Renewable Resources in Bavaria

PROFILES
PORTRAITS
PERSPECTIVES

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Editorial

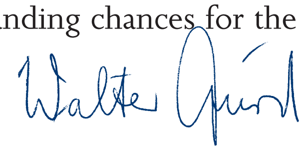
Renewable resources in the name of the future

Bavaria has been making a meaningful contribution to energy supply in a time of diminishing fossil resources, to sustainability and environment protection for many years.
On an international level, Bavaria is the first place to go, with the important pillars Kompetenzzentrum für Nachwachsende Rohstoffe (KoNaRo, competence centre for renewable resources), C.A.R.M.E.N. e.V., TU München, Fraunhofer–IGB as well as the Straubing BioCampus, which reinforces and supports science and companies for project development, networking and innovation processes.
In the context of the renewable energy transition, the biogas branch has known highs and lows, but ensured its continued use with the 2017 EEG.

The economic and ecological potential of "renewable resources" are illustrated by this publication:

- How is the extraction of resources for energy and materials to be ensured in the 21st century?
- What role does the marketing and energy network C.A.R.M.E.N. e.V. play in terms of sustainable resources, renewable energy and resource usage?
- How can the biobattery concept contribute to the energy transition?
- Which path does the professional association Biogas e.V. show its members in terms of active contributions to renewable energy?
- Which key concept helps us out from the energy cost trap?

Then and now, sustainable resources offer many possibilities, perspectives and beyond that, outstanding chances for the future.



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Foreword

Bavaria attaches great value to the production and utilisation of renewable natural resources, with biomass from agriculture and forestry covering around 10% of primary energy consumption. This makes renewable natural resources the number one source of renewable energy in Bavaria. Using biomass also reduces the dependence on energy imports on a lasting basis and makes an active contribution to climate protection. Thanks to the use of biomass, around 9 million tonnes less CO_2 is generated in Bavaria each year.

The utilisation of biomass is also a key economic factor, generating an annual turnover of approximately 2 billion euros in Bavaria. Farmers and forest owners utilise their operating resources as efficiently as possible. This type of diversification secures their income as independent entrepreneurs and creates both jobs and added value in rural areas.

Wood is the most important renewable natural resource, followed by biogas and biofuels. Bavaria's total annual consumption of energy-producing wood amounts to 5.9 million tonnes or 13.3 million solid cubic metres, most of it directly from the forest. This means energy-producing wood alone covers over 5% of primary energy consumption.

Agriculture is the second key source of renewable energy. Renewable natural resources are cultivated on around 450,000 hectares – 14% of agricultural acreage in Bavaria – and provide the basis for biogas plants and biofuel production. A smaller proportion is put to material use and goes into the production of permanent crops, short rotation coppice, Miscanthus, tall wheatgrass and cup plant.

We also have an impressive infrastructure. Bavaria currently operates just under 2,400 biogas plants with a total installed rated electrical output of 882 MW. This means it is home to around a third of such plants in Germany. In addition, there are approximately 3,400 large-scale wood-based biomass plants in operation, most of which are used to supply heat, and another 2 million or so small-scale wood boilers.

Bavaria has already achieved a very high level when it comes to using renewable natural resources. It goes without saying that this benefits the environment and also offers excellent opportunities for agriculture, forestry and the entire economy in Bavaria. Furthermore, an integrated food, energy and raw materials management system has gradually become established and forms part of a bio-based economy or "bioeconomy". I see this bioeconomy as a key point of focus for the future and a great opportunity for Bavaria with its abundance of farmland and woodland. In view of the limited resources available, we need new, sustainable approaches in order to produce the raw materials required for our modern-day lives. The wide-ranging possibilities and prospects of renewable natural resources offer excellent opportunities for Bavaria's future.

Helmut Brunner
Bavarian State Minister
for Food, Agriculture and Forestry

Bioeconomy grows in Straubing, Bavaria‘s „Region of Renewable Raw Materials“

Our society faces great challenges. A central topic of the 21.century is the sustainable sourcing of raw materials for energy and materials beyond fossil fuel – even more so in times of the climate contract of Paris or the German “Energiewende”. The concept of bioeconomy as a sustainable economic system based on biological resources and in which renewable raw materials play a decisive role, offers solutions. That is why Straubing in Lower Bavaria brands as “Region of Renewable Raw Materials”. The Free State of Bavaria clusters its activities in the areas of research, education, utilization and marketing around the topic of biomass in Straubing. The region is headed to become a best practice region within the fast-growing European bioeconomy. The raw materials needed are just a stone‘s throw away. What cannot be harvested off the fertile lower Bavarian “Gäuboden” area and the wood-rich “Bavarian Forest”, can be provided via Straubing‘s high-performing Danube port, mainly from the macroregion Danube area.

BioCampus Straubing

Infrastructure for biobased economy and research

Straubing‘s Danube port specializes in biomass handling. It establishes a profile as Green Chemistry Port and offers a dedicated area for biobased industry applications called BioCampus, the BioCubator Entrepreneur‘s Centre, as well as ready-to-built on industrial sites. Here, companies working along the biomass value chain can find fitting options for laboratories, offices and business spaces. Above this, space for test cultivation of diverse plantbased resources is readily available.

Distances in Straubing are short: the internationally renowned Centre of Competence for Renewable Raw Materials (KoNaRo), where, amongst others, chairs of the TU Munich do research on chemical-material and energetic utilization of biomass and the Fraunhofer IGB institutional part BioCat are located in close proximity to Straubing-Sand, the Green Chemistry Port and its area dedicated for the upscaling and demonstration of scientific research results. Especially the KoNaRo-part Scientific Center Straubing will undergo massive development in the coming years. 18 new chairs and four new Bachelors and four new Masters degree programs on bioprocess engineering, biobased materials, industrial biotechnology and bioeconomy aim to educated up to 1.000 students in 2019. A regional business cluster “renewable raw materials” which is managed by the BioCampus Straubing GmbH, supports both scientists and businesses regarding project development, networking and innovation processes,

4 Million tons of goods are handled on average per anno in the Straubing Danube port – especially on the water freight side, biomass makes up a big part ■

The Straubing Centre of Sciences is growing: new study programmes are being developed, among them bioeconomy and industrial biotechnology. (Foto: Herbert Stolz) ■

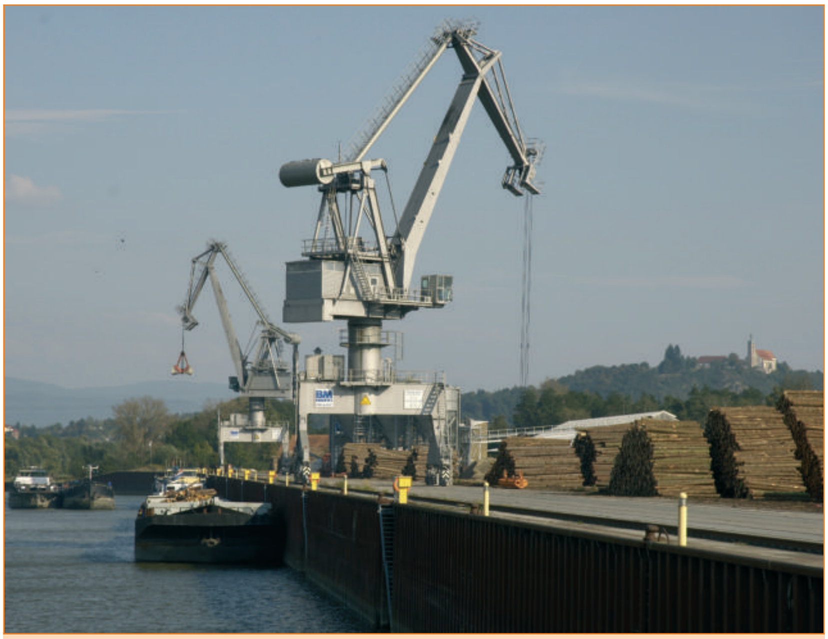
strengthening Straubing's competences as a best practice region for the utilization of renewable raw materials. In close cooperation with the actors of the KoNaRo, the BioCampus also works in the field of PR in order to inform the general public about the region's activities in the field. ■

Green Chemistry Port

Straubing's combination of sustainable resource availability, highly specialized infrastructure and excellent scientific expertise depicts an ideal source for innovations and start-ups and thus a unique feature within the European site competition. International bioeconomy

Laboratories dedicated for biotechnological and microbiological research and businesses have been furnished in the BioCubator. The Biotech-Startup CASCAT GmbH has found its new home here ■

players such as the agrogiant ADM or the Swiss speciality chemicals company Clariant already make use of this position in the port of Straubing. ADM in its rapeseed mill processes thousands of tons of rapeseed for the biodiesel production on a daily basis. In its demonstration plant, Clariant tests different types of lignocellulosic feedstock in its sunliquid© process, which transforms agricultural residue material into bioethanol without burdening food and feed sources. ■



Biomass is one of the major freight types handled in the port of Straubing ■

Investing in Green Start Ups

The region‘s special focus lies on stimulating and supporting young and innovative start up companies and spin-offs originating in Straubing‘s scientific milieu. Especially in invest-intensive branches such as green chemistry, biotechnology or environmental and energy engineering, there is a gap between potential and realization. Tailor-made offers are thus targeted to stimulating entrepreneurship. At the heart of these efforts lies the business plan competition “PlanB – Biomass. Business. Bavaria” organized by the BioCampus Straubing GmbH.
The competition has taken place twice yet and has accompanied almost 50 young founders from all over Bavaria on their journey to make their business idea reality. On top of this, the BioCubator entrepreneur‘s centre now offers modern microbiological lab spaces at a reasonable rate which can be rented to young companies with a need for lab. Start ups which cannot afford equipping a full-fledged laboratory thus get ideal circumstances for a successful start into the business world. The first 150 m^2 lab space have already been rented to the young biotech-start up CASCAT GmbH. CASCAT is a spin-off originating at the Centre of Science Straubing. With its innovative cascading synthesis processes for the manufacturing of biobased chemicals, CASCAT was able to win the first volume of the “PlanB” business plan competition.
Overall, the region‘s goal is to further strengthen Straubing‘s role on the international bioeconomy-stage in the years to come and renewable raw materials will have to play a decisive role. ■

The ensemble of the technology- and start up centre Straubing on the left and the BioCubator on the right ■

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Biogas – An All-Rounder as Energy Carrier

Heat, Power and Fuel

Introduction

Biogas is produced through the anaerobic digestion (methane fermentation) of organic matter in natural or technical systems. It is a mixture of the main components methane, carbon dioxide and water vapor as well as additional trace gases *(Table 1)*. The methane producing microorganisms (methanogenic archaea) are the final link in a food chain and live in close association with syntrophic bacteria (Schieder et al., 2015).

The process of methane fermentation is the dominant source of methane emissions into the atmosphere. As summarized in *Table 2*, the total amount of methane produced in anaerobic digestion plants is still about two orders of magnitude lower than the sum of all other methane sources.

Since the global warming potential of methane is 25 times stronger than that of carbon dioxide (over a 100-year time horizon), it is essential to minimize the leakage and maximize the utilization efficiency of biogas in anaerobic digestion plants.

Methane sources (Alley *et al.*, 2007)	Mass, Tg a^{-1}	Share, %
Natural processes of "methane fermentation" (swamps, domestic and wild ruminants, rice fields, waste, termites, oceans)	285 – 665	70 – 74
Other sources (biomass combustion, production of fossil energy carriers, plants, geological sources, natural fires)	122 – 229	30 – 26
Total	407 – 894	100
For comparison: Overall methane production of biogas plants in Europe (EurObserv'ER, 2014)	(7,7)	(1 – 3)

Tab. 2: *Global sources of methane from natural and technical systems* ■

Biogas is termed an all-rounder among renewable energy carriers because:

- The range of potential feedstocks for biogas production is very wide, including residues / waste, e.g., from agriculture, food processing industry and municipalities, as well as energy crops;
- The design and scale of the technology can be adjusted to different input materials and site conditions;
- There are various pathways for utilizing biogas as an energy carrier to supply heat, electricity or transport fuel, or in coupling with electricity from wind or solar power by means of the "power-to-gas" technology;
- Biogas can be utilized on site or, after upgrading, fed into the gas grid to substitute natural gas; and finally
- The digested residue (digestate) can be used in agriculture and horticulture to (partly) replace mineral fertilizer for resource protection.

While not economically viable in the short run, it is expected that biogas biorefineries in which the biogas (or its precursors) is used as energy carrier and raw material will become feasible in the medium to long term. ■

Biogas production

The process of biogas production is a sequence of interlinked reaction steps whereby the original organic matter is broken down into smaller molecules and, finally, methane and carbon dioxide. Different groups of microorganisms are involved that use the products of the preceding steps for their metabolism. Technically, the process can be implemented by the

Component	Methane (CH_4)	Carbon dioxide (CO_2)	Water vapor (H_2O)	Nitrogen (N_2)	Hydrogen (H_2)	Oxygen (O_2)	Hydrogen sulfide (H_2S)
% (v/v)	50-60	40-45	2-7	0-3*	0-1	0-1*	0-1

*) Nitrogen and oxygen in the biogas originate from blowing air into the digester head-space with the purpose of "internal biological desulphurization".

Tab. 1: *Typical ranges for the composition of biogas from anaerobic digestion plants.* ■

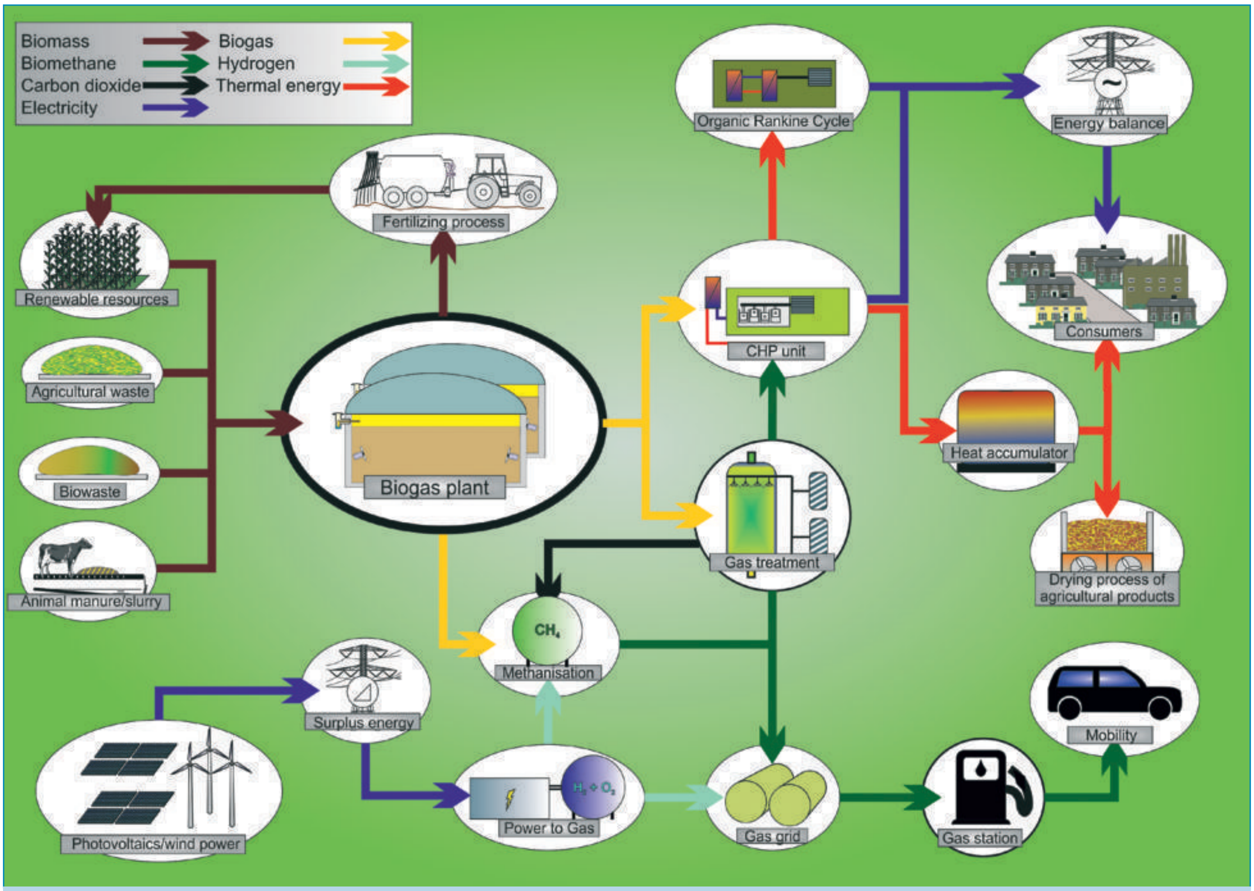

Fig. 1: *Schematic of material flows and utilization pathways for biogas.* ■

use of one or several reactors/ digesters.

In the agricultural sector, the main input materials are so-called energy crops (whole crop silage from maize or cereals, grass silage, etc.) which have a relatively high biogas yield with respect to fresh weight. Animal slurries have the second highest share as input materials in German biogas plants, but their biogas yield is only about a tenth of that of energy crops. In the municipal sector, the utilization of organic residues and bio-waste in biogas plants is growing. ■

Biogas utilization

Currently, the biogas from anaerobic digestion plants is mainly used for combined heat and power production (CHP), employing reciprocating engines with an electrical power output of 30 kilowatts up to several megawatts. For this purpose, water vapor and hydrogen sulfide in the biogas have to be removed to the most part. The CHP units achieve electrical efficiencies of 30 to 45 % and thermal efficiencies of 55 to 40 %. To meet the respective emission limits and still reach a high electrical efficiency, the exhaust gas has to be treated with a catalytic converter or by post-combustion.

An alternative technology to reciprocating engines is micro gas turbines. These are marked by very low pollutant emissions but a significantly lower electrical efficiency. Together with their relatively high price, they are currently not an economical alternative in the agricultural sector (Effenberger et al., 2006)

Fig. 2: *View of a biogas driven co-generation unit with reciprocating engine (center) and generator (left side; Photo: LfL)* ■

In most cases, the electricity that is produced from biogas is fed into the grid, completely, and remunerated at the rates specified in the Renewable Energy Act. As far as the thermal output of the CHP unit is concerned, in middle European climate up to 20 % are needed to heat the digesters. To optimize the greenhouse gas and energy balances of the biogas plant, as much of the surplus thermal energy as feasible has to be utilized to substitute fossil energy carriers. Possible heat consumers are households, public buildings and swimming pools, industry, and drying facilities for agricultural goods *(see Figure 1)*. If there is no adequate direct use for the heat, it can be utilized in tri-generation units for cooling. Another option is to use the heat in an Organic-Rankine-Cycle or steam engine to generate electricity, though the electrical efficiency of these processes is only 10 to 15 %.

As an alternative to electricity generation on site, the biogas can be upgraded to so-called biomethane and fed into the gas grid *(see Figure 1)* for counterbalancing. If a suitable heat consumer is only a few kilometers away, the biogas may be piped to a satellite CHP unit, after dewatering and desulphurization. There are various technologies available to upgrade the biogas to the standards of the natural gas grid. The processes of pressure swing adsorption (PSA) and pressurized water scrubbing (PWS) are employed at larger scales, while for lower throughputs, membrane technology or chemical scrubbing are more feasible. In the course of upgrading, carbon dioxide and trace gases are removed from the biogas to achieve a methane content of more than 97 %. The CO_2 can be recovered and used in glasshouse horticulture, for methanisation with hydrogen from renewable sources (via power-to-gas technology) or as chemical feedstock. Biomethane can be used on all possible pathways to reduce imports of natural gas and mitigate global warming. ■

Utilization of the digested residue

The residue from anaerobic digestion is a valuable fertilizer for agriculture, provided that no contaminated input materials were used in the biogas plant. There is clear evidence that the digestion process has a partial sanitizing effect so that the germ counts in the digested residue are always much lower than in the input materials.

Due to the mineralization of organically bound nitrogen in the input materials, higher concentrations of ammonium nitrogen are found in digested animal slurries compared to raw animal manures. Therefore, while the mineral fertilizer equivalent of these organic fertilizers is increased, it is indispensable to minimize nitrogen losses via ammonia volatilization by using low emission techniques for land application. The digestate can be processed further to improve fertilization efficiency or facilitate transport over longer distances. The first step is usually mechanical separation which yields a “solid” fraction with 20 to 30 % dry matter content. The water content can be reduced further by drying whereby volatilization of ammonia must be avoided (Effenberger et al., 2015). Advanced technologies are available to produce various fertilizer products from the mechanically separated digested residue. ■

Environmental impacts

The factors that typically dominate the environmental impacts from energy supply based on biogas are: the types of input materials, particularly if these were produced exclusively for biogas production; the losses that occur along the process chain; and the amount of fossil energy carriers that is substituted by biogas. As illustrated in *Figure 3* for three case studies from farms in Bavaria, using biogas to replace fossil energy carriers can significantly reduce greenhouse gas emissions. Farm 1 uses mainly annual crops for biogas production. The CO_2-equivalent emissions from cropping as well as from building and operating the biogas plant with CHP production amount to 271 g per kWh of electricity fed into the grid. The largest part of the surplus heat output from the CHP unit is utilized to substitute natural gas for heating. In a life cycle approach, these avoided CO_2-equivalent emissions almost compensate the GHG emissions from the biogas chain, giving a net value of 2 g CO_2-equivalents for electricity from this plant. For the case of Farm 2, heat sales are lower, but the avoided emissions from conventional storage of the pig manure that is diverted to the biogas plant are almost equivalent to the methane losses from the biogas plant and CHPU, yielding net negative GHG emissions. As opposed to Farms 1 and 2 which use a part of their own electricity output, the biogas plant on Farm 3 is operated on electricity from the grid. In this case, the credits for avoided emissions are not sufficient to compensate for the emissions from the biogas chain. Nevertheless, in all three cases the specific CO_2-equivalent emissions of electricity supply from biogas are much lower compared to current grid emissions for Germany *(Figure 3)*.

Other important environmental impacts from agricultural biogas systems for energy supply are eutrophication, acidification and resource use. If animal manure is used as input material, there are neither significant advantages nor disadvantages compared to a reference system dominated by fossil energy carriers. How-

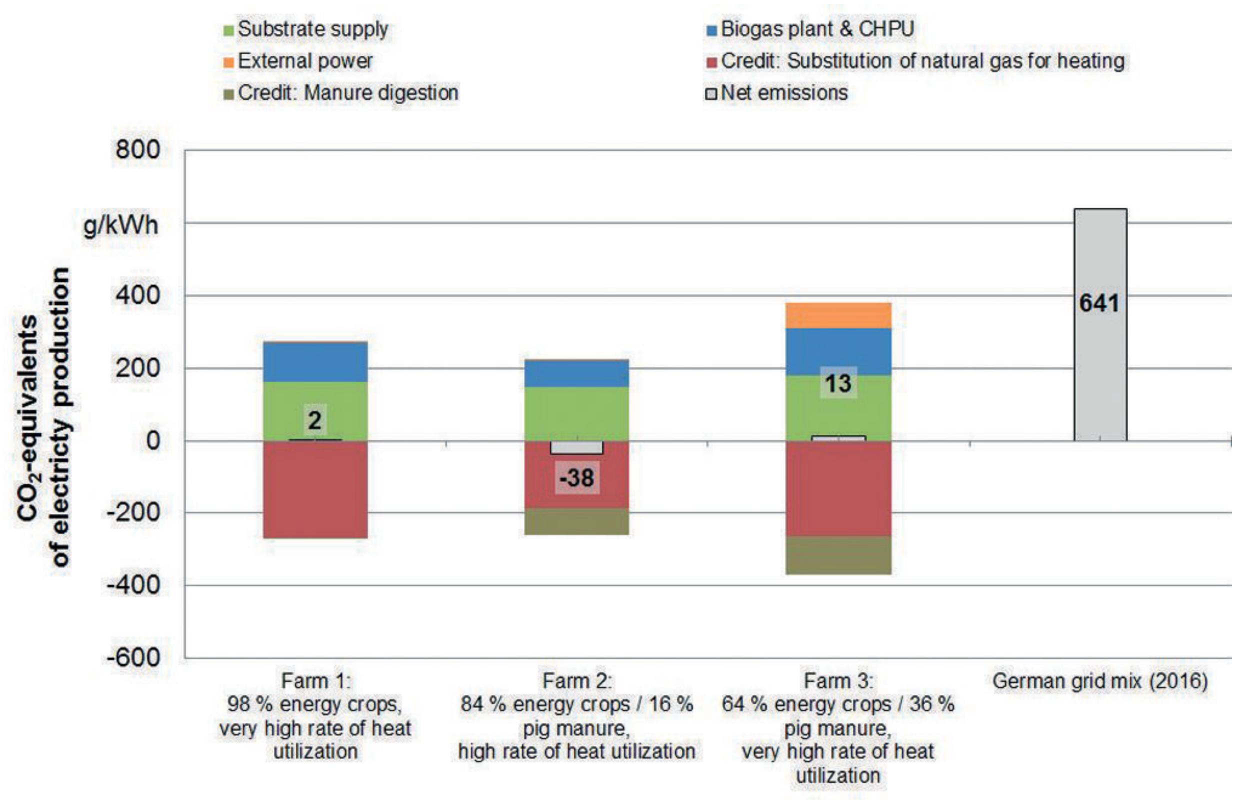

Fig. 3: *Specific GHG emissions / CO2-equivalents of electricity supply from biogas based on three farm case studies in comparison to the German grid mix* ■

ever, in case of annual crops exclusively produced for biogas production the environmental effects are significant (Hijazi et al., 2016). ■

Current challenges

Due to the strong growth of wind and photovoltaic power plants in Germany, situations with a power surplus in the grid have become more frequent. Despite aspirations of the Federal Government to curb the installation of wind and PV power, there exists a nationally determined goal of increasing the share of regenerative sources in power production to between 80 and 95 % by the year 2050. Within a system of regenerative energy sources, biogas has the advantage that it can be stored with comparably little technical effort to be utilized for electricity generation when needed. As illustrated in *Figure 4*, biogas power plants may thus be employed to reduce the residual load in the grid over the course of the day. To allow for a more flexible power generation, common biogas plants need to be upgraded with respect to biogas storage and electrical capacity. A larger CHP

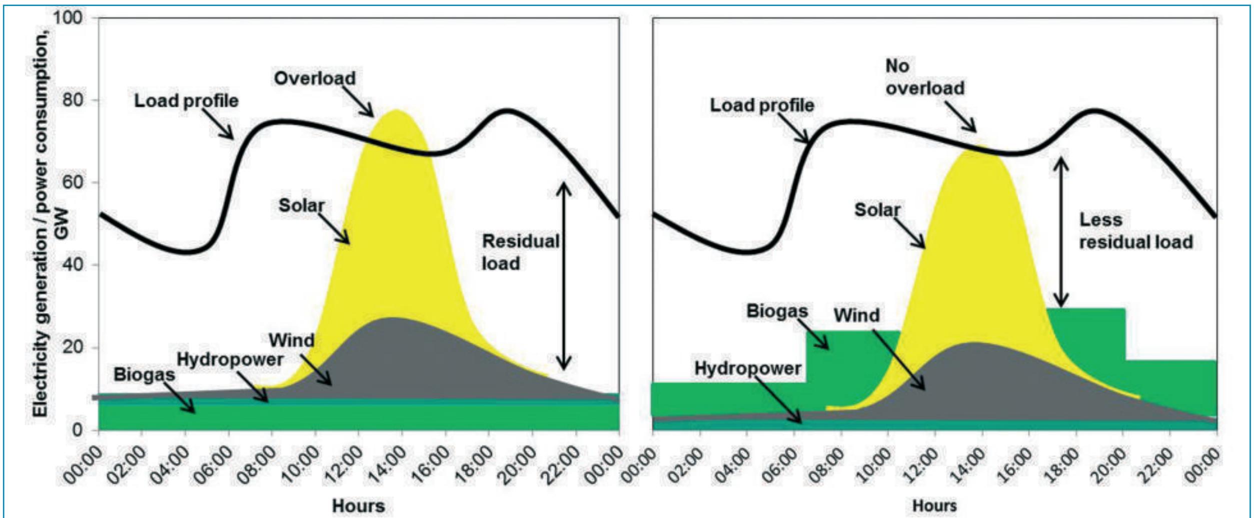

Fig. 4: *Illustration of the effect on the residual load over the course of a day by producing electricity from biogas according to grid load (diagram on the right) compared to continuous electricity production from biogas (diagram on the left)* ■

Fig. 5: *Demand-oriented electricity generation is tested on the biogas plant of the Bavarian State Research Center for Agriculture in Grub (near Munich)* ■

unit is needed to utilize more biogas in shorter periods of time, and the storage capacity for the biogas has to be increased accordingly. In addition, biogas power plants can also provide balancing power. As far as the heat output is concerned, a buffer storage tank might have to be installed. ■

Future prospects

In the amendment of the Renewable Energy Law of 2017 fixed feed-in tariffs for electricity from renewables were abolished in favor of tendering procedures. Contracts for electricity supply from new biogas plants are awarded to the bidders with the cheapest rates which will then be guaranteed for a period of 20 years. Existing biogas plants are also admitted to the tendering procedures, but receive a ten-year contract only, in case of acceptance.

In the mid-term future, biogas technology may also play its part in other innovations. E.g., a biogas plant, possibly with an upgrading unit, can supply carbon dioxide to power-to-gas units where it is combined with hydrogen from renewable sources to produce methane *(see Figure 1)*. This methane can be fed into the grid or used directly as vehicle fuel. At a number of biogas installations, surplus electricity is already buffered as heat via so-called power-to-heat units.

Overall, biogas plants will have to move from continuous production to demand-oriented electricity supply while at the same time ensuring efficient utilization of the heat. Within the process of the "Energiewende", biogas can play the keys of being a full-fledged substitute for natural gas with potentially very low greenhouse gas emissions. ■

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The Most Important Renewable Raw Material and Fuel: Wood

More than one third of Bavaria is covered with forests. The most are commercial forests, i. e. timber is being harvested again and again and young trees are replanted. About 20.5 million cubic meter of raw timber can be harvested per year, what is 2.6 % of the growing stock. This wood is the raw material base of many industries, which we sum up to the forest-based sector. 196.000 people are working in the forest-based sector in Bavaria. The sectors turn-over was 37 billion euros in 2012. The forest-based sector contributes 3.5 % to the whole production value of the Bavarian economy (Cluster-Initiative Forst und Holz 2016).

Wood is being used both as a raw material and as a fuel. If the wood is first used as a raw material and afterwards as a fuel we name it a cascade use.

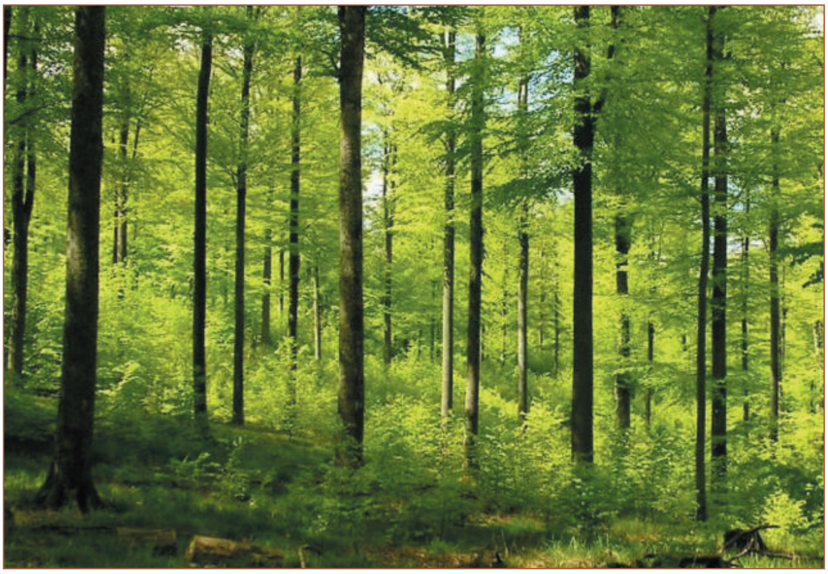

Fig. 1 shows the ways how wood is being used. At each stage of the material flow a part of the wood is being used as a fuel. At the first stage, in forestry about 36 % of the harvested timber is being prepared as firewood and wood chips for the use of a fuel. Firewood is mainly burned in small furnaces. Wood chips are a fuel for heating plants or cogeneration plants (heat and power). Stemwood is the raw material of sawmills. The sawnwood is being used in the building and construction industry and in other branches such as the furniture, packaging and parquet industry and in the handcraft. Along with the sawnwood by-products accrue like wood chips, sawdust, splinters and bark. A part is being used for the production of paper and boards; a part is processed to pellets or is being used immediately as a fuel.

The wood products can stay for a short time, e. g. paper or package, or for decades, e. g. a roof truss. The recovered paper collected from the users is to a great extent recycled. Also a part of the waste wood is reused to produce boards. But the main part of the waste wood is burned in cogeneration plants.

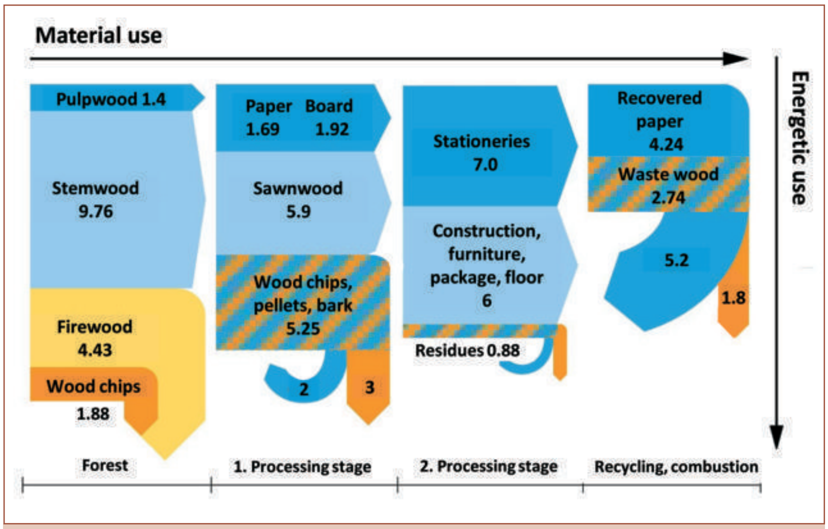

Fig. 1: *The flow of material and energetic use of wood (simplified diagram, source: Weidner et al. 2016)* ▪

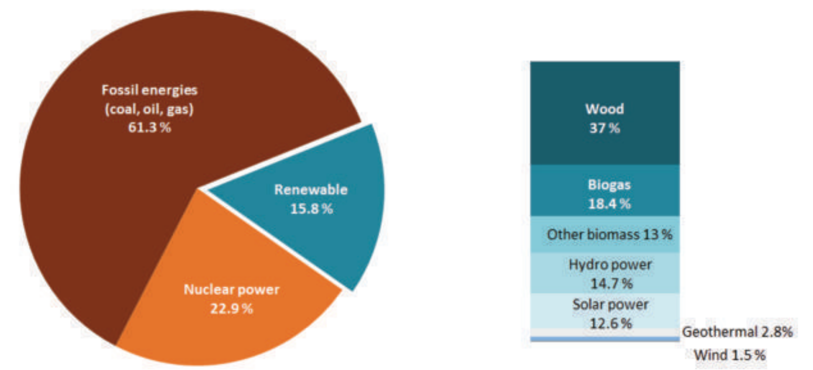

Fig. 2: *The composition of the primary energy use by energy sources in Bavaria 2013 (data derived from StMWi 2016). Wood has by far the largest portion among the renewable energy sources* ▪

Increasing demand of timber

The growing stock in the forests is regularly measured by forest inventories. During several decades considerably less timber was harvested than was added by photosynthesis. Thus the growing stock in the forests increased more and more. In the period from 1987 to 2002 the growing stock increased by 23 %. When it became apparent that far more timber could be sustainably harvested the Bavarian government made assiduous efforts to increase the use of this environmentally friendly produced raw material. If the CO_2 enclosed in wood is stored in buildings for a long time this contributes to climate protection. The portion of wooden buildings was raised from 12 % in 2003 to 20 % in 2015. Also more and more timber has been used for energy production. Wood has by far the largest amount among the renewable energy sources. Referred to the primary energy consumption wood had a share of 37 % of the renewable energy sources in Bavaria 2013. It was followed by biogas with 18 % and hydropower with 15 % (data derived from StMWi 2016). The amount of timber extracted from the forests correspondingly increased. The last national forest inventory from 2012 revealed that the growing stock in the forests was almost equal to that from 2002. Bavaria has still the largest growing stock per hectare forest area among all federal states of Germany. Timber can be continuously harvested at a high level in Bavarian forests. A further increase in harvesting might be possible in some places but not with regard to the whole country. Otherwise the growing stock will be reduced.

Still more potential for the construction of wooden buildings

Although far more buildings are today constructed with wood in Bavaria than in the past the proportion of wooden buildings among residential construction is significantly larger in other states like Austria and Sweden. The demand for wooden buildings and associated the use of long-lasting wooden products might be further increased in Bavaria. The question rises whether enough domestic timber exists for this purpose. This question can clearly be answered with ‚yes‘. On one hand Bavaria produces far more sawnwood than is domestically used. Bavaria had a net export of 1.2 million m^3 sawnwood 2015 (Bayer. Landesamt für Statistik 2016) representing about 20 % of the production. On the other hand the forest owners would be able to deliver more timber for material use instead of firewood (Cluster-Initiative Forst und Holz 2016). Especially owners of small forest properties often use the harvested trees for their per-

Short rotation coppices have a timber growth which is twice or threefold as much than that of forests (dry matter per hectare and year) (Photo: Bavarian State Institute of Forestry) ▪

sonal need of firewood although the timber would be suitable for sawlogs. Because this people own a large part of the forests the affected quantity is of relevance for the market. Here we have to examine how the market access for these owners can be made easier. An increasing material use of wood must not result in a decrease of energetic use. By establishing short rotation coppices on agricultural land much more firewood could by produced. Short rotation coppices are plantings of fast growing trees which can be harvested after few years. Mostly hybrids of poplar are used. Because new saplings sprout from the stumps the coppices can be repeatedly harvested without replanting. In short rotation coppices of poplar clones the double or threefold amount of timber can yearly grow up referring to dry matter compared to high forests. Wood chips from the biomass are used for energy production. Although it is a proven land use system with an unbeatable favorable energy balance (Burger 2010, Bystricky 2015) it was practiced only on 1.150 hectares in Bavaria in 2014 (Weidner et al. 2016).

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Renewable Resources for a Sustainable Chemical Industry

Renewable Resources are the basis of the frequently discussed "sustainability" in various economic areas. Sustainable building (plant fibres for insulation) or sustainable energy (plant oil power stations) are only two examples. The chemical industry as well intends to and has to become more sustainable. It has to exchange raw material which, at present, predominantly consist of limitedly available mineral oil and mineral oil based products with plant biomass.

Particular motivation for this is - besides securing raw material supply – to take care of the climate. Early 2010 the German chemical industry association (VCI), together with the German Chemical Society (GDCh), the Society for Chemical Engineering and Biotechnology (DECHEMA), and other organisations, has published a position paper, in which a clear commitment was made towards the necessary change in resources.

The history of applied chemistry has been shaped by many stages of changes in resources. During the last two hundred years the chemical industry frequently had to adjust to different raw material, ranging from simple products made of coal tar, which accumulated with the production of charcoal, to mineral coal and mineral oil. To enable the latest change in resources new chemical technologies, i.e. new methods and chemical catalysts, have to be developed. Exactly these technologies are

Fig. 1: *The path from biogenic raw material to the final product leads through different intermediates* ■

developed at the Straubing Center of Science. Several professorships from the Technical University of Munich (TUM), the project team "BioCat" of the Fraunhofer Institute for Interfacial Engineering and Biotechnology (IGB), and teams of other Universities do research with a growing number of scientists and technicians (currently more than 50) on new catalysts and biochemical processes. They combine methods of chemistry, white biotechnology, polymer chemistry and process technologies. Different fields of activity stand in focus *(fig. 1)*, some of them are described below in more detail. ■

From Cellulose to Sugar

Plant biomass consists of numerous different chemical substances. Most abundantly available are carbohydrates in form of sugar, starch, and, most of all, cellulose. With the transformation of sugar and starch to ethanol, different processes are established which are applied in large scale and generate an important bulk chemical. Even though currently this bio-ethanol mainly provides for fuel for energetic uses, it could also be transformed to ethylene. As a replacement for the ethylene which is obtained by cracking mineral oil it could be fed to existing chemical processes. However, in future, the utilisation of cellulose will be even more important. Firstly, in living nature it is more abundant than any other substance; secondly, it is not required as a food source. This way, the "table or tank" discussion can be avoided, although it is, in the true sense of the chemical use, rather a "pie or plastic" discussion as the cellulose will be used for the production of synthetic raw material.

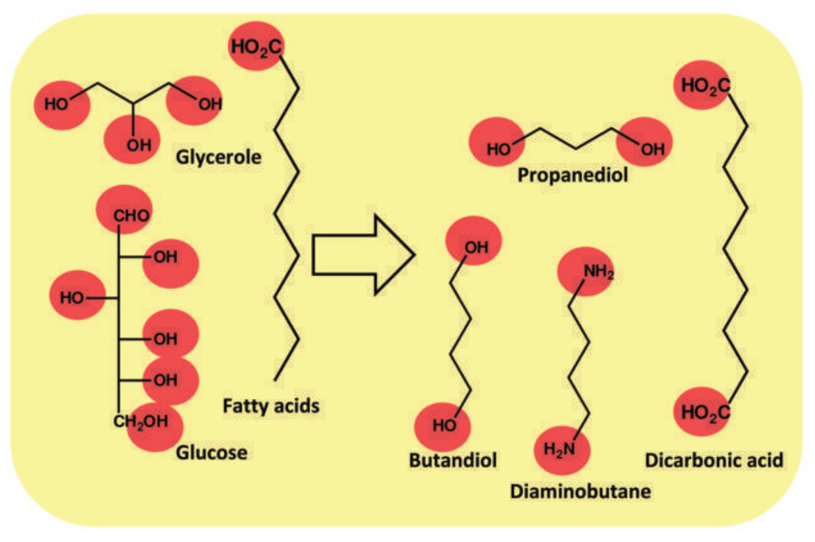

Fig. 2: *Typical monomers for Plastic material carry exactly two functional groups (red dots). Natural compounds like carbohydrates therefore have to be chemically „defunctionalized“* ■

In plants cellulose is stored together with lignin and other carbohydrates in form of a chemical composite, which has developed through millions of years of evolution to be stable and long-lasting. To break up this composite is a great challenge if the carbohydrates of cellulose shall be made available for the chemical industry. A number of companies and institutes worldwide work on methods that transform cellulose from cereal straw, wood chips, and other agricultural leftovers into glucose ("saccharification") which will be available as a source material for the synthesis of new chemical compounds. The developed process technologies vary immensely. Strong or weak acids or leaches are employed, using low or high temperatures and different enzymes. The multitude of processes shows that the optimal saccharification is not yet found, respectively, it has not yet prevailed even though considerable advances have been achieved during the past years.

At the Straubing Center of Science, too, new process technologies and enzymes are developed to achieve a better breakdown of lignocellulose. With a special combination of these process technologies and enzymes the chemical breakdown can be accomplished stepwise so that different important basic substances can be obtained in pure quality. ■

From Raw Material to Synthetic Material

From a chemistry point of view, monomeric carbohydrates like glucose or even glycerol are "overfunctionalized". With six respectively three functional groups *(see fig. 2)* these molecules are not suitable for the productiom of synthetic material. Fatty acids, on the other hand, are with only one function "underfunctionalized". With adequate catalysts these substances can be transformed into molecules with two functions (like e.g. propandiol or dicarbon acids) and used for polyesters, polyamides, or polyurethanes. An important chemical reaction to reduce functionality is the elimination of water molecules. Chemical catalysts can enable these reactions, however, they need very high temperatures under which a multitude of side reactions occur. Biocatalysts (enzymes and microorganisms) are better as they are more effective and gain higher yields. With these biotechnological methods transformations - like those indicated in *figure 2* – present themselves to be much simpler. However, the development of biocatalysts is very time consuming. At the Straubing Center of Science we work on methods of enzyme design and metabolic engineering to accelerate the development of enzymes and microorganisms. Soon, the biocatalysts from Straubing shall be adopted for industrial scale processes. ■

From Chemical Industrial Park to Local Refinery

A crucial difference between plant biomass and mineral oil lies in the quantity and locality of its availability. While mineral oil and its primary products can be transported through pipelines in great quantities without any problems and at little cost, plant products accumulate in smaller amounts across large areas. Transport across long distances is energetically very expensive and does not pay off. The advantages of biotechnological processes are that they require comparatively simple facilities. This fact enables smaller industries to operate locally where the biomass accumulates e.g. as agricultural leftovers. With this change in raw material the chemical industry can not only contribute to climate conservation but also help to bring back agricultural added value. ■

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