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Bioenergy




Plants
Raw materials
Products

Federal Ministry
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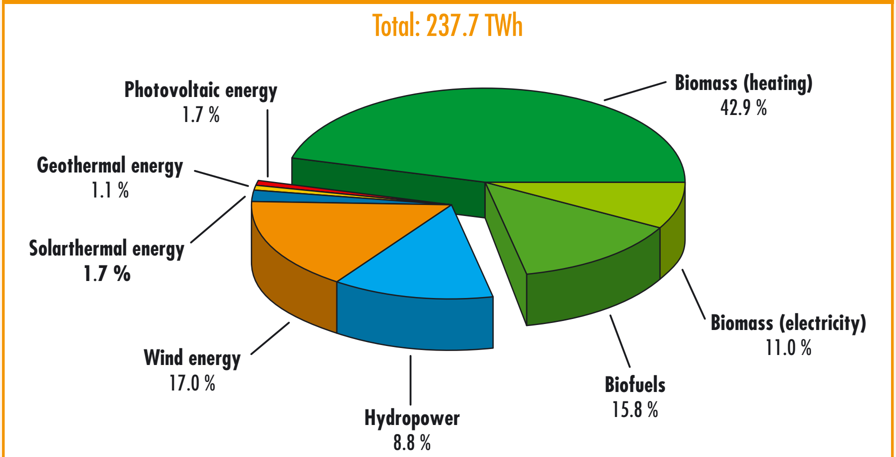
Why do we need bioenergy?

Whether in the form of heating, electricity or fuel, energy is needed everywhere and makes our lives pleasant. Generally speaking, the higher a country's standard of living, the more energy it consumes. If water, wind and wood supplied the energy necessary for industrialisation to take place in the 18th century, these renewable energy sources were quickly replaced in the 19th century by coal, oil and gas. Today, approximately 90 % of energy used worldwide is produced from fossil resources. Not only does this diminish coal and oil reserves, it also has consequences for the climate and for the environment. This is because producing energy from fossil raw materials releases large quantities of carbon dixiode (CO_2) into the atmosphere in a short time, exacerbating the greenhouse effect.

There is no threat of such consequences where biomass use is concerned. When wood, residues or energy crops are converted into energy, they only produce

Share of renewable energy of final energy consumption in Germany



Source: Federal Ministry for Environment (BMU), April 2009

Figure 1: 6.8 % of Germany's final energy consumption was covered by bioenergy in 2008. Its share of renewable energy was round 70 %.

about as much CO_2 as they had previously fixed during their growth. There is therefore a closed carbon cycle.

Biomass is not only available in large quantities in these parts, it also has another considerable advantage. It is the only renewable energy source that can be stored. Heating, electricity or fuel can thus be produced as and when they are needed. It is no wonder that biomass is already the largest renewable energy source in Germany (see Fig. 1).

It has only been over the last few decades that science has managed to develop the appropriate technology allowing bioenergy to be used efficiently in this country. This is not the case everywhere in the world. However wood, residues from lignocellulosic crops and even dung are the most intensively used energy sources in developing countries today. It is the responsibility of industrialised countries to make knowledge and technology accessible and to encourage states in the Third World to use the resources at their disposal efficiently and in a more environmentally friendly manner.

What is biomass?

In principle, any material of organic origin counts as biomass. Not just plants and animals but also animal excrements or plant components such as straw. Paper and cellulose, abattoir waste, organic waste, vegetable oil and ethanol are all biomass and can be used to produce energy.

Different methods are used to turn these various raw materials into liquid, solid or gaseous energy sources. Often there are several potential ways to transform a raw material into energy. Biomass can

for example be burnt in a power station to produce heat, fermented in a anaerobic digester to make biogas and then electricity and heat, or converted into a synthetic gas and fuel by thermochemical gasifiction. Which variant imposes itself not only depends on the cost and expenses involved but also on the prevailing political conditions.

The main raw materials come from:

- **Forestry**
  In Germany today, only about 80 % of annual timber growth is felled or used. Felling and thinning also result in waste timber and smallwood being left in the forests that is of no use as construction timber, for cellulose production or to make furniture. For the sake of sustainability, far more wood could be used for energy purposes without this having any harmful effect on the forests.

- **Agriculture**
  It is not only residues such as straw that can be used to produce energy; for the past few years, farmers have been specifically cultivating energy crops. Since less and less land is needed for the production of food in these parts, the cultivation of energy crops has great potential for the future. Oilseed rape has already imposed itself as a source of fuel, and there is currently a boom in maize and other energy crops. Field tests are being conducted with fast-growing species of trees such as poplars as well as new crops such as Chinese silver grass (Miscanthus sinensis) and particular grass species. Other new cultivation methods such as mixed or multi cropping systems are being tested. The aim is to find crops and rotations that are environmentally-friendly while also being economically viable for the farmer.

- **The wood and food processing industries**
  Off-cuts from sawmills or wood shavings in pellet form are predestined to be burnt, but fruit and vegetable waste as well as green waste from landscape conservation and horticulture can also be used in biogas plants and turned into energy.

Fuel		Fuel value
Fossil	Brown coal	5.6 kWh/kg
	Hard coal	8.9 kWh/kg
	Fuel oil	11.7 kWh/kg
Biogenic	Straw	4.0 kWh/kg
	Cereal plants	4.2 kWh/kg
	Wood	4.4 kWh/kg

Table 1: Energy content of various energy sources

How does energy get into biomass?

We have the sun to thank for the fact that we can use renewable resources to produce energy. In photosynthesis, carbon dioxide and water are transformed by solar energy into oxygen and carbohydrates and subsequently into fats and proteins. The plant fixes carbon dioxide, grows and releases oxygen into the environment. There are naturally differences in how much biomass is produced depending on the plant, the soil and the climate. Even if plants can only store a relatively small proportion of the available solar energy, the amount of energy fixed in the earth's biomass is still enormous: every year about 400 million tonnes of biomass grows, containing about 3,000 exajoules (EJ, 10^{18} joules) of energy. In comparison, humans use about 400 EJ annually, although most of this is derived from fossil fuels. Only about 45 EJ is produced from biomass. It may be difficult to get one's head round the sheer scale of these figures, but they do demonstrate that renewable resources could be far more intensively used as energy sources than has thus far been the case.

Type of plant	Average yield (t dry mass/ha)
Wheat (whole plant)	10.5 – 17.5
Oilseed rape (whole plant)	8.5 – 12
Maize (whole plant)	11 – 19
Miscanthus	10 – 30
Wood	4 – 18

Table 2: Annual dry mass yield of various plants (Source: Leitfaden Bioenergie, FNR 2005)

What is really meant by CO_2-neutral?

As carbon dioxide is often fixed in plants for years or even decades, they are referred and as CO_2 sinks. They play an important role in the earth's climatic balance. Fossil raw materials are CO_2 sinks too, albeit ones that have existed for millions of years.

When raw materials containing carbon are used for energy purposes, they combine with oxygen and produce carbon dioxide which is considered to be one of the main causes of the greenhouse effect. However this is also the case when plants are not used and rot.

Whereas in nature growth and decomposition are in balance, the concentration of CO_2 in the atmosphere is constant and the CO_2 cycle is closed, fossil raw materials are no longer bound into this cycle. When they are used for energy production, the CO_2 concentration in the atmosphere rises and the greenhouse effect is exacerbated.

From biomass to energy source

Biomass is transformed into liquid, solid or gaseous energy sources by various, more or less complicated methods and can then be turned into heat, electricity or fuel. Whereas it is relatively easy to turn the chemical energy fixed in the raw material into heat through oxidation during combustion, other methods are more complex. Gasification, for example, takes place without oxygen. The aim is to obtain the largest possible quantity of inflammable gas from the raw material so that it can be cleaned and then used for example in a gas engine. It is also possible to liquefy biomass by pyrolysis.

Energy source	CO_2 emissions (kg/MWh)	Annual CO_2 emissions (kg/a)	CO_2 savings compared with fuel oil (kg/a)
Fuel oil	342	5,472	0
Natural gas	228	3,648	1,824 = 33 %
Wood pellets	68	1,088	4,384 = 80 %
Firewood	8.8	141	5,331 = 97 %

Table 3: About 16 MWh of energy are used each year in a detached house, producing widely differing amounts of CO_2 emissions depending on the energy source used.

In addition to these thermochemical processes, certain physical-chemical methods can also be used. For example, it only requires pressing or chemical extraction to produce oil from sunflower seeds or oilseed rape. In contrast, biochemical methods are responsible for converting biomass into biogas or to ferment biomass with a high sugar, starch or cellulose content into alcohol. It is obvious that some of the options are in competition with each other; for example, a given amount of wood can either be burnt directly or transformed into synthesis gas by a gasification process or into a liquid energy source. The choice of transformation method is in many cases not just a technical question but above all an economic question: the more complex the procedure is, the higher the cost of the finished energy source will necessarily be.

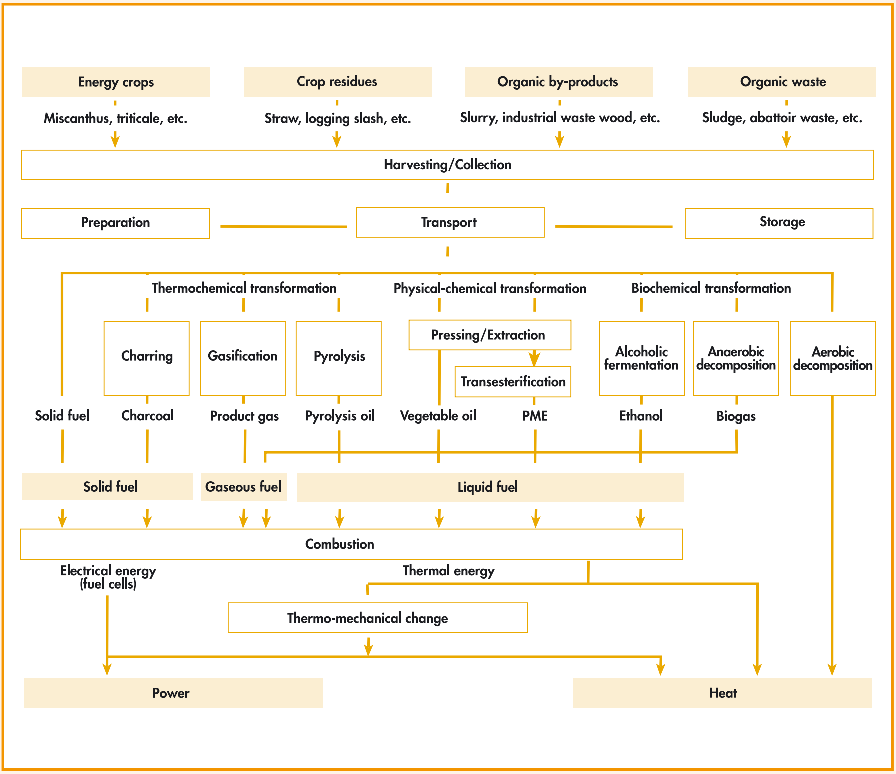


Figure 2: Biomass and potential uses for energy

What is the potential?

Biomass may represent an inexhaustible supply of energy but there are limits to how much can be produced annually. It must not restrict plant production for food, nor should it disturb the ecological balance. Biomass production for energy should therefore be planned and implemented with great care.

The amount of bioenergy that can be generated in Germany doesn't only depend on the volume of wood that grows each year, nor on the amount of organic residues that accumulates. In the future, energy crops will also have an important role to play. There is a need to sound out which plants produce the greatest amount of energy. The various plants and end-products can be said to be in direct competition with each other. While it is mainly maize and mixed crops that are grown to contribute to fermentation in biogas plants today, by 2030 they might have been replaced by plants that are particularly well-suited for the production of synthetic fuels. In principle it is assumed that yields will increase with time and that methods of utilisation will become more efficient. It is the technical potential that determines how large a contribution bioenergy will make towards covering our energy needs at a certain point in time. This calculation takes technical as well as structural and ecological constraints into account. Estimates for the year 2030 give some impression of what bioenergy might look like in the future. At around 12,750 petajoules, energy requirements in Germany will be slightly lower than they are today, but about 17 % of this total could be supplied by domestic renewable raw materials.

It is interesting to look at the concrete energy sources. Today about 57 % of bioenergy comes from wood, but the future clearly belongs to energy crops which, according to projections, will account for the majority of energy produced from biomass in the year 2030. 4.3 million hectares would then available to plant crops for electricity, heating or fuel. As a comparison, about 17 million hectares are used for agriculture today. Biomass will therefore be superior to other source of renewable energy in Germany by far but does have its limits. Imports will be essential. The objective is to reach a balanced system of energy supplies to which all forms of renewable energy contribute according to their technical, economic and ecological possibilities.

In other countries and on other continents, there are good prospects for energy to be produced from completely different raw materials. In Asia for example, large quantities of rice husks, of bagasse from sugar processing and of dung are available. Depending on the local geographical conditions, a wide range of energy crops could grow in importance. If one adds all these possibilities together, then biomass could supply over 100 EJ and hence over a quarter of today's worldwide energy needs. Using biomass for energy opens up new prospects for the world as a whole.

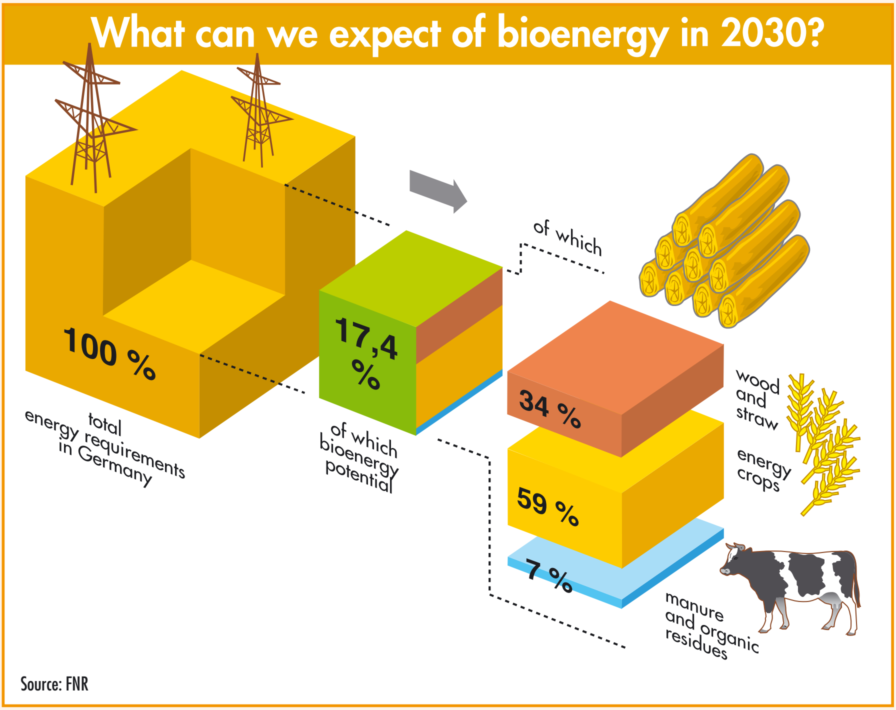


Figure 3: Biomass presently supplies about 6.8 percent of Germany's electricity, heating and fuel needs – and this could rise to over 17 % in the year 2030. There is enormous potential and not just from biogas, logging slash, smallwood, residues from wood processing and the currently unexploited proportion of new wood growth, which is considerable. Energy crops and straw will also play an important part in future energy production.

Renewable raw materials and sustainability

Fossil energy sources are running low and in order to spare them and halt climate change, we will have to gradually switch to renewable energy over the coming decades. Bioenergy, which already is the largest contributor among regenerative energy sources in Germany with about 70 % of the total, will continue to play a central role in the future. Renewable raw materials are already of great importance in the materials sector too.

A fundamental prerequisite for the increased utilisation of plant raw materials and energy sources is however that they are produced and used sustainably. Sustainability, as defined in the 1987 Brundtland Report, means meeting the needs of the present generation without compromising the ability of future generations to meet their own needs[1)]. Sustainability therefore has an environmental, an economic and a social dimension. When applied to renewable raw materials, this means that their utilisation needs to strike a balance between what is economically necessary, such as high and guaranteed biomass yields, and what nature can be expected to tolerate. The social component refers among other things to people's working conditions, new income opportunities and a share of value-added processes.

There are many different approaches to sustainable production in European agriculture and forestry. One of the Federal Ministry of Agriculture's (BMELV) main funding domains is to test these approaches through research projects and to further develop them. Some of the strategies that are being pursued are:

- Increasing the species diversity used in energy crop production;
- Breeding new varieties;
- New production methods using lower doses of pesticides and fertilisers as well as year-round vegetative cover on fields;
- The use of especially efficient conversion processes;
- Cascading use models (material use of renewable raw materials followed by energetic use);
- The recycling of residues as fertiliser.

The BMELV's task is to fund research in an appropriate and consistent manner so as to develop the most suitable methods for a sustainable energy and raw material industry. It will then require the whole of society to put these methods into practice: it is business and consumers who have to integrate these new processes and products into their daily lives.
Agricultural markets have long been globalised. The needs for bioenergy and

renewable raw materials are thus increasingly satisfied by international markets and this cannot help but have an impact on questions of sustainability. In the tropics, there are different problems than in Europe, as areas of rainforest are cleared to grow food, feed and energy crops such as oil palm and soya, the workforce is exploited and indigenous peoples are displaced. A pilot project for a certification system, funded by the BMELV, intends to remedy this situation. Its aim is, as a first step, to authorise only biomass with a certificate of sustainability to be used in the production of biofuels. Later, such certificates will be applied to all possible methods of using agricultural raw materials so as to avoid displacement effects. The certification project, which is now beginning a two-year test phase, is thus also a suitable instrument to test the sustainability requirements of draft Federal and EU-wide laws[2)].

After all, the situation in Southern countries is exactly the same as in the North: bioenergy can be as much a threat as an opportunity for the ecosystems and people who live there. If in the South, for example, small farmers can be established as biomass producers and the large areas of uncultivated land can be taken back into production for energy crops, then the advantages outweigh the disadvantages. Extremely drough-resistant plants such as jatropha (also called "physic nut") offer possibilities to revegetate desert-like areas.

In the North, new varieties of energy crops and new production methods can ensure greater diversity and sustainability. What is more, in rural areas, bioenergy is a first-rate instrument for structural development: it offers new sources of income, new economic configurations and greater independence to regions that are presently often some of the more structurally disadvantaged, problem areas.

Paths towards a sustainable, renewable society do exist. It is now a question of choosing them and developing them not only economically but also environmentally and socially. The BMELV is making its contribution by funding research and raising awareness.

1) In 1983, the World Commission on Environment and Development (Brundtland Commission) chaired by the former Norwegian Prime Minister Gro Harlem Brundtland used the term "sustainability", which originally came from forestry, for the first time in a development context. This definition is quoted from the Brundtland Commission's final report "Our Common Future" (also known as the Brundtland Report) from 1987.

2) Draft sustainability directive by the German Federal Government (2007), which prescribes that only sustainably produced biofuels may be considered for the quotas (Biofuel Quota Act), as well as draft guidelines from the European Commission to promote renewable energy (2008).

Heating with biomass

Although wood has been used for heating for thousands of years, modern combustion plants and biomass boilers with an efficiency rate of over 90 percent are much more effective at turning it into heat. To produce the same amount of heat, not only is less biomass needed but there are also less waste residues. Whether it is in central heating, heat plants or combined heat and power stations, wood remains the number one biofuel for heating in Germany.

Since wood contains a high proportion of volatile substances, woodburning boilers must be built differently from oil or coal boilers. The boilers are also adapted to different types of biofuel in order to operate as efficiently and pollute as little as possible. A different construction is thus required for logs than for woodchips or pellets.

Biomass heat plants

As biogenic solid fuels naturally contain less energy in proportion to their weight than fossil raw materials, it is best to use them where they occur. Bioelectricity and bioheat are therfore mainly produced in small or medium-sized decentralised plants. There are now biomass heat plants of between 500 kW (kilowatts) and 30 MW (megawatts) all over Germany, which either supply blocks of flats, schools, swimming pools and small companies or are connected to a local heating network. They mostly use woodchips from thinning or left-over wood from industry. These materials are cheap and ensure that biomass heat plants are also a viable alternative from an economic point of view. Many municipalities make use of smallwood and thinnings from their own woodland. They do not necessarily have to prepare it themselves; the chopping is often done by a service provider. For some time now, there have also been companies who produce and market woodchips in large quantities.

Small-scale biomass boilers

There are more and more small-scale household biomass boilers in rural areas. This is because consumers have recognised that modern wood burners function efficiently and that there are cost benefits to having a locally available source of fuel. Since the technology to make use of woodchips is relatively complicated and expensive and woodchips take up a lot of storage space, such households generally install log and pellet boilers. Both of thse fuels have their advantages: pellet boilers run fully automatically and earn points for their ease of use. Logs are however the cheapest form of fuel, especially for users who go about getting the wood themselves.

Heating with logs

Modern log boilers come with a capacity of between five and several hundred kilowatts. Although the wood still has to be put in by hand, latest technology ensures that combustion is much more efficient and cleaner than before so that there is no problem in complying with strict German legislation regulating emissions. Thanks to a lambda probe and control, there is enough oxygen for the wood to burn completely and far less air pollutants such as carbon monoxide (CO) and hydrocarbons are produced.

Figure 4: Log gasification boiler

Log gasification boilers spatially separate the releasing of light volatile particles (gasification) from the transformation of these gases into heat (combustion). When combined with a staged combustion air stream, the efficiency can reach more than 90 %. To make the most efficient use of the heat produced, log boilers are combined with a hot water reservoir which releases heat into the heating system as and when required.

Heating with pellets

Pellets are produced on an industrial scale from sawdust and wood shavings. These pressed objects are 6 to 8mm thick and about 10 to 30mm long and there is a standard that guarantees consistent quality. Pellets are not only little bundles of energy (2 kg of pellets are the equivalent of 1 litre of fuel oil); they are also very easy to transport. Pellet boilers are often preferred for detached houses because

the fuel takes up less space. Thanks to modern technology, a pellet boiler equipped with a fan or a screw conveyor can manage the flow of pellets it requires to produce the level of heat the user has determined. This is not only comfortable

Figure 5: Woodfired heating fitted to save space

but also particularly efficient and environmentally-friendly. A small reservoir for buffer or hot water for use (boiler) is enough to store the heat produced by combustion. To complete the range, there are combination boilers that burn both pellets and logs, as well as pellet stoves.

Using straw and grain as fuel

Grain and straw not only fix similar amounts of energy to wood, they are also relatively homogeneous fuels that are available all over Germany. They have however been little used for energy production until now as some particular characteristics and elements in them can cause problems when they are burnt and therefore require special solutions. The low ash softening point leads to slagging of the ash inside the boiler and the high chlorine content can cause corrosion. Dust and nitrogen oxide emissions will also have to be controlled. Manufacturers are trying to deal with the problem from a construction point of view as well as by adding cleaning systems.

Present and future emissions regulations for dust cannot be respected without installing air pollution cleaning systems. To capture the very fine dust particles, tests are being carried out on filtering or electrostatic separators as well as secondary heat exchangers that cause the flue gases to condense. These not only have to work, they also cannot be too expensive so that they represent a viable investment for the farmer.

Large-scale plants already exist that can fire whole bales of straw, break up bales or use so-called cigar burners to produce energy from them. Urgent work is being done on the technical adaptation of smaller boilers so that they can use straw and other stalk plants as fuel. Several boiler manufacturers have already launched promising specialised grain boilers onto the market.

One interesting alternative for the future are also straw and stalk pellets. Straw is already being made into pellets and these are being fired on a small scale.

As straw and grains offer considerable biomass potential that can make an important contribution to an ecologically sustainable supply of energy, the German federal government supports research in this area.

Electricity from wood and straw

In 120 B.C., Heron of Alexandria already described how steam produced by combustion could be used to carry out mechanical work. Yet it was only in 1770 that James Watt laid the foundations for the Industrial Revolution by inventing the first low pressure steam engine. Since then, steam power has become and integral part of industrial society. Although steam hammers were originally used to produce mechanical energy directly, electricity was successfully generated for the first time at the end of the 19th century. In 1882, Edison was instrumental in the creation of the first steam power stations in London and New York.

The conversion of solid fuel into electricity is even today measured in terms of the steam power process. Modern steam power stations attain steam parameters of 250 bar and 560 °C, giving degrees of electrical efficiency of 43 percent or more. How these power stations operate is very complex from a thermodynamic point of view. The power stations can be up to 1,000 MWh (thermal output) and more in size.

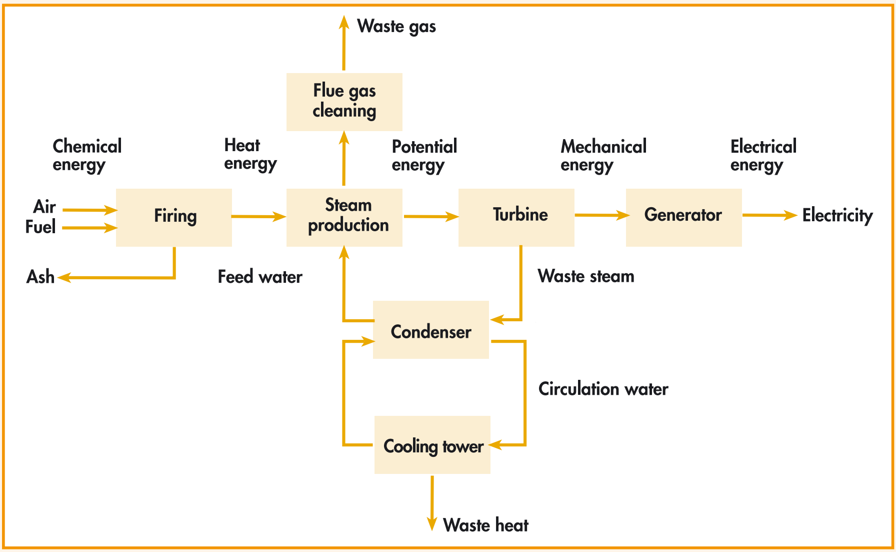


Figure 6: Diagram of a steam power station

As wood, straw and energy crops are collected on a decentralised basis, it is not always viable to use them in large-scale centralised power stations. The combustion properties of straw and grain for energy do not necessarily always fulfil the requirements of the steam power process with the high temperatures and pressure it needs. Steam power stations are therefore more or less given over to using waste wood. All other solid types of biomass are transformed into electricity in relatively small, less complex power stations at lower steam parameters. This also explains why the electrical efficiency of biomass power stations of around 35 % is presently lower than that of large coal-fired power stations.

One efficient alternative for decentralised power stations is the combined heat and power plant (CHP) which, along with electricity, also decouples the resulting heat so that it can be used. Since this type of plant produces heat and electricity at the same time, the energy fixed in the biomass can be used very efficiently.

Alternative conversion technologies

The available alternatives for electricity production are limited by the fuel characteristics of solid biomass. Three important processes today are the Organic Rankine Cycle (ORC) process, the steam engine and the Stirling engine. Since all of these have relatively low electrical efficiency, it only makes sense to use them if there is also a client for the heat produced. The ORC process and the steam engine are for instance to be found in the wood processing industry where off-cuts can be used as fuel and where both electricity and heat are required.

Organic Ranking Cycle (ORC) process: the ORC process makes use of organic working fluids that have better evaporation properties than water. For example, silicon oil can conduct large amounts of energy even at low temperatures and pressures. In this case electricity production also takes place via a steam engine, albeit a somewhat modified one. ORC plants come as compact designs with an electrical capacity of 100 kWh_{el} and above and they can attain an electrical efficiency of over 12 %.

Steam engines: the steam engine can be regarded as a modern version of the classic Wattsian steam engine except for the fact that it operates in a closed cycle. As the electrical efficiency does not exceed 15 percent, this engine only makes sense in places where the (waste) heat is also needed.

Stirling engine: although the Stirling engine was patented in 1817 by a Scottish vicar of the same name, it has been un-

Figure 7: ORC plant

able to impose itself in the market until now. A gas, generally helium, converts energy into labour via a cyclical process of changing temperature and pressure. Although the Stirling engine can run on just about any biofuel, there are still problems with the technical implementation of the Stirling machine, which explains why it has yet to play any major practical role in the use of biomass. Prototypes of Stirling engines have an electrical output of below 10 to 40 kW_{el} and some larger units can be found. Recently, the main emphasis has been laid on CHP by combining pellet ovens with Stirling engines. In thermodynamic terms, an electrical efficiency of 25 percent can be attained and 10 percent has been reached in the laboratory.

Thermochemical gasification: the great hope for the future

Engineers and scientists have been working on gasification for over 80 years to try and resolve the problems connected with the combustion of solid materials. During gasification, the fuel is heated under oxygen deficient conditions and converted into an inflammable gas, which is often then cleaned before further use. Electricity and heat are then produced from this gas in a gas engine or gas turbine. Present-day gasification techniques achieve a 70 to 80 % conversion rate of fuel energy into the product gas.

While fixed bed gasifiers are being tested in the 2 to 5 MW_{th} range, fluid bed systems are preferred for larger power ranges. In the future, larger plants (with furnace thermal capacities over 20 MW_{th}) might well grow in importance. In these, gasification takes place under pressure (20 to 100 bar) and leads to the production of synthetic fuels.

With an electrical efficiency of about 30 percent, gasification is already an interesting way of converting biomass into electricity. People are hoping for over 40 percent from an integrated gas and steam turbine process (IGCC: Integrated Gasification Combustion Cycle). The use of fuel cells should also be successful in the long term and the electrical efficiency could well exceed 50 percent. For the time being though, thermochemical gasification has not yet become the technical standard for any range of capacity. There are not only problems with the quality of the product gas but also with a lack of stability in the gasification process. In the medium term however, thermochemical gasification could provide a suitable alternative for electricity production from biomass.

Biogas

Biogas forms in any place where organic matter decomposes in a moist environment without light and air: in marshes and bogs, or in ruminants' alimentary canal. Methanogenic bacteria are doing the main job in this process. Biogas can however also be produced systematically from organic matter in a biogas plant (anaerobic digester) with the help of various bacteria. The yield and composition of the biogas varies according to the material or mixture of materials used.

What goes into it?

To begin with, cattle, pig or chicken slurry and manure were the main materials used in farm biogas plants but nowadays other biomass is increasingly being mixed in with them. In addition to organic residues and waste from the food industry or biodegradable waste, energy crops such as maize, sorghum, sunflower grown for this purpose give especially high yields of biogas. If maize is chopped and made into silage for storage, it can be

Elements	Formula	Concentration (Vol.-%)
Methane	CH_4	50 – 75
Carbon dioxide	CO_2	25 – 45
Water vapour	H_2O	2 – 7
Oxygen	O_2	< 2
Nitrogen	N_2	< 2
Hydrogen sulphide	H_2S	< 2
Ammonia	NH_3	< 1
Hydrogen	H_2	< 1

Table 4: Average composition of biogas

Substrate	Biogas yield (m^3/t fresh mass)	CH_4 content (Vol.-%)
Cattle slurry	20 – 30	60
Pig slurry	20 – 35	60 – 70
Cattle manure	40 – 50	60
Pig manure	55 – 65	60
Chicken manure	70 – 90	60
Maize silage	170 – 200	50 – 55
Rye whole-crop silage	170 – 220	55
Organic waste	80 – 120	58 – 65
Grass cuttings	150 – 200	55 – 65

Table 5: Biogas and methane content of various substrates

used as and when necessary. Grass silage, beet and grain silage are fermented in biogas plants too. It is to be expected that biogas will be used more intensively and this must be well-managed. Scientists are therefore developing new energy crops and agricultural systems to ensure that energy crop production can be expanded in an ecologically and economically sustainable manner.

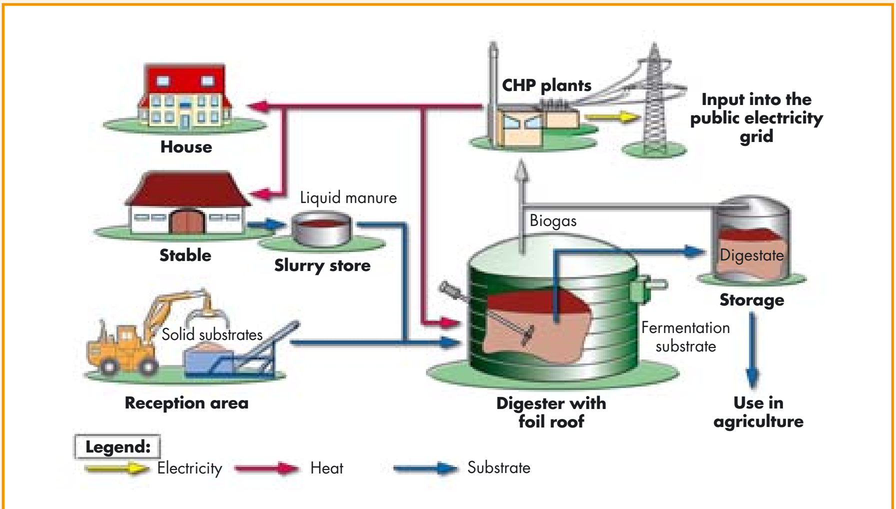


Figure 8: Scheme of a agricultural biogas plant

How does a biogas plant work?

Figure 8 shows how an on-farm biogas plant works and how its basic elements are arranged: storage and mixing tank/ substrate insertion, digester, digestate storage and biogas utilisation. If substrates that could potentially spread epidemics, e.g. abattoir or food waste, are added to the fermentation process, then these have to be made hygienic and heated at over 70 °C for at least an hour to kill off the germs. Slurry and co-substrates are stored temporarily and crushed, diluted or mixed in the slurry store if necessary. The heated digester, also known as a fermenter, is the cornerstone of the plant. For fermentation to be effective, it not only needs to be gas- and watertight but also has to shut out all light. A stirring device ensures that the substrate stays well-mixed and homogeneous and that bacteria and substrate are in close contact with each other.

When the substrate has fully degraded, it is pumped into the digestate storage and can then be spread as fertiliser. The biogas produced is first of all cleaned and desulphurised and then flows into a gas storage container before for example being converted into electricity in a combined heat and power plant (CHP). The heat from this operation can be used to heat the biogas plant and neighbouring residential and commercial buildings.

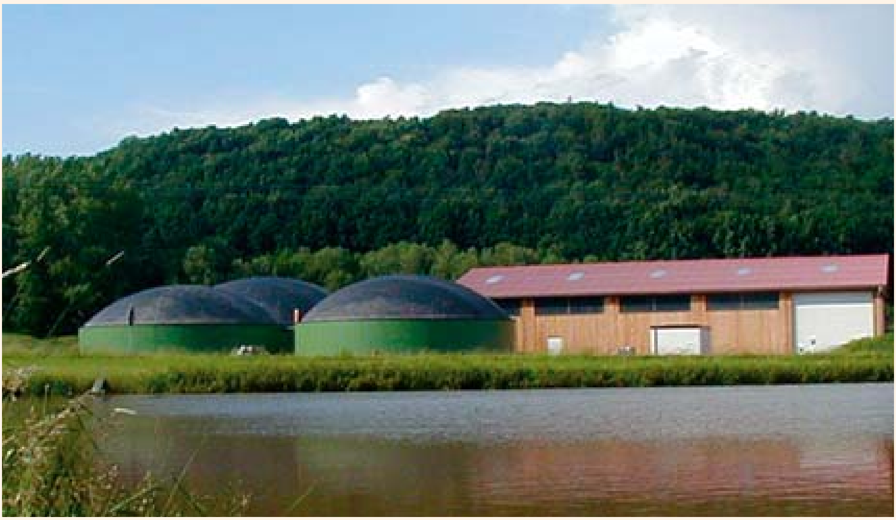


Figure 9: Agricultural biogas plant

What happens in the fermenter?

Biogas plants differ according to their chosen substrate, the technology used and even the working termperature. Fermenters with a working temperature of between 32–42 °C are called mesophile plants; those between 50–57 °C are known as thermophile ones. The fermentation process in the digester is nevertheless fundamentally the same: the biomass decomposes in four separate biological stages with different microorganisms participating in each of them. The organisms that are bound to a liquid phase consume the products from the previous steps in the decomposition and at the end they produce biogas. Whereas single-stage plants carry out all these stages in one fermenter, two-stage plants separate the first two stages from the following once.

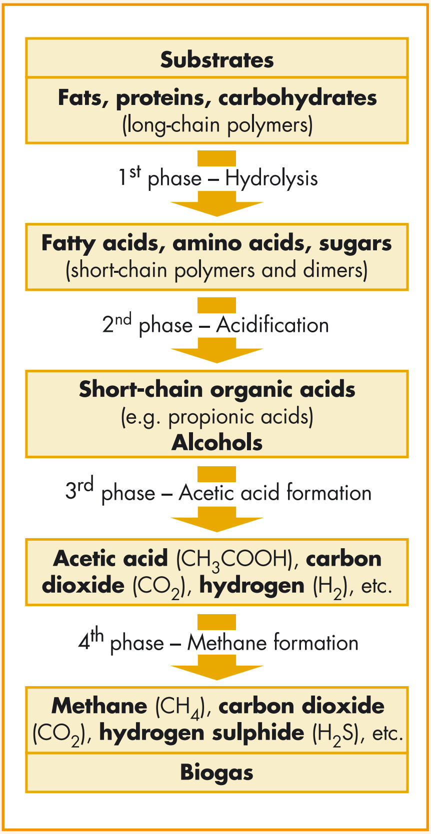


Figure 10: Simplified scheme of how organic substances are broken down in a biogas plant

Biogas as an energy source

Biogas is predominantly converted into electricity in combustion engines that in turn drive a generator. CHP plants use either gas Otto engines or spark-ignition engines. Gas Otto engines are ones that have been specifically developed for gas production and are similar to four-stroke engines in motor vehicles. Spark-ignition engines, on the other hand, work on the same principles as diesel ones. Since biogas does not ignite spontaneously when it is compressed, an ignition oil (about 10 % of the fuel capacity) is injected to produce a self-igniting mix of gases. A biogas plant can be run very efficiently if the waste heat can also be sold.

This is because only about 35–40 % of the energy contained in the biomass can be converted into electricity using conventional technology. About 40–50 % of the generated energy in a CHP accrues as waste heat.

Researchers are for example currently testing whether biogas can be used in fuel cells that convert the chemical energy in purified biogas directly into electricity and thus exploit its electricity capacity better. Although fuel cells have been too expensive up till now, they do run quietly and can reach a degree of electrical efficiency of up to 50 %.

Figure 11: Dry fermentation biogas plant

There are new opportunities in preparing and feeding biogas into the natural gas network. This is because the biogas can then be utilised in places where heating is needed. Although the cleaning and preparation are expensive, current examples demonstrate that it can be worthwhile feeding the gas into the network. When prepared in this way, biogas can also be used as fuel in cars that run on natural gas, as shown by the first German biogas filling station inaugurated in 2006.

Biogas without slurry – dry fermentation

Since the dry fermentation process does not require liquid manure, arable farmers can also become energy farmers. Energy crops, crop residues and biogenic waste can be fermented either continuously or discontinuously. Whereas continuous dry fermentation requires a constant supply of fresh substrate to the fermentation chamber and constant removal of the fermentation residue, with discontinuous fermentation the fermenter has to be stopped every four to six weeks to allow it to be emptied and filled with new substrate. Dry fermentation methods provide an alternative to the widespread wet fermentation process and hold great promise for the future, in particular because it makes fermentation technically easier and can be done without using liquid manure.

Biofuels

If we want sustainable mobility, then there is no getting around biofuels. They are currently the only renewable alternative. Electric engines driven by fuel cells will not be available for the forseeable future. The focus therefore remains on the combustion engine.
Biofuels must therefore resemble petrol or diesel and can then be used in highly-developed engines without these having to be greatly adjusted. Biodiesel has been the first of these fuels to impose itself on the market. But pure vegetable oils and ethanol made from plants with a high sugar or starch content are already in use too. As part of a pilot project, the first biogas filling station was opened in Wendland in June 2006. The gas is cleaned and prepared so that it can be used by vehicles that run on natural gas.

Synthetic or BtL (biomass to liquid) fuels are in development. Most biofuels are liquid and can therefore be easily transported. Not only are they CO_2-neutral but they also biodegrade quickly and are either hardly or not at all dangerous for water, which is an advantage in case of leaks or accidents.

In 2008, 6.1 % (2007: 7.3 %) of all fuels were already derived from renewable resources. Germany is one of the leading countries in Europe for biofuels and is setting a good example to others. The aim is to reduce the greenhouse gas emissions of the German fuel consumption by 7 % through increasing the share of biofuels on the German total fuel market by 10 – 12 % in 2020. The EU target is to increase the share of renewable energies

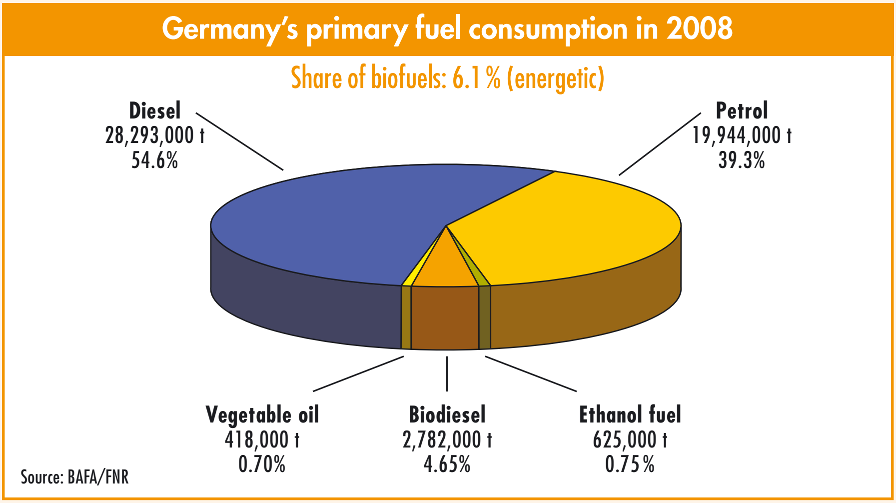


Figure 12: Primary fuel consumption in Germany in 2008

for the European transport sector to up to 10 % in 2020.

Vegetable oils

In order to use **vegetable oils** like rapeseed oil in modern diesel engines, the engine has to be adjusted. Special conversion sets are available on the market. Since the quality of the oil has a decisive effect on how well the engine works, a lot of attention is being paid to ensuring producers keep to the DIN 51065 preliminary standard. It has mainly been farmers and foresters as well as haulage firms who have switched their fleets over to this biofuel. In 2008, 418,000 tonnes of vegetable oils were used for fuel.

Biodiesel

Biodiesel, or fatty acid methyl esters (FAME) can be produced from a large variety of oils and fats by esterisation. Rapeseed oil has established itself as a raw material in Germany, giving rise to the name rapeseed oil methyl ester (RME). During the production process, the three fats present in the oil are split from the glycerine through a catalyser and then esterised using methanol. As biodiesel so closely resembles diesel that

it can be used in modern high-performance diesel engines, some vehicle manufacturers have given their approval for the use of biodiesel. The requirements covering fuel quality are contained in the Europe-wide DIN EN 14214 standard.
The Working Group on Quality Management in Biodiesel (AGQM) guarantees a consistently high level of fuel quality and this is signalled by a logo on filling pumps. About 2.8 million tonnes of biodiesel were used as fuel in Germany in 2008. And more than 1.1 million tonnes were used as pure fuel mainly by haulage fleets and also in private cars and the agricultural sector. Oil companies have been mixing in up to 5 % of biodiesel into traditional diesel since 2004. This equals more than 1.6 million tonnes just for the year 2008. In February 2009 the new national standard DIN 51628 came into effect which allows the blending of diesel with up to 7 % biodiesel. Rapeseed oil and biodiesel can of course also be used as fuel for stationary heat production or for combined heat and power produc-

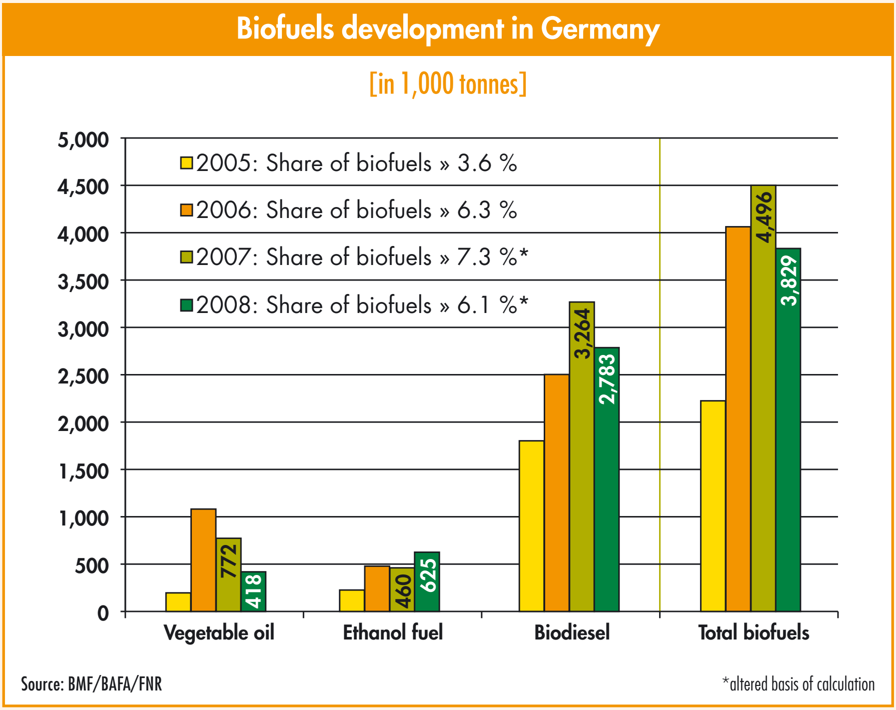


Figure 13: Development of the biofuels situation in Germany over the last years

tion in CHP plants. Although conventional oil heating systems can be converted technically to biodiesel, this has not generally been the case until now due to the cost.

Ethanol

Whereas vegetable oil and biodiesel drive diesel engines, bioethanol can replace Otto engine fuels (petrol, four-star, four-star plus). If oxygen-containing ethanol is mixed in, then the fuel not only burns more efficiently, it also produces less pollution. Ethanol is produced when the sugars contained in plants that are high in starch (potatoes, maize, grain) or sugar (sugar beet) ferment. This sugar is converted into ethanol and CO_2 using yeast and enzymes. The various stages of distillation and dehydration allow the alcohol to be enriched to up to 99.9 % ethanol. Following DIN EN 228, ethanol can be mixed in with Otto engine fuels in proportions up to 5 %. It can also be converted into ethyl tert-butyl ether (ETBE). It is mixed in with Otto engine fuels to improve their octane count and replaces the fossil-fuel-based methyl tert-buthyl ether (MTBE). The first large-scale ethanol factories have now started up in Germany and ensured that about 625,000 tonnes of ethanol could be used in cars in 2008. So-called Flexible Fuel Vehicles, that run on fuel with up to 85 %

ethnol, have been on sale in this country since 2005. However, due to the lower energy content, drivers must take into account the fact that they will use more fuel. Presently, more than 250 ethanol (E85) filling stations have been set up in Germany.

Synthetic fuels

Although synthesis fuels have not yet been produced on a large scale, much hope has been invested in them. So-called Biomass to Liquid fuels (BtL, otherwise known as Synfuel or Sunfuel®) have a great many advantages. Not only can they be produced from a wide array of different raw materials and are ideally suited to modern engine designs but they can also be sold through the existing network of filling stations. In their production, straw, wood or energy crops are first converted into a synthesis gas by thermochemical gasification and this can then be used specifically to make petrol or diesel. Due to the chemical properties of hydrocarbons, BtL fuel burns efficiently and completely, as well as causing less pollution than traditional fuels. The fuels can be tailored to requirements through changes in pressure, temperature and catalysers during synthesis and through their subsequent preparation. There are several companies and research institutes working in Germany and Europe to produce BtL fuels at a pilot level. Although these developments are very promising, it will hardly be possible to achieve a completely self-sufficient supply of biofuels in the densely populated countries of central Europe. But the next step has been made: the first industrial BtL production plant has started its operation in Germany in 2008. Nevertheless, experts predict that biofuels produced in Germany will have a 20–25 percent share of total fuel supplies as early as 2020. This is an impressive figure when one considers that we are presently almost entirely dependent on oil producers and refiners. Only the future will tell if our mobility can be entirely renewable by the end of the century. But there is no doubt that there is sufficient biomass potential for this to happen.

Figure 14: Pilot plant to produce BtL fuels

Legislation and prevailing conditions

Where, how and how much biomass contributes to energy supplies depends to a great extent on the legal context. There are not just considerations of regional development, planning and pollution to take into account but also laws regulating waste and fertiliser use. Alongside these are laws such as the Renewable Energy Sources Act or the Mineral Oil Duty Act that are forcing the expansion of bioenergy by fixed payments for electricity from biomass or tax relief on biofuels. The German Federal Government is supporting the expansion of bioenergy through various research, development and market introduction programmes.

Anti-pollution measures

Although burning biomass is largely carbon-neutral, thereby protecting the climate, burning solid fuels can release noxious gases. The Federal Immission Control Act (BImSchG) and its consequent directives and administrative provisions (1. BImShV, 13. BImSchV, 17. BImSchV and Technical Instructions on Air Quality Control (TA Luft)) provide the framework here. A minimum plant size is fixed according to the type of fuel, the objective being that as few harmful substances are released into the environment as possible. While natural wood can be used as an energy source even in small boilers, straw and coated wooden materials have to be used in larger plants as these can ensure that less pollution is emitted during burning.

The legal requirements for biogas plants are far more complicated. Alongside the anti-pollution laws, there are a great many additional regulations intended to make the construction and running of biogas plants as environmentally-friendly as possible. A person who wants to design a plant will therefore not only have to deal with building, water and fertiliser regulations but also with numerous safety-related requirements. Biogas plants and large incineration and gasification plants also have to comply with epidemic control standards.

Renewable Energy Source Act

The most important legal instrument in Germany to support the production of electricity from renewable sources is the Renewable Energy Source Act (EEG), which first came into action in the year 2000. Since than the EEG has been amended in 2004 and recently in 2008 to cope with the chancing requirements.

The EEG regulates the preferential connection of plants that produce electricity from renewable energy sources and the purchasing, transmission and payment of electricity by the operator of the grid. The EEG defines payment rates for every kilowatt hour of renewable electricity that is fed into the public grid. The basic payments differ according to the type of renewable energy source, the conversion technology and the capacity of the plant. The level of fees shall be determined according to the share of a plant's capacity which falls between the relevant threshold values. In this case, the capacity of the plant will not be deemed to be its effective electrical capacity, but rather the ratio of the total of the kilowatt hours to be fed in to the grid during the calendar year in question to the total number

EEG tariffs for the next years

	Share of capacity	€cents/kWh		
		2009	2010	2011
Basic tariff	up to 150 kW_{el}	11.67	11.55	11.44
	from 150 to 500 kW_{el}	9.18	9.09	9.00
	from 500 kW_{el} to 5 MW_{el}	8.25	8.17	8.09
	from 5 MW_{el} to 20 MW_{el}	7.79	7.71	7.63
Cultivated biomass bonus	up to 150 kW_{el}	7.00	6.93	6.86
	from 150 to 500 kW_{el}	7.00	6.93	6.86
	from 500 kW_{el} to 5 MW_{el}	4.00	3.96	3.92
Manure bonus	up to 150 kW_{el}	4.00	3.96	3.92
	from 150 to 500 kW_{el}	1.00	0.99	0.98
Landscape conservation material bonus	up to 500 kW_{el}	2.00	1.98	1.96
Emission reduction bonus	up to 500 kW_{el}	1.00	0.99	0.98
Technology bonus	up to 5 MW_{el}	2.00	1.98	1.96
CHP bonus	up to 20 MW_{el}	3.00	2.97	2.94

Table 6: Payments for electricity from biomass according to the Renewable Energy Source Act

of full hours for that calendar year. The EEG also stipulates an additionally increase in the electricity payments through various cumulative bonuses that are linked to specific conditions. There are e.g. bonuses for the utilisation of wood and other renewable raw materials specifically grown for energy production (biomass bonus), for the external utilisation of the heat produced (combined heat and power) and for the use of innovative technologies such as Stirling engines, fuel cells or upgrading biogas to natural gas quality (biomethane). Table 6 shows the EEG payments for electricity from biogas according to the updated amendment (valid from the January 1st 2009).

The EEG guarantees the plant operators fixed tariffs for electricity fed into the grid for a period of 20 years – plus the year it was taken into operation. The basic payment as well as the bonuses are subject to an annual degression of 1 % based on the basic rate applicable in the previous year. The fee paid depends on the defined tariff in the year the plant brought online.

Over the last years, the EEG's payment regulations have led to a considerable increase in electricity production from biomass. The improved payment schedule contained in the new 2004 version of the EEG contributed to an expansion of energy production from farm biogas plants and biomass heat and power stations.

The Energy Saving Regulation (EnEV)

In the residential building sector, the Energy Saving Regulation (EnEV) also play a role. Since the 1st February 2002, these have fixed the maximum primary energy needs of a house in terms of heating and hot water. They also take account of the primary energy efficiency of various different energy sources as well as the degree of effectiveness and environmental impact of plant technology. Modern wood combustion techniques such as pellet central heating and log gasification boilers provide a real alternative in this context, both for new housing and for the renovation of old buildings.

The Market Incentive Programme for Renewable Energy

Using biomass to produce energy is generally more expensive than using fossil energy sources such as oil or gas where investment costs are concerned. Not only are the plants technically more complex but they are also produced in relatively small quantities at the mo-

ment. As bioenergy could only assert itself slowly on the market despite its positive environmental effects, the Federal Government and the Federal States decided to accelerate its market introduction by various promotional schemes.

Since 2000, the Federal Office of Economics and Export Control (BAFA) has been supporting the purchase of biomass plants such as central heating units using logs or wood pellets, biomass power stations and biogas plants in order to conserve the limited resources of fossil fuel and to make a contribution to environmental and climate protection. This promotional scheme has given an impressive stimulus on the sales of renewable energies technology on the market and is also enhancing its cost effectiveness. The amended promotional scheme of the market incentive programme which came into effect in March 2009 now sponsors among other technologies manually loaded log gasification boilers between 15 and 50 kilowatts rated heat output, automatically charging solid biomass heat plants up to 100 kW so as innovative heat and cold production and low emission technologies. For more information visit www.bafa.de/bafa/en/.

The Kreditanstalt für Wiederaufbau (KfW), a promotional bank under the ownership of the Federal Republic and the Federal States, is managing a programme to promote renewable energies. It supports the installation, expansion or purchase of biomass or biogas plants for heat and power production with loans with fixed rate of interest below the capital market level and long-term duration. For more information visit www.kfw-foerderbank.de/en_home

In addition, numerous biogas and biomass plants have been built in the agricultural sectors thanks to the Agricultural Investment Support Programme (AFP) of the joint scheme on "Improving the Structure of Agriculture and Coastal Protection".

Biofuel legislation

Biofuels are regulated by European and national framework conditions. The EU passed Guideline 2003/30/EG in order to increase their share of the market. This commits member states to increase the share of biofuels to 10% by 2020.

Under EU Guideline 2003/96/EG, member states can grant partial or full tax relief on biofuels. Biofuels were free of tax until July 2006 under the oil tax law in Germany, but now fall under the Energy Tax Law. This sets tax rates that rise year-on-year between August 2006 and 2012 until they reach the level of diesel and petrol. The agricultural and forestry sectors do not have to pay any taxes on biofuels.

There are also strict regulations about mixing biofuels in with other fuels. Fuel standards allow five percent of biodiesel to be added to diesel (DIN EN 590) and of ethanol to petrol (DIN EN 228) respectively. Germany aspires a higher share of biofuels mixed into conventional ones for the future. The Biofuel Quota Act obliges the petroleum industry to mix in set quotas of biofuels since 2007. In February 2009 the new national standard DIN

Concluding remarks

Twenty years ago, many regarded using biomass for energy as a utopian project; it has now been acknowledged as an alternative that has to be taken seriously. Scientists, politicians and the general public all agree that raw materials from agriculture and forestry have a great future as energy sources ahead of them. It is not only people's awareness that has changed; there has also been much technological progress. It has been possible, thanks to a great deal of research, to close most of the gap between biomass and fossil resources. New, effective conversion methods have been developed and new types of biomass as energy sources have been discovered.

The better the conversion methods become, the greater the potential scientists ascribe to biomass. It is not only dwindling fossil fuel reserves that stand to benefit from the 17.4 % of our energy needs that biomass should be able to supply in 2030. The environment also wins because the more biomass is converted, the less CO_2 goes into the atmosphere.

However it is not only in environmental terms that we can achieve something by using bioenergy more intensively. There are also economic and geographical considerations. The use of renewable resources for energy provides solutions to a very serious problem: it gives agriculture and rural areas new options and can help ensure that they create jobs and added value. There are also new prospects for farmers as energy producers.

The relatively low energy content of biogenic energy sources in proportion to their weight is not only a disadvantage. It means that the most efficient place to use wood, slurry and energy crops is where they are produced. New jobs can therefore be created in rural areas for the cultivation, harvesting and transport, as well as their conversion of raw materials into electricity, heat or fuel. Rural areas will thereby not only supply themselves with energy but also win back some control over their original role as suppliers to the cities.

Bioenergy is also an exceptionally interesting area from a scientific point of view. A wide array of raw materials can be used and there are many different ways of converting them into electricity, heat and fuel. We are far from having discovered every possible technique, let alone having developed them to their full potential. Which of these different possibilities will actually be used will not simply be decided on the basis of cost but also to a great extent by the prevailing conditions. Politicians have also identified the possibilities that bioenergy offers in recent years and have started to define laws, provisions and support schemes to encourage the use of renewable raw materials in energy production.

Of course, the expansion of bioenergy must be well planned and carried out in a spirit of sustainable management. It should no more be allowed to restrict the supply of food than it should damage environmental concerns. Bioenergy is by no means the universal remedy for the energy supplies of the future. However, it will, along with the other renewable energy sources, make a significant contribution to providing us with heat, electricity and fuel in the years to come.

Further information

Fachagentur Nachwachsende Rohstoffe e.V. (FNR)
Agency for Renewable Resources
www.bio-energie.de · www.fnr.de

Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz (BMELV)
Federal Ministry of Food, Agriculture and Consumer Protection
www.bmelv.de

Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU)
Federal Ministry for the Environment, Nature Protection and Reactor Security
www.erneuerbare-energien.de

Johann Heinrich von Thünen-Institut (vTI)
Federal Research Institute for Rural Areas, Forestry and Fisheries
www.vti.bund.de

Kuratorium für Technik und Bauwesen in der Landwirtschaft e. V. (KTBL)
Association for Technology and Structures in Agriculture
www.ktbl.de

Technologie- und Förderzentrum im Kompetenzzentrum für Nachwachsende Rohstoffe
Centre for Technology and Assistance in the Competence Centre for Renewable Resources
www.tfz.bayern.de

Bundesverband BioEnergie e.V. (BBE)
German Bioenergy Association
www.bioenergie.de

Deutsches BiomasseForschungsZentrum gGmbH (DBFZ)
German Biomass Research Centre
www.dbfz.de

Deutsche Energieagentur (dena)
German Energy Agency
www.dena.de

Fachverband Biogas e.V.
German Biogas Association
www.biogas.org

Union zur Förderung von Oel- und Proteinpflanzen e.V. (UFOP)
Union for the Promotion of Oil and Protein Plants
www.ufop.de

Agentur für Erneuerbare Energien
Agency for Renewable Energy
www.unendlich-viel-energie.de/en

International Energy Agency Bioenergy
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