering costs, both in building and in operating the biogas plant. Above all, this is a matter of utilising the energy produced in the best possible way.

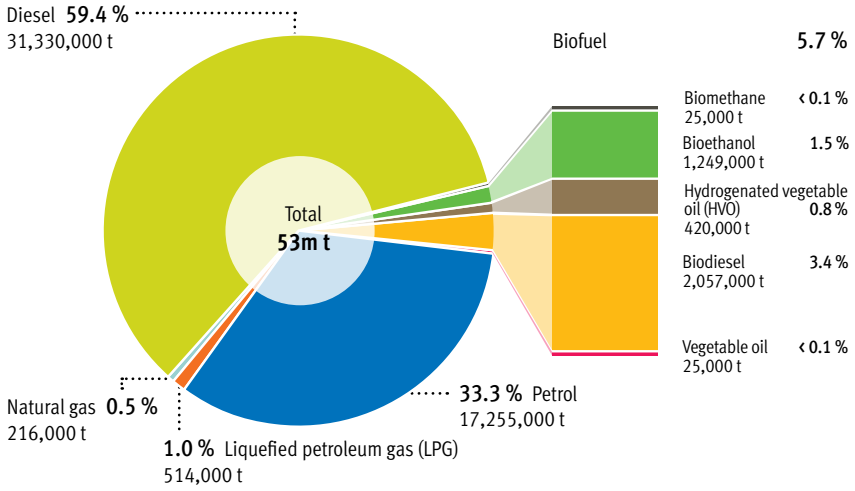
7.3 Biofuels as liquid bioenergy sources

Liquid bioenergy sources such as vegetable oils, biodiesel and ethanol are now already substituting petroleum and diesel fuels. Yet they are also substituting heating oil in boilers, used in single-family or multi-family

residential buildings, or in CHP units that generate electricity and heat in municipalities. Above all, this is due to the high energy density that liquid energy sources offer advantages in transport and storage. A large part of modern infrastructure is set up to suit liquid energy sources; this is done in order to make sure that, when it is distributed, liquid biomass can make use of the available transport and storage systems. While electricity and heat from biomass are primarily generated through solid fuels and biogas, biofuels are the most important renewable alternative with regard to mobility.

Our society is now more mobile than ever. Even if current forecasts predict a downturn in levels of use of personal transportation, primarily due to new traffic concepts, goods traffic on our roads is set to increase significantly. Current status indicates that electromobility does not yet offer any alternative: thus liquid fuels can be expected to continue to dominate our heavy-goods road transport, ship transport and air travel, at least, over the next decades to come. Likewise, for personal vehicles engines fuelled by petrol and diesel will not disappear from one day to the next. These factors make it all the more true that sustainability and avoidance of greenhouse gases are taking centre-stage in the discussion on mobility, as are efficiency and the economical use of resources. Biofuels such as biodiesel, ethanol and vegetable oil are making a decisive contribution here.

FUEL CONSUMPTION IN GERMANY 2012



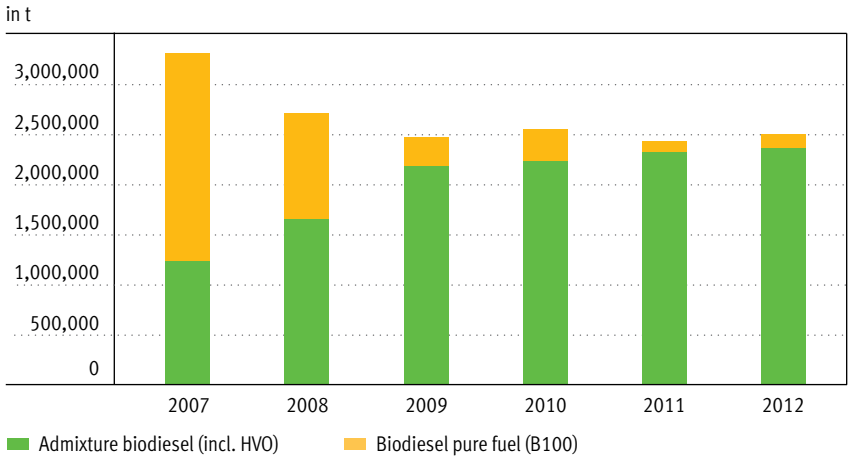
Source: BAFA, erdgas mobil, DVFG, BMF, FNR (2013)

Of the 53 million tonnes of petroleum and diesel consumed in Germany in 2012, approx. 5.7 percent (in terms of their energy content) were substituted by biofuels – mainly by an admixture (see box on page 43). With sales of 3.8 million tonnes, Germany takes the leading position within the EU. The sale of biofuels is more or less constant, after the major downturn in 2008 – in 2007 the share was yet 7.2 percent. To help support the market introduction, pure biofuels were initially largely exempted from taxes (mineral oil tax/energy tax). The step-by-step introduction of taxation, together with increasing raw material prices, caused a collapse in the market for pure biofuels – especially in the commercial vehicles sector. Since January 2013, the tax concession no longer applies to biodiesel and vegetable oil as a pure fuel. Up to the year 2020 – due to the current biofuel objectives – a major increase in the use of biofuel can be expected in Germany.

BIODIESEL

Biodiesel or also fatty acid methylester (FAME) accounts for the largest market share of biofuels consumed in Germany, at approx. 65 percent. At over 30 production sites, it is produced from vegetable oils and fats – primarily rapeseed oil; so called rapeseed oil methylester (RME). In production, the three fatty acids contained in the oil are separated off from the glycerine in the presence of a catalyst and then esterified with

BIODIESEL SALES IN GERMANY



Source: Bafa, FNR (2013)

methanol. The requirements applicable to fuel quality are established by the norm DIN EN 14214, which is valid Europe-wide.

Since 2004, oil companies have been admixing up to 5 percent biodiesel to traditional diesel, and from 2010 up to 7 percent – hence the name of the fuel “B7”. While in 2006 only around 40 percent of German biodiesel was sold through the admixture process, it is now over 90 percent.

ADMIXTURE

According to the Biofuel Quota Act (Biokraftstoffquotengesetz), the oil companies have an obligation as the party that “places (the fuels) on the market” to ensure that certain minimum proportions of biogenic fuels are used in their sales of diesel and petrol. Defined binding quotas apply here. Requirements are met mostly by the admixture of biodiesel to diesel or respectively by the admixture of bioethanol to the petrol category “Super”. The upper limits are established in the fuel quality norms: According to this, up to 7 percent biofuels can be admixed to the diesel and up to 10 percent to the petrol.

With this admixture obligation, Germany complies with requirements regarding climate protection. Accordingly, the EU's Renewable Energies Directive requires that, by 2020, 10 percent of final energy consumption in the transport sector must originate from renewable energies in all Member States.

From 2015, the biofuels quota in Germany is being converted into a greenhouse-gas avoidance quota. This means that what is decisive is no longer the quantitative proportion of the biofuels released into the market, but their contribution to reducing greenhouse gases.

While pure fuels played an important role in the early years of the biofuel boom in Germany, admixtures now dominate the market. Admixed biofuels and other biofuels that contribute to meeting the biofuels quota are not tax-exempt.

VEGETABLE OIL

A further source of pure biofuel is rapeseed oil. Mainly in agriculture and forestry, it is an option in modified engines. While in the case of biodiesel the fuel is adapted to the necessary engine characteristics by means of esterification, with vegetable oil fuel the engine needs to be adapted to suit the fuel. Appropriate distribution outlets offer special equipment for making the conversion. As the oil or fuel quality respectively has a decisive impact on perfect functioning, compliance with the rapeseed oil fuel norm DIN 51605 is highly significant in this.

Combined heat and power unit fuelled by rapeseed oil

Like for biodiesel, a reduced energy tax rate applied to rapeseed oil fuel until December 2012. By contrast, in agriculture and forestry, this use of pure fuel is exempt from energy tax. The current limited level of competitiveness compared to conventional diesel fuel has caused sales of vegetable oil fuel to collapse from 840,000 tonnes (2007) to less than 25,000 tonnes (2012).

Vegetable oils are used in Germany not only as fuel, but also for the generation of electricity and heat. In 2010, around 1,400 CHP units fuelled by vegetable oil produced approx. 1.8 TWh electricity (i.e. 1.8 billion kWh). With an average electricity consumption in German of approx. 3,600 kWh per household and year, this corresponds to electricity production for 500,000 households. CHP units fuelled by vegetable oil are usually operated on a highly-efficient heat-led basis – the advantage is high overall efficiency, at over 80 percent. Even if there is remuneration for generating electricity from vegetable oil in existing installations, via the Renewable Energy Sources Act (EEG) – see also Chapter 3 – high prices for these raw materials in recent years have made it harder for them to be run on a commercially viable basis. For new installations going into service from 2012 onwards, the EEG remuneration no longer applies, so this form of use will not be further expanded in the future.

BIOETHANOL

While vegetable oil and biodiesel provide the fuel for diesel engines, bioethanol can replace "Super"-category petrol. Ethanol

emerges in the anaerobic digestion of carbohydrates that are present in crops containing starch (potatoes, maize, grain) or sugar (sugar beet, sugar cane). Using yeast and enzymes, this sugar is converted to ethanol and to CO_2. For the use as fuel, the alcohol content must then be raised, to at least 99.7 percent, via distillation and draining process in several stages.

In Germany, ethanol is primarily produced from grain or sugar beet. Six large installations and several smaller ones, with a total production capacity of more than 1 million tonnes, currently produce approx. 0.6 million tonnes of ethanol per year. In 2012 the industry sold approx. 1.2 million tonnes of bioethanol, almost all of which was used as admixture in the fuel category "Super" (Super E5, Super E10). Only approx. 1 percent or 17,000 tonnes of E85, as a pure fuel, were sold at German service stations.

E10

While up to 2010 a maximum of 5 percent of bioethanol was admixed to petroleum fuels in Germany (in terms of volume), since January 2011 it is possible to double the biogenic share to up to 10 percent. Bioethanol is admixed to basic petroleum in the refineries. From there it is distributed to the service stations. "E10" – the new term used for it at the petrol pumps – is compatible with the engines of more than 90 percent of petrol-fuelled vehicles. The remaining vehicles are essentially not suitable for operation with E10 due to incompatibility of materials. That is why German service stations continue to offer petrol of the category "Super" with an ethanol share of up to 5 percent (E5). There is no indication of negative consequences in terms of how suitable vehicles run when fuelled by E10 (e.g. cold-start problems, output performance). Neither does the 10 percent bioethanol content in the petrol have a significant effect on fuel consumption, compared to conventional petrol. On the one hand, the difference in terms of energy content is only small, especially compared to E5; on the other hand, subject to having the appropriate engine technology any loss can, to a large degree be compensated for by the advantageous characteristics of ethanol fuel (e.g. high level of heat of evaporation, high octane rating). This is confirmed by tests on vehicle fleets, for example tests conducted at Vienna Technical University.

E85 AND FLEXIBLE FUEL VEHICLES (FFV)

So-called Flexible Fuel Vehicles (FFV) have been on the market in Germany since 2005. These vehicles' engines are able to use fuels with a higher ethanol content (E85), as well as conventional petrol. E85 is a fuel mixture consisting of 85 percent ethanol and 15 percent petrol. As ethanol has a lower energy content, when using E85 a 10–30 percent higher rate of consumption must be expected, compared to E10. However, extra consumption is in part balanced out by a lower fuel price. E85 is available at more than 300 service stations in Germany.

SUSTAINABILITY

What is common to all biofuels sold in Germany and elsewhere in the EU is that since 2011 they are required to fulfil particular requirements with regard to their sustainable production (cf. Chapter 5). The Sustainability Ordinance (Nachhaltigkeitsverordnung) defines criteria which ensure that, in cultivating biomass, no valuable habitats for rare plants or animals – such as moorlands or rain-forests – are lost worldwide. From 2011, biofuels must also reduce greenhouse gases along the entire value chain, of at least 35 percent (from 2017: 50 percent and from 2018: 60 percent) in relation to fossil fuels – thus a positive effect on the environment is required by law.

THE FUTURE

At present and for the foreseeable future, it is primarily vegetable oil methylesters (from rapeseed, but also from soy oil and palm oil) and bioethanol (from grain, maize, sugar cane and sugar beet) that are and will continue to be used, as a constituent part of fuel mixtures. The prospects are that biomethane and new biofuel options of the future, including ethanol from lignocellulose (straw) or synthetic biofuels (biomass-to-liquid fuels), will noticeably broaden and supplement this product range.

The production of synthetic fuels from solid biomass is currently still in the development stage; relevant pilot installations are expected to go into operation in 2014. This gives rise to the hope that the processes for making so-called BTL fuels (biomass-to-liquid) will achieve market readiness in the years to come. These fuels promise a range of advantages: the biomass is used in its entirety, not merely individual constituent parts of the plant, such as oil or starch. Accordingly, BTL achieves strong land efficiency results; also, a broad base of natural materials is suitable for its production – such as wood chip, straw or municipal organic waste – some of which do not compete with food production.

Researching bioenergy

8 BIOENERGY VILLAGES AND BIOENERGY REGIONS

Many villages and communities are already supplying their needs, wholly or partially, with electricity and heat from biomass – they have become bioenergy villages. A bioenergy village pursues the aim of covering the main body of its need for heat and electricity on the basis of regionally and sustainably produced biomass, often supplemented by other renewables such as wind and solar energy.

Villages and communities in which the majority of the residents as well as the farmers, foresters and municipal representatives are convinced by the idea of a "bioenergy village", have the best prospects for successfully implementing concepts for becoming a bioenergy village. The largest stumbling blocks usually arise, not due to technical problems or a lack of availability of biomass, but rather due to incomplete information and doubts among the population. It is the village residents who are the ones that need to be convinced about the project, as customers and/or operators. In setting up and running biomass heating facilities, wood-burning CHP units or biogas plants, and in constructing heating networks or small gas grids, farmers and foresters can become energy farmers. Residents and business people can come together to form operator companies in control of such facilities, building up an energy supply that is sustainable and secured over the long term. For instance, energy cooperatives give all participants the opportunity to actively participate in the project and to have a financial stake in it.

In Germany, not only bioenergy villages have realized the opportunities that biomass offers for employment and economic-value creation, as well as for setting up sustainable economic cycles. Entire regions are doing so and by now they have benefited as bioenergy regions. The Federal Ministry of Food, Agriculture and Consumer Protection has been promoting such developments since 2009 through networking and PR. The thereby established bioenergy networks are being run by effective managements, which train key involved parties and build up acceptance among the population. In this way, in the course of the projects, it has proven to be possible to create a suitable climate for bioenergy investments. In the following projects, the key issues are efficient use of natural resources, additional value creation in the region, exchange of experience, and giving continuity and stability to structures. Knowledge is gained by scientific guidance and support on technical, commercial and social aspects. For those involved, this knowledge highlights the approaches that lead to improvement and optimization. In the brochure "Bioenergie in Regionen" (bioenergy in regions), the experience gained so far is adapted in a user-friendly way, as well as being made available to other municipalities and regions as a basis for decision-making and a planning aid.

9 FURTHER INFORMATION AND SOURCES

FNR information and literature

The FNR offers more detailed information on bioenergy in brochures, guidance documents and market overviews. At the following sites:

www.fnr.de
http://bioenergie.fnr.de
http://heizen.fnr.de
http://biogas.fnr.de
http://biokraftstoffe.fnr.de
http://energiepflanzen.fnr.de

more detailed FNR publications are available to you, for ordering – in most cases free of charge – and for downloading.

Other information

National Biomass Action Plan for Germany
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU)
Federal Ministry of Food, Agriculture and Consumer Protection (BMELV)
(September 2010)
www.bmelv.de

National Action Plan for Renewable Energy, according to Directive 2009/28/EC for Promoting the Use of Energy from Renewable Sources – issued by the German Government on 4 August 2010
www.bmu.de/N46291-1

Energy Concept for an Environmentally Sound, Reliable and Affordable Energy Supply
Federal Ministry of Economics and Technology (BMWi), Berlin, www.bmwi.de
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), Berlin
www.bmu.de (September 2010)
www.bundesregierung.de/Content/DE/StatischeSeiten/Breg/Energiekonzept/dokumente.html

Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=Oj:L:2009:140:0016:0062:en:PDF

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