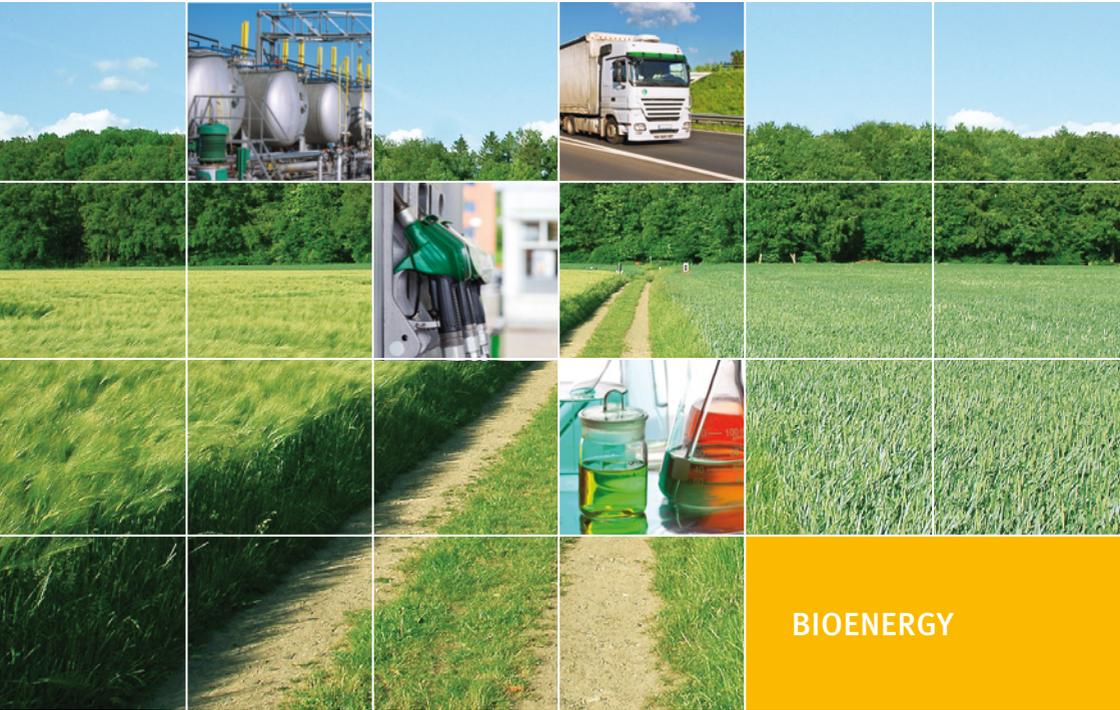




BIOFUELS



With support from



Federal Ministry
of Food
and Agriculture

by decision of the
German Bundestag



Fachagentur Nachwachsende Rohstoffe e.V.

IMPRINT

Published by

Fachagentur Nachwachsende Rohstoffe e. V. (FNR)

Agency for Renewable Resources

OT Gülzow, Hofplatz 1

18276 Gülzow-Prüzen

Tel.: +49 3843/6930-0

Fax: +49 3843/6930-102

info@fnr.de

www.fnr.de

With support from the Federal Ministry of Food
and Agriculture, based on a decision of the Parliament of
the Federal Republic of Germany

Editing

Fachagentur Nachwachsende Rohstoffe e. V. (FNR),

Department of Public Relations

Pictures

Title: Heiner Witthake, zorandim75, kasto, am, Alex Ishchenko/all Fotolia.com

So far as the picture makes no indication to the contrary:

Fachagentur Nachwachsende Rohstoffe e. V. (FNR)

Design/Implementation

www.tangram.de, Rostock

Printed by

www.druckerei-weidner.de, Rostock

Printed on 100 % recycling paper using vegetable oil-based colours

Order no. 230

4th Edition

FNR 2016

BIOFUELS



CONTENTS

1	Introduction	4
1.1	Definition	4
1.2	Why biofuels?	5
1.2.1	Security of supply and protection of resources	5
1.2.2	Climate protection	6
1.2.3	Value creation in rural areas	8
2	Biofuels in Germany – the market and the framework conditions	10
3	Fuels from sustainable biomass	13
3.1	Do we have enough area?	13
3.2	Sustainability and certification of biofuels	14
3.3	Indirect land-use changes (ILUC)	16
4	Biofuels currently available	17
4.1	Vegetable oil as a fuel	17
4.1.1	Raw materials	18
4.1.2	Manufacture	18
4.1.3	Properties and quality of the fuel	19
4.1.4	Market presence/use	20
4.1.5	Environmental aspects	21
4.2	Biodiesel	22
4.2.1	Raw materials	22
4.2.2	Manufacture	23
4.2.3	Properties and quality of the fuel	24
4.2.4	Market presence/use	26
4.2.5	Environmental aspects	26
4.3	Ethanol	28
4.3.1	Raw materials	28
4.3.2	Manufacture	29
4.3.3	Properties and quality of the fuel	30
4.3.4	Market presence/use	32
4.3.5	Environmental aspects	34

4.4	Biomethane	35
4.4.1	Raw materials	36
4.4.2	Manufacture	37
4.4.3	Properties and quality of the fuel	37
4.4.4	Market presence/use	38
4.4.5	Environmental aspects	39
4.5	Hydrogenated vegetable oils (HVO)	41
4.5.1	Raw materials	41
4.5.2	Manufacture	42
4.5.3	Properties and quality of the fuel	42
4.5.4	Market presence/use	43
4.5.5	Environmental aspects	44
4.6	Electro-mobility and biofuels	44
5	Future biofuel options	46
5.1	BtL fuels	46
5.1.1	Raw materials	47
5.1.2	Manufacture	47
5.1.3	Properties and quality of the fuel	48
5.1.4	Market presence/use	49
5.1.5	Environmental aspects	50
5.2	Bioethanol made from lignocellulose	50
5.3	Bio-butanol	51
5.4	Hydrogen	51
5.5	Biofuels from algae	53
6	Future prospects	54
7	More detailed information	56

1 INTRODUCTION

Mobility, the ability to move, is a basic need that human beings have. The scientist Gabriele Geiger once characterised humans as an “animal migrans”, a creature that moves from place to place in order to live.

Indeed, for a long time mobility was the factor securing human survival or making it easier; it meant increased communication, knowledge and prosperity. Today, in the age of modern technology and high population density, the means of mass transportation have become “simultaneously the blessing and the curse”: They represent freedom, involvement and experience, but also stress, over-development of land, and environmental damage.

Attempts to restrict mobility are perceived as presumptuous interference and a con-

straint on people’s liberty; they are met with resistance. This basic need cannot be abolished as such, all we can do is try to limit the negative developments that accompany it. This brochure examines only a small part of the wide range of topics involved in mobility and transportation – namely biofuels for combustion engines, to be used in cars, lorries, agricultural and forestry vehicles, ships and aircraft.

1.1 Definition

Biofuels is the term given to liquid or gaseous energy carriers obtained from plant-based or – in rare instances – animal-based biomass. They rank among the renewable energies, such as wind, water and solar energy, because plants always grow back, provided that the necessary resources – such as the agricultural area – are used sustainably. Biofuels can be fundamentally divided into those already introduced into the market and biofuel options of the future.

Market-introduced biofuels is the term characterising fuels that are produced using established production procedures. They are available on the market in significant quantities or can be made available via existing technologies. The drive technologies in which these biofuels are used are established or are available for a mass-scale introduction. For instance, these biofuels include vegetable oil and biodiesel, as well as



Aviation: unthinkable without liquid fuels

ethanol and biomethane produced through the fermentation of biomass, in addition to hydrogenated vegetable oils (HVO).

The **future biofuel options** include synthetic fuels obtained from biomass (BtL fuels), ethanol sourced from cellulose, bio-fuels from algae, and also bio-hydrogen. Compared to the biofuels introduced to the market, their manufacturing processes are still in an early stage of technical development, or respectively are in a pilot-project or demonstration-project stage.

It is only to a limited degree that biofuels can be divided into '1st, 2nd and 3rd-generation' fuels. This is because results vary depending on the criteria selected (costs, raw material or stage of development in the manufacturing process).

1.2 Why biofuels?

1.2.1 Security of supply and protection of resources

Petrol, diesel fuel, aviation fuels and other fuels are manufactured from petroleum; the known global stocks of this resource are running out in the foreseeable future. In economic terms the decisive issue is not that of precisely when the supplies are used up, but rather that of the cost development for this increasingly-scarce resource: the more expensive petroleum becomes, the less economically viable it becomes as a fuel.

In 1973/74 the oil price climbed up from \$ 3 to \$ 12 per barrel, causing a powerful

economic downturn in the wake of the first 'oil crisis'. Today the price spiral is turning less rapidly but it is doing so at a higher level: in 2001 the UK-Brent variety of crude oil cost an average of \$ 24 per barrel – currently, the price of \$ 50 per barrel Brent crude oil is again quiet moderate after 2015 peak. Nevertheless, it has to be assumed that fossil oil is becoming scarcer and thus cost will rise even more over the long term.

The transport sector is especially dependent on petroleum: road transport in its entirety, also air travel and sea travel, agriculture and forestry, and a certain proportion of rail transport (around 10 % on German Federal Railways), depend on petrol, diesel, kerosene or marine diesel sourced from petroleum.

Thus, as renewable fuels, biofuels offer the chance to lessen the dependence on and consumption of petroleum and to secure the supply of fuels. Alongside heating and electricity, mobility is one of the fundamental areas in which people generate a demand for energy. In this context, the European Union (EU) designates the transport sector as the one in which the problem of security of supply is greatest. In its Directive issued in 2009 and aimed at promoting renewable energies, it has therefore established a binding goal for all Member States: by 2020, at least 10 % of the energy consumed in the transport sector is required to be obtained from renewable energies. The EU thereby seeks not only to counteract bottlenecks in supply, but to simultaneously initiate economic developments that can benefit the rural areas

in the Member States. This is because, unlike petroleum, which is mostly imported to Europe, biofuels can to a large degree be produced in the European countries themselves. They contribute to the reduction of Europe's dependence on oil supplies from countries susceptible to crises.

Of course, a 10 % share for renewable energies cannot solve the transport sector's supply problem in the long term; thus the plan must be a continued increase in the share taken by renewable resources. In this context, much hope is placed in electromobility based on renewable electricity; yet vehicles that are more efficient and more sparing on resources, greater use of local public transport and other new mobility concepts, are also building blocks in a successful turnaround for energy consumption in the transport sector.

1.2.2 Climate protection

Carbon dioxide (CO₂) is one of the most relevant gases in relation to the greenhouse effect. Large quantities of additional CO₂ are generated when fossil-based energy carriers are burned, thereby contributing to the increase in average global temperatures – from the start of the 20th century to today, the increase has been around 0.8 °C. Climate scientists are reckoning on there being a further rise, by the end of this century, comprising between 2 °C and 6 °C. As a comparison: the temperatures in the last Ice Age, ending around 10,000 years ago, were 'only' 5–6 °C below those of today!

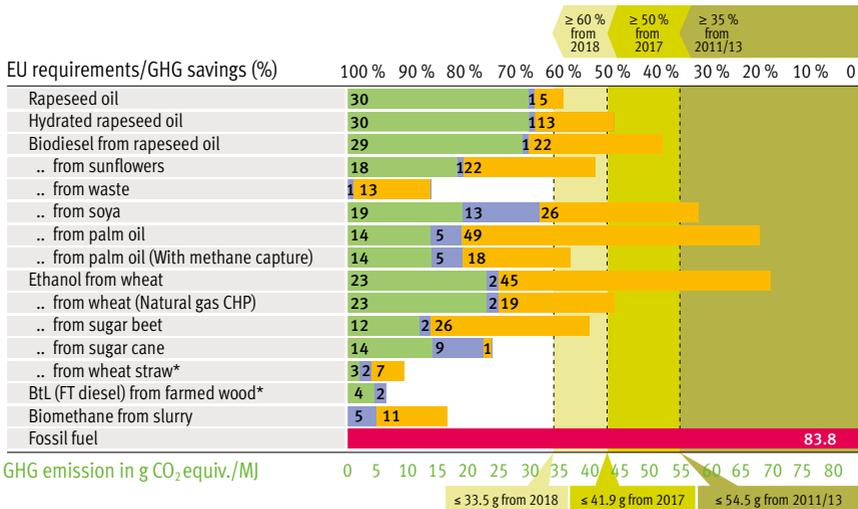


A certain amount of renewable energy is standard in fuels today.

The use of biofuels can counteract climate change because, in their combustion process, they release approximately only the same quantity of CO₂ that the plants have removed from the atmosphere during their growth. Likewise, fossil-based fuel resources emerged a long time ago from biomass of plant and animal origin, thereby constituting gigantic stores of CO₂. Yet while these resources' emergence required millions of years, humans are now burning them up within just a few decades. The CO₂ released is thus creating an additional burden on the atmosphere; conversely, when plants are used the process can be viewed as almost a closed cycle. Petroleum is created so slowly that its CO₂ bonding would not be able to 'put the brakes on' climate change.

Yet climate fuels are also not 100 % climate-neutral, because planting them and converting the biomass both expend energy that today still mostly originates from fossil-based sources. Depending on the resource used and the manufacturing process, this expenditure of energy reduces the greenhouse-gas saving

STANDARD GHG EMISSIONS FOR BIOFUELS



■ Cultivation ■ Transport ■ Processing

* Future biofuel options,
basis: estimated standard figures from 2009/28/EC

Source: FNR, according to UFOP (2011 – EU Directive 2009/28/EC)

© FNR 2011

in relation to the fossil-fuel-based alternatives. To make it more difficult for less efficient biofuels to gain market access, the EU's Renewable Energies Directive has established a minimum required greenhouse-gas-saving of 35 %. For instance, if a fuel fails to comply with this, its contribution cannot be credited against the required biofuel quota valid in Germany. The minimum values are becoming successively more demanding, the aim being that biofuels will spare the environment to an ever-increasing degree.

In its Directive promoting renewable energy, the EU established sustainability criteria, including minimum values for savings in terms of biofuels' greenhouse-gas emissions. Taking as the reference the fossil-based fuel used for comparison – the reference value used is 83.8 g of CO₂equivalent per megajoule – biofuels must reduce the greenhouse-gas emissions, along the entire chain of production and use, currently by 35 % and, from 2018, by 50 %.¹ To calculate the GHG emissions, conservative

¹ New facilities built in or after 5th October 2015 must attain a greenhouse-gas saving of 60 % from 2018 onwards.

standard values were defined for the planting of the source product, the transportation and the manufacturing process Companies can base their calculations on these standard values; alternatively, they can make detailed individual calculations. Above all, the latter option is available with regard to modern facilities that can offer significantly better GHG reduction-values than the average.

Savings on GHG emissions are a prerequisite for crediting of contributions to the bio-fuels quota and also for biofuels' tax-breaks eligibility.

1.2.3 Value creation in rural areas

Nature dictates that rural areas are where the energy crops are grown for biofuels. It is likewise in rural areas that the product is further processed in oil mills, biodiesel and ethanol facilities, and also that the biogas is adapted to form biomethane equivalent to natural gas; this is also where the jobs, income, corporate profits and tax revenues are generated. The rural regions keenly need these benefits because many of them are combating economic-shrinkage processes. Whereas 100 years ago 38 % of those in employment worked in agriculture, today it is no more than a good 2 %. The phenomenon of "rural exodus" further reduces what, even without it, is a declining population. Yet for several years now a counter-trend is making itself ever more evident: the great turnaround in energy is upgrading the value of rural areas, because it is here, not in the urban centres, that the great potential for solar energy, wind energy and bioenergy is located. Contrasting



with what are predominantly imported fossil fuels, biofuels – like other sectors of bioenergy – are establishing value-creation chains in the region itself.

Yet German agriculture is also an importer, namely with regard to protein feed. Soya meal from South America is the protein feed most frequently used in cattle-farming, also playing a role as feed for pigs. Here too, biofuels can help to keep purchasing power inside the region: the manufacture of vegetable oil also gives rise to a protein-rich coupled product, namely rapeseed cake or rapeseed extraction meal; in many activity areas this can supplement soya or in part even replace it. Likewise, the thin stillage emerging from ethanol manufacturing contains proteins, fats, sugar and starch, and is used as additional feed.

BIOFUELS IN THE MOBILITY AND FUELS STRATEGY

In June 2013, Germany's Federal Cabinet adopted the Federal Government's Mobility and Fuels Strategy (MFS). It describes what are currently the most promising approaches for the transport sector to attain the Federal Government's goals with regard both to security of supply and to savings on energy and CO₂-emissions. Alongside the already-mentioned goal of "10 % use of renewable energies in the transport sector by 2020", the most important goals in Germany are as follows:

- Reduction of final energy consumption in transport activity, by around 10 % no later than the year 2020 and by around 40 % no later than 2050 (in relation to 2005).
- Across all activity sectors in the electricity, heating and transport industries, greenhouse-gas emissions are to be reduced, taking 1990 as the base year, by 40 % no later than 2020 and by at least 80 % no later than 2050.

Key measures for reaching these goals, as referred to by the MFS, are the use of a wider portfolio of fuels and innovative drive technologies. Combustion engines must also be made more energy-efficient and the activity sequences in transport must be optimised.

Within biofuels, the Federal Government discerns bright prospects for biomethane ('natural gas') sourced from recycled and waste materials, among other sources, and also for bio-kerosene for aviation. Biomethane from recycled and waste materials is deemed to have bright prospects due to its high potential for CO₂ reduction and the limited extent to which it competes with food production. Bio-kerosene is already being deployed in aviation on a test basis; it is mostly based on vegetable oils and is admixed to fossil kerosene. Kerosene produced from algae or from biogas is currently still in the development stage. Yet the industry is pursuing ambitious goals of its own: the International Air Transport Association is aiming for its members to attain a replacement of 10 % of its kerosene consumption by 2017, using alternative fuels. Bio-kerosene is at present the sole tangible option for this. The Federal Government sees biofuels as highly promising – especially as a transitional solution on the path to long-term solutions such as algae-sourced fuel, electricity-to-kerosene, and hydrogen.

In the use of traditional liquid biofuels, the Federal government acknowledges in principle the possibility for a greenhouse-gas reduction. A contribution to this is the conversion of the biofuel quota to a greenhouse-gas reduction quota, starting in 2015. Similarly to the EU, the Federal Government also sees a need to act on the ILUC issue, i. e. that of biofuels forcing food and feed production out onto areas hitherto unused for agriculture.

2 BIOFUELS IN GERMANY – THE MARKET AND THE FRAMEWORK CONDITIONS

Anyone driving into a fuel station today is (also) tanking up on biofuel: diesel contains biodiesel (e. g. from rapeseed). Petrol such as ‘Super’ grade, ‘Super E10’ grade etc. contains an admixture of ethanol sourced from sugar-beet, wheat or maize. Vehicles fueled by natural gas also tank up on at least a share of biomethane.

By contrast, pure vegetable oil and pure biodiesel are still mostly the domain of freight forwarders or agricultural machines; their engines are adapted accordingly.

Up to 5 % bioethanol in ‘Super’ grade, 10 % bioethanol in ‘Super E10’² grade and 7 % biodiesel in diesel fuel, as well as up to 100 % biomethane in natural gas, are standard nowadays on fuel-station forecourts, not only in Germany, and are suitable for engines without extra modifications. Other countries are keeping pace or are even further ahead. For instance, Brazil (mixtures with up to 100 % bioethanol), Sweden (E75 with 75 % bioethanol) or the USA (E15) are adding very much higher proportions of ethanol.

There has been a crucial shift in the situation in Germany in recent years. Whereas in the 1990’s pure biofuels launched what was

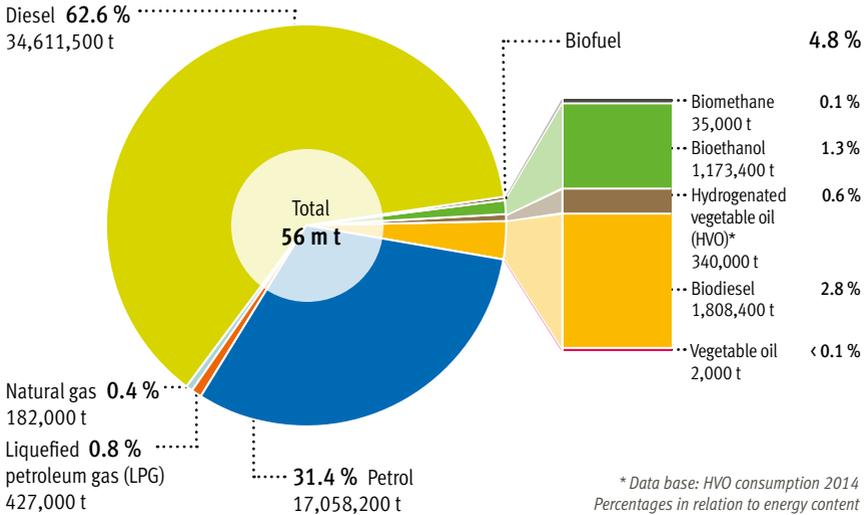
indeed an impressive career, today’s market is almost exclusively dominated by admixed biofuels. For a long time, pure biofuels were exempted from mineral-oil tax and thus economically attractive in comparison to traditional fuels. In parallel, many manufacturers, especially from the VW Group and the French PSA Group (e. g. Peugeot and Citroën), gave a green light for use of pure biodiesel in their engines.

Increasingly-challenging EU exhaust-gas norms, introduced in ‘Euro 4’ and ‘Euro 5’, heralded the end of the market for pure biofuel, at least for the time being. These requirements made the manufacturers tailor their drive-concepts and their engine management to the fuels; in the wake of this, they issued no more approvals for pure-biofuel vehicles. In Germany, this process was accelerated by the stage-by-stage introduction of energy tax on pure biofuels and the introduction of binding, fully-taxed biofuel quotas, taking effect from 2006 onwards.

At present (2015), sales of biofuels amount to around 3.4 million tonnes, i. e. 5 % of what is a somewhat-declining total figure for fuel consumption in Germany. In this context, the markets are (still) substantially dependent on the framework conditions: measured

² E 10 is usable for many new petrol engines, but not for all older petrol-fueled vehicles: it is crucial to abide by manufacturers’ instructions.

FUEL CONSUMPTION IN GERMANY IN 2013



Source: FNR, according to BAFA, Destatis, DVFG, BMF (July 2016)

© FNR 2016

in terms of the pure manufacturing-costs, biofuels currently cannot usually compete with fossil fuels. This is where Governmental regulation intervenes: It determines a GHG saving of 4 % from 2017 on. After 2020 this will increase to 6 %.

Biofuels already have to prove a GHG saving today: unless the greenhouse-gas emissions are reduced by at least 35 % in comparison to fossil fuels, it is not permitted to offset them against the quota requirement. The same applies to other sustainability requirements to be demonstrably complied with, all along the chain of manufacture and supply. The chapter “Fuels from Sustainable Biomass” examines this in greater detail.

Other biofuels are only available on the market to a limited degree. While biomethane can already be obtained at many fuel-stations supplying natural gas, other biofuels are partly in the demonstration stage and partly in the pilot-project stage. Bioethanol from lignocellulose is currently estimated to be market-ready in just a few years; by contrast, fully-synthetic biofuels (BtL) still need rather more time to reach the industrial standard. Biofuels from algae or other alcohols are currently in a comparatively early test-stage and, over the medium term, will hardly be available at price-competitive prices in quantities meriting mention. To that extent, over the medium term the classic biofuels – biodiesel, ethanol and

vegetable oil, and also biomethane – are expected to remain the most important renewable alternatives in the mobility sector.

THE SPECIAL POSITION OF AGRICULTURE AND FORESTRY

Exceptions apply to agricultural and forestry businesses: they can use pure biodiesel or pure vegetable oil and get the energy tax (currently ca. EUR 0.45/litre biofuel) re-

imbursed. As these businesses also pay a significantly reduced tax rate for so-called agricultural diesel, there is a limit to the economic attractiveness of biofuels in these sectors. Therefore, the predominant majority of agricultural and forestry businesses uses traditional diesel, containing up to 7 % biodiesel. It is primarily for businesses with their own oil mill where commercial framework conditions can favour the use of biofuels produced by the company itself.



Rapeseed harvest

3 FUELS FROM SUSTAINABLE BIOMASS

Biofuels are perceived in vastly different ways. Apart from electrical drives – a rising business sector – they are currently the sole renewable source of mobility available on a larger scale. When the issue is that of highlighting substantial alternatives to fossil fuels, and simultaneously attaining marked reductions of greenhouse-gas emissions, today the favoured means of doing this is biofuels, combined with reduced consumption. As things now stand, they will retain this status for years (decades) to come: at least, they will hold it until the across-the-board introduction of electrically-powered vehicles or vehicles powered by hydrogen based on renewable electricity.

Yet the public discussion is increasingly concentrating on the negative accompanying effects triggered off by biofuels. “Biofuels are not sustainable” – this is the essence of the current criticisms. Their production competes for limited areas of agricultural land, so the argument goes; it thus causes increasing food prices and ultimately hunger in developing countries. In addition, it is said, biofuel use is promoting the destruction of the rain forest, so as to set up palm-oil plantations there, or it favours other monoculture systems with emphatically negative environmental consequences. These arguments carry weight and cannot be summarily dismissed.

Doubtless, biofuels tie up agricultural areas for their production – currently around 2 % of arable land – and ultimately contribute to the rise of price levels for agricultural raw materials. Yet whether increasingly expensive agricultural products should acknowledge responsibility for world hunger or conversely are indeed promoting agricultural development in the threshold countries and poor countries, is a fervently discussed topic among scientists.

3.1 Do we have enough area?

The available recycled-material and waste-material resources are rather limited, reveal no growth trend and are in large degree already being used. Such materials are also suitable for centralised production structures only to a limited degree, because of the difficulties of transporting them. Thus if biofuels are to fuel engines to any noteworthy extent, waste material’s potential needs to be raised but also energy crops need to be planted. The areas of potential for this are available, in Germany, in Europe and globally: over the medium term, Germany has 4 m. hectare (ha) and the world has around 300 m. ha. available for cultivating raw-material plants for their use as an energy source and as materials, without this questioning the primacy of food and



feed supply, even for an increasing population. Accordingly, the Federal Ministry of the Environment³ forecasts a share of around 20 % for biofuels in the transport sector's total energy consumption by 2050. This scenario envisages that, over the long term, biofuels will assert their position in the mobility-sector market to a significantly greater degree than will electricity, natural gas or hydrogen.

Nevertheless, numerous demands are being placed upon agricultural areas. Food and feed; protection of nature and the environment; organic farming etc., incl. extensive forms of farming; all these also demand land areas, just as raw-material plants do. Finding an appropriately balanced coexistence of these needs is proving to be a major and enduring challenge.

3.2 Sustainability and certification of biofuels

Sustainability is a topic that biofuels tackle head-on, in a very transparent way, with regard to cultivation, processing and greenhouse-gas emissions. For the agricultural cultivation of energy crops, as of any other crops, the European Union has enforced exacting standards of sustainability, i. e. the so-called Cross Compliance rules.

Nevertheless the cultivation of the relevant energy crops is certainly not free of controversy in Europe, especially in Germany. Yet rapeseed (for biodiesel) now ranks as one of the most important cultivated crops for lessening the domination that cereal now largely has in our farming, and for easing peak workloads in the agricultural enterprises. The processing of rapeseed also generates very large quantities of protein as

³ *Leading Study (Leitstudie), Federal Ministry of the Environment, 2011*



a coupled product; these are used as feed and otherwise would have to be imported. The same applies to sugar-beet (for bioethanol). Although the biofuels used in Europe are mainly sourced from European production, biofuels and their pre-products are subject to interwoven trade relationships. Accordingly, so as to ensure sustainability standards, the binding sustainability certification has been introduced Europe-wide for biofuels.

The large-scale destruction of the rain forests and the subsequent agricultural cultivation on former areas of primary forest amount to an international problem of the highest order, one for which so far a satisfactory solution is yet to be found. The rain forest and other areas worthy of protection are best safeguarded by international binding rules that are also implemented and supervised accordingly.

So as to prevent the promotion in the EU of biofuels produced on former rain forest areas or on other areas worthy of protection, for some years now biofuels' use is tied to rigorous, certified proof of sustainability. Based on the certification systems approved by the EU, corresponding certification authorities use a painstaking process to follow up on and monitor the whole chain of production, processing and trading for energy crops, raw materials and biofuels; they thereby ensure that all biofuels match the valid sustainability criteria.

This dovetails with the maintenance of proof provided by declaration of balances for greenhouse-gas-related activities. Currently biofuels must save at least 35 % of greenhouse-gas emissions compared to fossil fuel and from 2018 it will be 50 %⁴. While the proof can at present be provided via standard values, the more demanding

⁴ *New facilities constructed in or after 5th October 2015 must attain a GHG saving of 60 %.*

threshold values introduced from 2018 onwards require a differentiated consideration and in part a facility-specific one, taking into account the renewable energies deployed in the production process.

The certification process is elaborated in detail in the film “Sustainability in biofuels” at: www.youtube.com/fnrvideos

3.3 Indirect land-use changes (ILUC)

The legally-binding sustainability rules for biofuels, applied in Germany since 2011, relate to **direct** changes to land-use. Model calculations indicate that so-called **indirect** ‘ILUC’ effects can also emerge, if the production of food and feed is forced out from areas already used and onto areas worthy of protection. Accordingly, in such scenarios palm-oil production for margarine, chocolate, washing materials and cleaning agents can be pushed by biofuel use onto new areas worthy of protection.

However, such ILUC effects are not measurable per se but can at best be represented in scientific models. Thus a European Commission proposal from 2012 takes assumptions and model calculations as its basis. Simultaneously the aim is to promote progressive biofuels, not competing with production of food and feed.

ILUC is a challenge in the international discussion surrounding the protection of valuable areas of land and it requires an appropriate solution. Therefore, from the outset the Federal Government has supported the Commission’s efforts to draw up appropriate rulings at European level. Part of the goal in this is to attain a genuine protection of existing resources, so as to safeguard domestic agriculture and rural areas against undesired effects of market forces. Biofuels’ enormous contribution to fulfilment of climate-protection goals in the realm of transport must not be allowed to be forgotten in this context.

4 BIOFUELS CURRENTLY AVAILABLE



The biofuels already introduced to the market include biodiesel, ethanol, and also pure vegetable oil, in addition to hydrogenated vegetable oils (HVO) and biomethane. These usually involve use of plants sourced from agriculture, such as rapeseed, cereal, sugar-beet, maize, soya or oil palms, from which the actual raw material is obtained through further processing: the oil, the sugar or the starch which is then in turn processed to form the biofuel. This usually generates co-products for which there is primarily a demand as animal feed.

Alongside plants, waste materials are also already being used for the production of biodiesel, HVO and biomethane.

4.1 Vegetable oil as a fuel

Vegetable oils are used not solely as edible oil or as an admixture to animal feed. The chemical industry also uses quite substantial quantities, e.g. for the manufacture of

KEY NOTES: VEGETABLE-OIL FUEL

Raw material: Rapeseed oil

Yield per hectare: 3.5 t of rapeseed generate circa 1,500 l of rapeseed oil (and 2 t of feed)

Fuel equivalent: 1 l of rapeseed oil replaces 0.96 l of diesel fuel

GHG emissions*: 36 g of CO₂equiv./MJ (Fuel used for comparison – diesel: 83.8 g of CO₂equiv./MJ),
GHG reduction: 56 %

techn. information: see DIN 51605

* Standard values for GHG emissions according to EU Directive 2009/28/EC.

lubricants, washing-up liquid and cleaning-agents etc. Lastly, part of the vegetable oil used in Germany is processed into biofuels. Vegetable oils are not only the starting materials for biodiesel production, but can also be deployed directly as a vegetable-oil fuel in specially converted diesel engines. Rudolf Diesel, the diesel engine's inventor, realised this himself: "The use of vegetable oil as a fuel may be insignificant today. But over the course of time such products can become as important as petroleum and coal-tar products are today."

4.1.1 Raw materials

Rudolf Diesel's prediction is being fulfilled today, predominantly by domestic oil plants serving as sources of raw materials. Accordingly, in Germany it is primarily rapeseed oil that is used as a fuel (DIN 51605). It is also possible to use soya oil, palm oil and sunflower oil (DIN 51623). In this country, rapeseed is the most important oil plant and simultaneously the most important supplier of protein: around two-thirds of the seeds are processed to provide protein-rich feed. On around 1.4 m. ha, or about 12 % of the arable area, rapeseed is cultivated as the most significant leaf crop in our cereal-focused crop rotation arrangements. Taking into account the domestic demand for rapeseed-oil in food and feed applications and

also for industrial products, what remains is an available area of circa 1 m. ha., e. g. for use as a source of energy. The use of rapeseed, and thus also of rapeseed oil as a fuel, contributes not solely to the securing of income within agriculture; through advantages in farming plants and other crops, it secures sustainable husbandry of our agricultural areas and cultivated landscapes.

4.1.2 Manufacture

In principle, there are two manufacturing processes for vegetable oils: decentralised cold pressing, often taking place in agricultural enterprises or in cooperative-based businesses, and centralised production in large-scale industrial facilities.



Rapeseed-oil fuel for agriculture

In cold-pressing – usually done in decentralised oil mills, with a processing capacity of 0.5–25 t of oil seed per day – the purified oil seed is pressed out exclusively by means of mechanical pressure at temperatures of max. 40 °C. The suspended matter in the oil is removed by filtration or sedimentation procedure. Apart from the oil, what remains is a press cake with a residual oil content of 10–18 %, as protein-rich feed. In cold-pressing, the oil yield is in fact lower compared to central oil pressing; yet the sparing method of pressing used is in fact a prerequisite for the production of high-value, native edible oils. For use as fuel, simple follow-up treatment processes reduce deposit-forming and ash-forming elements in the rapeseed oil (phosphorus, calcium, magnesium) to a minimum.

Central, industrial oil mills can process up to 4,000 t of seed daily and press out the oil seeds after a pre-treatment at higher temperatures. The remaining oil is extracted from what is left of the oil press cake, us-

ing solvents at temperatures of up to 80 °C. Extracted meal is left, which also finds use as feed. Evaporation separates the oil from the solvent. After these procedural steps, the oil contains some unwanted accompanying substances that are then removed by refinement operations. The end-product is a vegetable oil characterised as a fully-refined product.

4.1.3 Properties and quality of the fuel

Pure vegetable oil has certain properties differentiating it from diesel fuel and making it possible to use it in a combustion engine only after certain adaptations. Primarily it is the higher viscosity – at low temperatures, above all, it is up to ten times higher than that of fossil-based diesel – that proves technically challenging, especially in winter and on cold starts of the engine. Solutions were drawn up for various systems over the last few years. Irrespective of whether it is via the one-tank system, that includes a pre-heating of the fuel and usually also

TAB. 1: COMPARISON (DE)CENTRALISED MANUFACTURE OF VEGETABLE OIL

Oil yield from 1 t of rapeseed*		decentralised	centralised
Degree of packing	[%]	80	99
Oil yield – solid	[kg/t of seed]	336	416
Yield – rapeseed cake	[kg/t of seed]	660	–
Yield – extracted meal	[kg/t of seed]	–	580
Oil yield – liquid	[l/t of seed]	365	452
Oil yield – liquid	[l/ha]	1,278	1,582

Source: TFZ, FNR

* Oil content of the seed: 42 %

an optimisation of the engine control, or via the two-tank system, in which the problematic start-phase and the process of switching off are implemented using traditional diesel fuel – re-fit concepts to make engines suitable for vegetable oil have proven their worth in practice.

A key element in disruption-free operation is the quality of the vegetable-oil fuel. As the results of many years of studies and activities in defining norms, the Standard DIN 51605 was published – “Fuels for vegetable oil compatible combustion engines – Fuel from rapeseed oil – requirements and test methods”. Because the parameters of this norm take rapeseed oil as their reference point, the use of other vegetable oils is only possible to a limited degree. In order to elaborate a standard for vegetable oils of different origin, the standard DIN 51623 was developed. Tractor manufacturers, already offering vegetable-oil-compatible engines ex works, or companies that refit diesel engines to suit vegetable-oil operation, not only take the standards as their reference point but also determine maintenance intervals specific to vegetable-oil use. So as to guarantee a vegetable-oil quality compatible with the standards, the correct storage of the fuel is a crucial factor to keep in mind. High temperatures, air, light, and contact with certain materials can rapidly render vegetable-oil fuel unusable.

4.1.4 Market presence/use

In Germany, because of attractive raw-material prices, huge quantities of vegetable oil were used as fuel in the middle of the



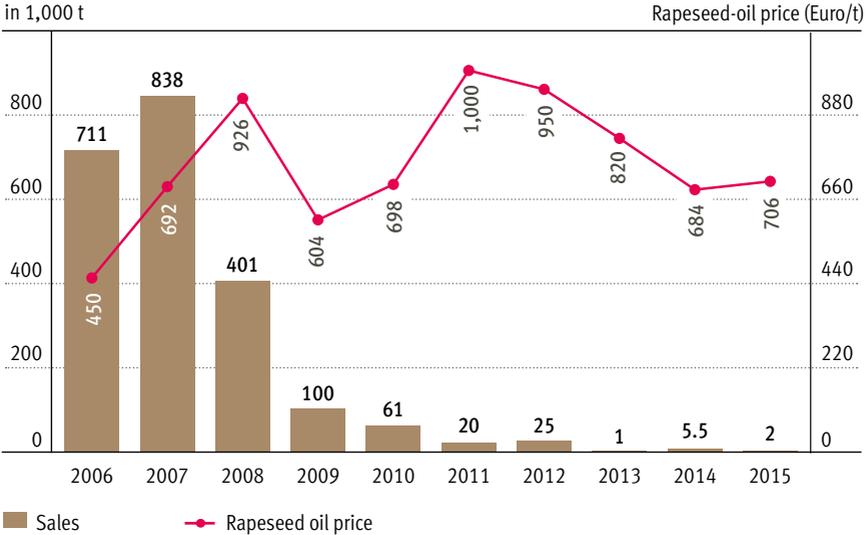
Decentralised vegetable-oil pressing

last decade. For agriculture and forestry, but primarily for freight-forwarding companies, vegetable-oil fuels offered a commercially interesting and environmentally-friendly alternative to diesel fuel.

Amid rising raw-material costs over the last years, it was no longer possible to make up for the extra costs for engine adaptation, maintenance, insurance and storage. Consequently, vehicle fleets converted their vehicles back to diesel. Compared to the maximum level, 840,000 t in 2007, sales of vegetable-oil fuel today are well below 10,000 t. The stage-by-stage introduction of tax of vegetable oils also contributed to this. Thus, since 2013, a full energy-tax rate is applied to vegetable-oil fuel.

In agriculture and forestry, the use of bio-diesel fuel and vegetable-oil fuel is exempted from energy tax. Yet because fossil-based diesel is also favoured in terms of taxation, the incentive to use vegetable oil also remains limited here. Without a price

DEVELOPMENTS IN SALES – PLANT OIL FUELS



Source: FNR/BAFA/AMI (2016)

© FNR 2016

gap compared to diesel fuel, one must assume that sales of vegetable oil as a pure fuel will have no substantial role to play in the future. Estimates in the industry state that, in order to compensate for the additional resource commitment involved, and depending on the type of use and the annual fuel consumption, a price gap of around EUR 0.20/litre is necessary.

4.1.5 Environmental aspects

Vegetable-oil fuel is categorised as being non-dangerous to water and thereby primarily well-suited for use in environmentally-sensitive areas of agriculture and forestry, right through to inland navigation.

Its ignition point, at above 220 °C, is considerably higher than that of normal diesel. Therefore vegetable-oil fuels are particularly safe and easy to handle in terms of storage and transport.

In calculation terms, vegetable-oil fuel exhibits comparatively high GHG emissions at cultivation, and very low ones in terms of the processing. If one were to take a part of the emissions caused by cultivation and allocate them to the proportion for feed, a factor that also always emerges when rapeseed is pressed, pure vegetable oil gets very good results compared to other biofuels.

4.2 Biodiesel

Biodiesel is the most well-known biofuel in this country. Around 1.8 m. tonnes of biodiesel from vegetable oils are consumed in Germany each year. This corresponds to roughly two-thirds of German biofuel sales.

4.2.1 Raw materials

For many people, 'biodiesel' calls to mind blossoming fields of rapeseed, and in Germany it is indeed primarily sourced from rapeseed. However, other vegetable oils and also used edible fats and animal fats can serve as possible alternative starting materials.

Whereas, for climatic reasons, in Central Europe it is rapeseed that dominates in the production of biodiesel, in Asia it is normally manufactured from palm oil and in America from soya oil. Biodiesel sourced from recycled materials is also gaining in significance. Compared to biodiesel obtained from cultivated biomass, it is primarily the lower GHG emissions that are stated as an advantage of biodiesel sourced from used edible fats.

In this country, biodiesel is mostly obtained from rapeseed, as a native raw material. The cultivated area, almost constant in recent years at around 1.4 m. ha, lends emphasis to the great significance of rapeseed cultivation in Germany. Manufacture of edible oil, margarine, etc. requires a rapeseed cultivated area of around 300,000 ha. Industry accounts for around 120,000 ha, using the

KEY NOTES: BIODIESEL

Raw materials: Rapeseed oil among other vegetable oils, animal fats

Yield per hectare: 3.5 t of rapeseed generates circa 1,500 l of biodiesel (and also 2 t of feed and 130 kg of glycerine)

Fuel equivalent: 1 l of biodiesel replaces 0.91 l of diesel fuel

GHG emissions*: 52 g of CO₂equiv./MJ of biodiesel from rapeseed oil (fuel used as comparison: diesel: 83.8 g of CO₂equiv./MJ), GHG reduction: 38 %

techn. information: DIN 14214

** Standard values for GHG emissions according to European Directive 2009/28/EC.*

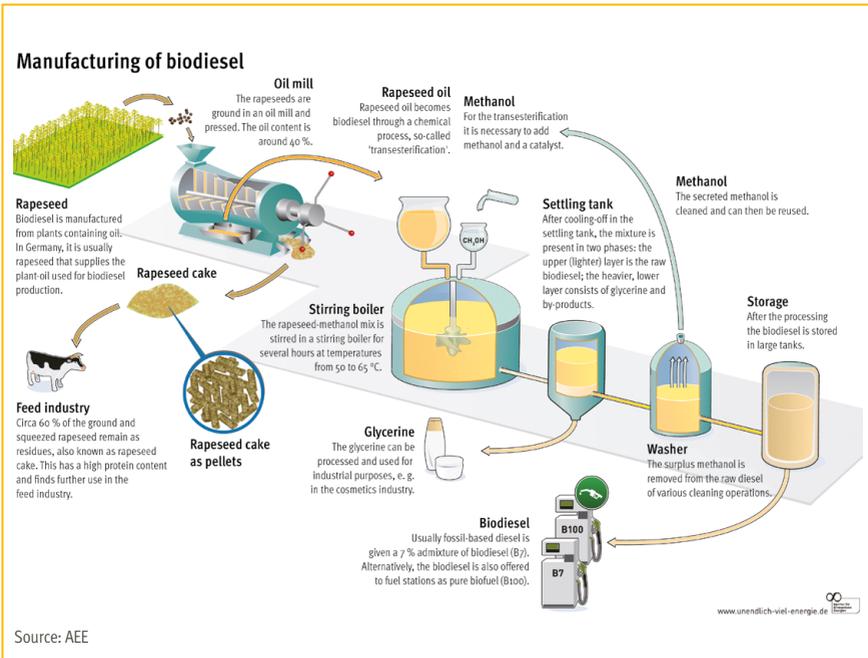
product as a material. Yet the lion's share that remains, around two-thirds of domestic rapeseed area cultivated, is available to biofuel production and, where applicable, to export.

For a chemist, biodiesel is in fact vegetable-oil methyl ester, or respectively it is characterised as fatty acid methyl ester (FAME). The abbreviation RME is also established for rapeseed-oil methyl ester. Thus biodiesel is not to be confused with vegetable oil but is manufactured from it.



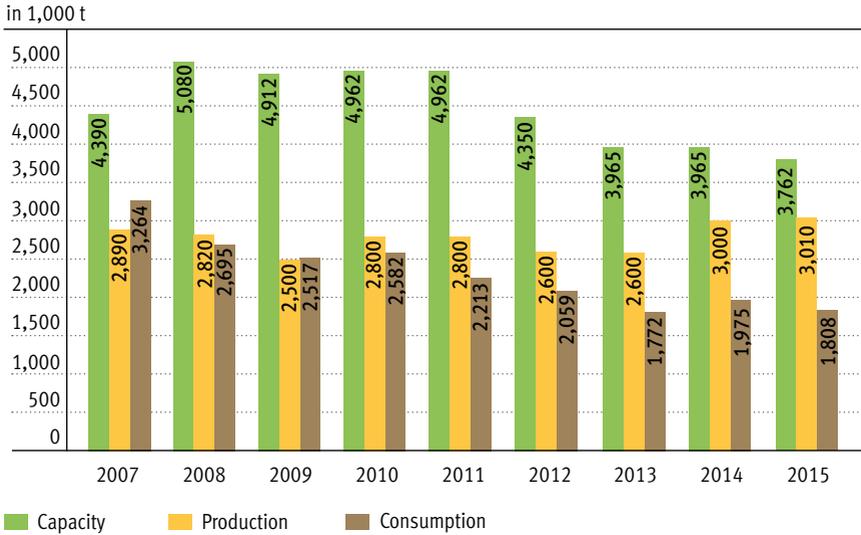
4.2.2 Manufacture

In Germany the first facilities for biodiesel production were set up in the 1990's. It is manufactured by transesterification of vegetable oil with methanol: for this, vegetable oil is mixed with methanol in a 9:1 ratio. To accelerate the process, 0.5–1 % of a catalyst (sodium hydroxide or potassium hydroxide) is added and the mixture is stirred at temperatures of 50–80 °C for several hours. In the chemical reaction that follows, the vegetable-oil molecule, consisting of glycerine and three fatty-acid chains, is split. The trivalent alcohol, glycerine, is replaced by the monovalent alcohol,



Biodiesel manufacturing

DEVELOPMENT OF BIODIESEL. PRODUCTION AND SALES IN GERMANY



Source: Ufop, VDB, BAFA, BMF, FNR (August 2016)

© FNR 2016

methanol, so that the fatty acids combine with methanol to form biodiesel. What remains at the end of the reaction is raw biodiesel and raw glycerine in two easily-separable phases.

So as to attain biodiesel of the desired product quality, raw biodiesel must go through several steps of processing. The same applies to the glycerine, an alcohol that finds use in many business sectors, such as pharmaceuticals, the food industry and the oil sector, and is normally manufactured synthetically.

4.2.3 Properties and quality of the fuel

For the use of vegetable-oil fuels, the engine needs to be adapted to the fuel; in the case of transesterification to form biodiesel, the fuel is adapted to suit the engine. As regards viscosity and its ignition performance, it has similar characteristics to fossil-based diesel. Through using additives, as is also customary for traditional fuel, the product is made suitable for winter use: as low as -20°C , biodiesel can be used without problems. The lubricity of biodiesel, important to keep wear-and-tear on the engine low, is even higher than that of fossil fuel. By contrast, the energy content per litre is somewhat

lower; this can lead to additional consumption of up to 5 %.

Im 2003 the requirements necessary for fuel quality were established in the DIN EN 14214 norm, valid throughout Europe. The integration of the latter into the 10th Federal Immission Protection Ordinance (10. BImSchV) also anchors these requirements in national law. If biodiesel is offered at public fuel-stations, it is obligatory to make known the quality of the fuel, according to the norm, by attaching the DIN sticker to the fuel-pump column.

The oil companies add up to 7 % biodiesel (B7) to traditional diesel, without any need for the vehicle-holder to take any technical prerequisites into account. To comply with the norm for fossil-based diesel fuel (DIN EN 590), the mineral-oil manufacturers may only add biodiesel that in turn corresponds to the biodiesel norm DIN EN 14214. On the fuel-pump column, a sticker stating “Contains up to 7 % biodiesel” directs attention to the so-called B 7-fuel.

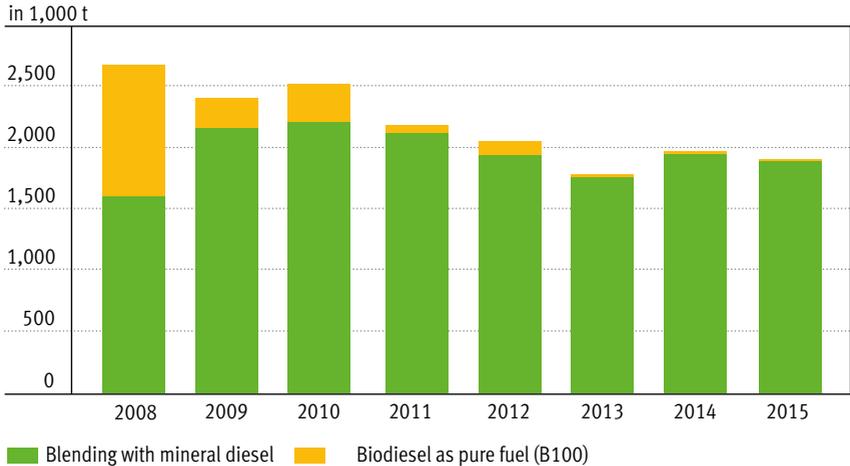


As is customary for petrol and diesel, additives are also put into the biodiesel in order to improve its properties. Information on quality-assurance with regard to biodiesel is offered by the Association Quality Management Biodiesel e.V. at www.agqm-biodiesel.de an.

APPROVALS FOR BIODIESEL VEHICLES

For use of biodiesel as a pure fuel or in mixtures with a biodiesel proportion of >7 %, approval by the manufacturers is necessary. In non-approved vehicles, biodiesel's properties, similar to those of solvents, can lead to problems; where applicable, the product can attack plastic and rubber components, such as seals and petrol-ducts in the engine. Overviews with regard to vehicle approvals for biodiesel (B 100) in agricultural and forestry use, but also for the commercial-vehicles sector more broadly (B 100 and B 30), can be accessed on the internet pages of the Union for the Promotion of Oil and Protein Plants (abbreviation: UFOP) at www.ufop.de. Likewise, when retrofitting particle filters it is essential to ensure that the filter and vehicle are approved for biodiesel use.

BIODIESEL SALES IN GERMANY



Source: FNR, according to BAFA, BMF (July 2016)

© FNR 2016

4.2.4 Market presence/use

Supported by complete tax-exemption, the history of biodiesel in Germany began with the sale of pure fuels – also known as B 100. Vehicle fleets tanked up their commercial vehicles with biodiesel and numerous car models obtained approvals for use of this fuel. The biodiesel market in Germany changed with the stage-by-stage introduction of tax from mid-2006 and with the biofuel quota, created as a countervailing measure. Higher raw-material prices and increasingly demanding requirements regarding emissions adversely affected sales of B 100, such that today biodiesel as a pure fuel comprises less than 1% (around 3,000 t) of total biodiesel sales – more than 99% of the total consumed is added directly to diesel fuel by the oil companies.

At 3 m. tonnes, biodiesel production exceeded domestic sales of 1.8 m. tonnes in 2015. In this context the manufacturers in this country – with a production capacity of 4 m. tonnes in all – primarily use native raw materials. Accordingly, in Germany in 2015 around 650,000 ha of rapeseed were used for the production of biodiesel and vegetable oil.

4.2.5 Environmental aspects

Through the use of 1.8 m. tonnes (t) of biodiesel in Germany in 2015, more than 1.8 bn. litres of diesel fuel were replaced and around 2.1 m.t of greenhouse-gases saved. Thus biodiesel's contribution to the protection of resources and of the environment is undisputed. That contribution will further in-

crease because it is to be expected that the latest requirements of the sustainability ordinance (among other things) will generate further optimisations in biofuel production.

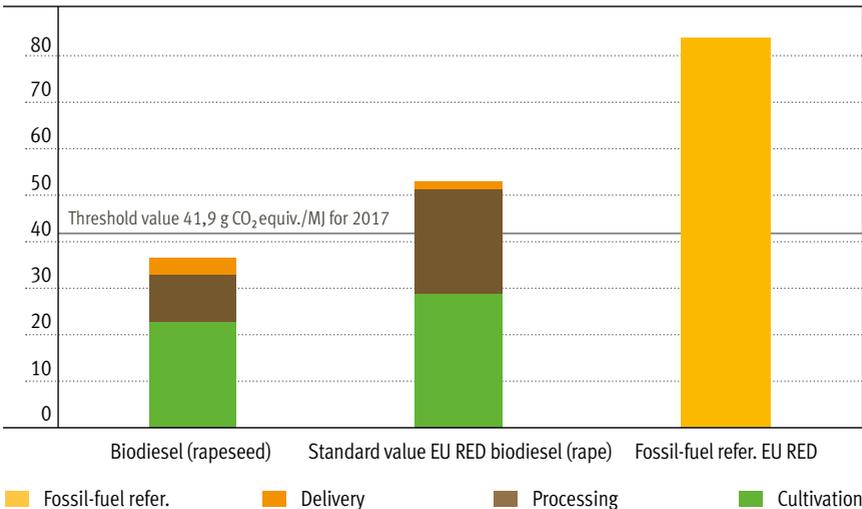
The production of biofuel causes emissions, along the chain of manufacture and supply, that are primarily to be attributed to the activity areas of cultivation and processing. The latest targets stipulate a GHG saving of 35 % in relation to a reference value for fossil-based diesel fuel; from 2018 the relevant value is raised to 50 %. How many GHG emissions the biodiesel saves in the individual case can be calculated for one particular facility or via the standard values from the “EU Directive on the Promotion of

Energy from Renewable Sources”. According to this, biodiesel made from rapeseed saves at least 38 % of GHG compared to the reference fuel; biodiesel from sunflowers even saves 51 %.

It is the cultivation of biomass, above all, that provides potential for savings. Thus an optimised deployment of fertiliser and the taking into account of average rapeseed yields (that are by now further increased) positively affected the GHG balance. The DBFZ calculates that, in practice, the emissions in the case of biodiesel sourced from rapeseed could therefore be roughly one third below the conservative EU standard value.

GHG EMISSIONS: BIODIESEL FROM RAPESEED

GHG emissions in g CO₂equiv./MJ



Source: FNR, using DBFZ information

© FNR 2014

4.3 Ethanol

With production at over 70 m. tonnes, bioethanol is the most significant biofuel worldwide, at triple the global production level of biodiesel (around 25 m. tonnes). While vegetable oil and biodiesel are suitable for diesel engines, bioethanol can replace petrol, i. e. 'Benzin' and 'Super' grade fuel. In this country, ethanol as a fuel is also traded in the form of ethyl-tertiary-butyl-ether (ETBE) and E85 fuel (a mixture of petrol and ethanol, with an ethanol content of 70–90%). In 2015 domestic ethanol sales were at 1.2 m. tonnes, of which 740,000 t were produced in Germany. Prompted by the required biofuel quota, at the refinery the oil industry admixes into petrol over 99% of the ethanol that is sold. Accordingly, 'Super' grade includes up to 5% bioethanol.

Since 2011, with E10 there is an additional fuel available at German fuel stations, with a higher proportion of bioethanol. This is a petrol with a maximum bioethanol content of 10% (in terms of volume). At present E85 is only playing a subordinate role.

4.3.1 Raw materials

Ethanol is obtained by fermentation of sugars in plants. In principle, plants containing sugar, starch and cellulose are suitable. In Germany specifically, the sources are primarily wheat, rye and sugar beet. Production of one litre of ethanol requires around 2.5 kg of cereal; at the same time, one kilogramme of protein feed emerges as a by-product. In this way, in 2015 ethanol sourced from

KEY NOTES: ETHANOL

Raw materials: Cereal, sugar beet, maize

Yield per hectares: 2,800 litre/ha*
(in addition to 2.2 t of animal-feed)

Fuel equivalent: 1 l of ethanol replaces circa 0.66 l of petrol

GHG emissions:** 44 g of CO₂equiv./MJ*
(fuel used as comparison – petrol:
83.8 g of CO₂equiv./MJ),
GHG reduction: 48%

techn. information: E 10 = proportion of ethanol equals up to 10% by volume (caution: approval must be obtained)

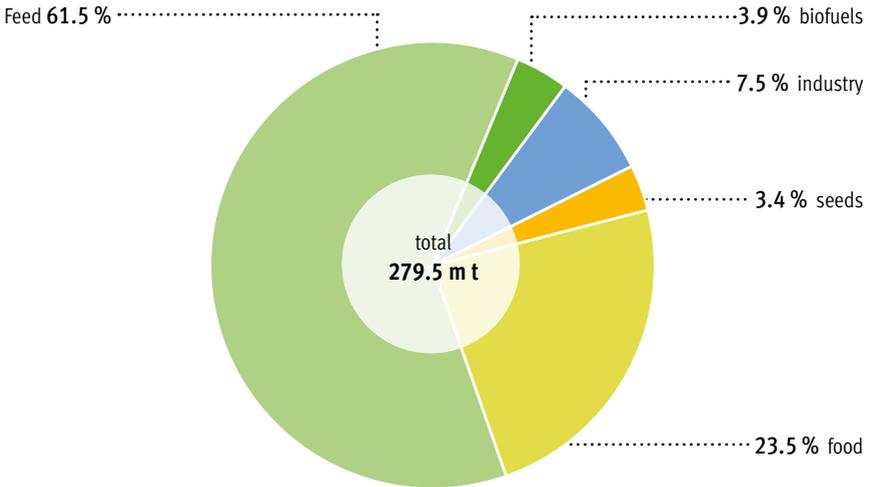
* For ethanol sourced from wheat.

** Standard values for GHG emissions according to EU Directive 2009/28/EC.

animal-feed cereal produced more than 500,000 t of protein feed 'on the side'.

Much more ethanol is sold in Germany than is produced in it. First and foremost, it is European imports that close the gap. In the USA and in European countries other than Germany, ethanol is produced primarily from maize, while Brazil bases its production on the fermentation of sugar from sugar cane. The development of suitable enzymatic procedures means that wood, energy plants and straw can also be fermented (see Chapter 5.2 "Ethanol made from lignocellulose", Page 50).

USE OF CEREALS IN THE EU-27 (2011/12)



In 2014, more than 60 % of the European Union Member States' cereals crop, amounting to 279.5 m. tonnes, was used as animal feed. Around 3.9 % of it was used for biofuel production.

Source: European Commission (2015)

© FNR 2015

The use of cereal in the EU-28 is estimated to be around 280 m. tonnes per year. Almost two-thirds of this is attributable to animal-feed production, while 24 % or 67 m. tonnes are used for food. The industrial use of cereal has a 7.5 % share, or 21 m. tonnes. Cereal for biofuel among the EU-28 plays a subordinate role, at 3.9 % or 11 m. tonnes. Accordingly, ethanol's influence on the price of cereal is also rather limited.

4.3.2 Manufacture

The manufacture of alcohol has been familiar to human society for thousands of years. Consequently production of ethanol as a fuel follows long-known process steps. The sugar contained in the plants serves as the starting material; using yeast to ferment into ethanol. In the case of plants contain-

ing starch, the starch needs to be saccharified before fermentation.

In the first step, the ground cereal is mixed with water, heated and given special enzymes. As a result, the starch in the cereal is converted into sugar; what emerges is called the mash. In sugar-beet molasses the

TAB. 2: BIOETHANOL (RAW MATERIALS USED FOR PRODUCTION)

Raw materials	Biomass yield (FM) [t/ha]	Bioethanol yield [l/ha]	Necessary biomass per litre of fuel [kg/l]
Maize	9.9	3,960	2.5
Wheat	7.7	2,760	2.6
Rye	5.4	2,030	2.4
Triticale	5.6	2,230	2.5
Sugar beet	70.0	7,700	9.1
Sugar cane	73.0	6,424	11.4
Straw	7.0	2,349	2.9

Source: Meo, FNR (2015)

FM: Fresh mass

sugar is already available directly, and can be introduced to the fermentation without processing. In order to ferment the mash or respectively the molasses, yeast must be added; this converts the sugar into alcohol and carbon dioxide. By distillation, the alcohol is separated from the remainder of the mash, which now in turn is known as stillage. As part of this, the alcohol vaporises and subsequently condenses to form an alcohol-water mixture. Linking into this process, the proportion of alcohol is increased stage-by-stage to more than 99%. In this form, ethanol is mixed with ‘Super’ grade petrol to form E5, E10 and E85.

In producing ethanol, the various process stages give rise to coupled products and waste materials, which in treated form serve as feed or substrate for biogas installations. Animal-feed is the most important market sector. Thus, for instance, stillage is dried and

pelleted to form Dried Distillers’ Grains with Solubles (DDGS). Likewise, sugar beet cossettes or vinasse, a residue from distillation, are further processed to make animal feed.

4.3.3 Properties and quality of the fuel

Ethanol has properties that improve the quality of types of petrol. Thus E85 fuel, with a research octane number of 104, exhibits a higher octane number than traditional types of petrol.

Because the energy content of the ethanol is around one third lower than that of petrol, one litre of ethanol replaces only around 0.66 litres of petrol. Conversely this leads to an increased fuel consumption of 20–30% or respectively a proportional increase, depending on the ethanol-petrol mix. Nowadays a fuel-recognition capability in modern vehicles works out the proportion

TAB. 3: FUEL – ESTABLISHMENT OF NORMS

Fuel	Norm	Explanation
Petrol (E 5)	DIN EN 228	Unleaded petrol containing up to 5 % (V/V) ethanol or respectively 15 % (V/V) ETBE (status: 10/2014)
Petrol E 10	DIN EN 228	E 10 petrol – with up to 10 % (V/V) ethanol (status: 10/2014)
Ethanol	DIN EN 15376	Ethanol as component in blend for petrol (status: 12/2014)
Ethanol E85	DIN 51625	– at least 75 %; up to max. 86 % (V/V) ethanol – Class A (summer) – at least 70 %; up to max. 80 % (V/V) ethanol – Class B (winter) (status: 08/2008)

Source: FNR

V/V: percentage by volume

of ethanol and can influence the control of the engine. Consequently the advantages of the higher octane number can at least partly compensate for the disadvantages of lower energy content. As an admixed component, ethanol also increases the fuel's steam pressure. Especially in summer, suitable measures are necessary to counteract an increase in steam pressure and thus the possibility of steam-bubble formation. Vehicles suitable for ethanol with proportions

in the petrol mixture that exceed 10 % are characterised as flexible-fuel vehicles (FFV). Their fuel-relevant components such as conduits, injection jets, fuel pumps, etc. are coordinated so as to function with higher proportions of ethanol.

Today, for all ways of using ethanol, whether as a component in blended mixtures (E5, E10) or for E85 fuels, there are specifications or respectively norms.

KNOCK RESISTANCE

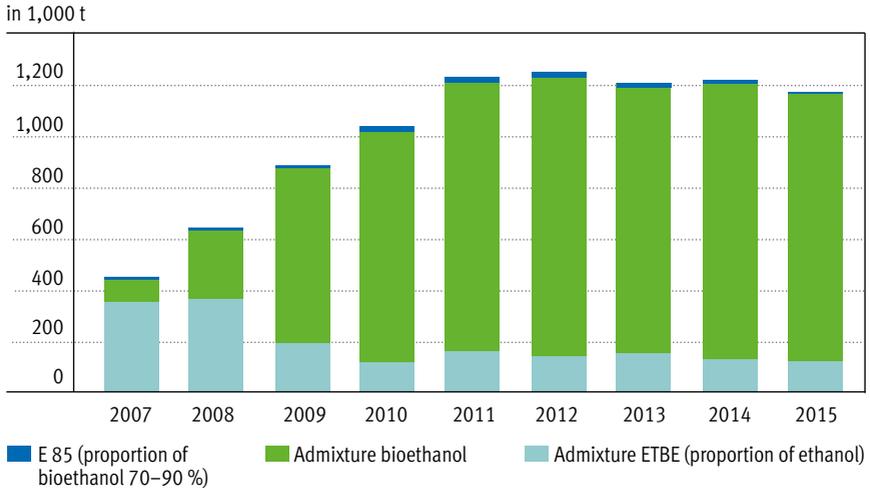
As far as possible, the combustion of the fuel in the petrol engine should be triggered exclusively by the ignition spark, in order to minimise the mechanical and thermal burden. A high octane number stands for a fuel with high knock-resistance, permitting high levels of compression and thus making the best possible use of the engine's performance potential. In the past, high levels of knock-resistance were attained by adding lead compounds. After the ban on fuels containing lead, alternatives such as methyl-tertiary-butyl-ether (MTBE) were used. Consistent with the EU goal of increasing the use of biofuels, fossil-based MTBE was successively replaced by ETBE. Ethyl-tertiary-butyl-ether (ETBE) is a compound consisting of 47 % ethanol and 53 % isobutane. Unlike ethanol, ETBE is not mixable with water. It can be admixed to petrol up to a proportion of 15 % (by volume).

4.3.4 Market presence/use

For the most part, the oil industry uses pure ethanol as an admixture. More than 1 m. tonnes or around 99 % of German ethanol is sold in this way. In 2015 the proportion of ETBE, at somewhat almost 120,000 t, amounted to only 10 %. E 85 has a low level of market relevance. Consumption in Germany remains at a low level, at 7,000 t in 2015. In Sweden, the USA and Brazil flexible-fuel models are being sold to an increasing extent for several years now, with the result that these countries have extensive experience in the admixture of ethanol to petrol. Accordingly, due to the first oil crisis, the national “ProAlcohol” programme was launched in Brazil in 1975, providing for a continuous increase in ethanol pro-

duction from domestically-cultivated ingredients, primarily sugar cane. The ethanol was used as a pure-fuel or as an admixture to petrol. Brazil now has more than 14 m. such vehicles with ethanol-compatibility. In addition, a significant and growing proportion of the new vehicles built provide flexible-fuel technology. Even E 100 is offered as a fuel in Brazil.

DEVELOPMENT OF BIOETHANOL SALES IN GERMANY



Source: FNR using BAFA information (2016)

© FNR 2016

E 10

The Federal Government's goal was to make it easier for the oil industry to use this type of fuel (Ethanol E10) to fulfil the already-existing biofuel quota of 6.25 %. Even if E 10's sales increased in 2015, at 14 % its market share remains far behind the former expectations. By contrast, "Super"-grade petrol (E 5) – permitting a proportion of ethanol not exceeding 5 % – has an almost 80 % share in the market for petrol.

The use of E 5 and E 10 usually has no negative consequences in terms of the technicalities of the engine, because of the comparatively-low ethanol content. For more than 90 % of vehicles in service, E 10 does not cause problems. Yet around 10 % of vehicles, mostly older models, have no E 10 approvals. These vehicles still have 'Super' and 'Super plus' grades available to them at the German fuel pumps, with a maximum admixture of 5 percent ethanol. In Germany, this ruling is of unlimited duration; elsewhere in Europe a transitional phase spanning several years applies. Information on vehicles with E 10-capability are obtainable from vehicle manufacturers and dealers respectively and also from automotive workshops. A list of these vehicles can be accessed at the website of Deutsche Automobil Treuhand GmbH at www.dat.de/e10.

With E 10, the lower energy-content of ethanol leads to additional consumption of 1.5–3 % (source: ADAC), with E 5 the figure is 0.5–1.5 %. Depending on how well the engine technology can make avail of the positive effects of a higher octane number, the disadvantages in fuel consumption can be balanced out.



4.3.5 Environmental aspects

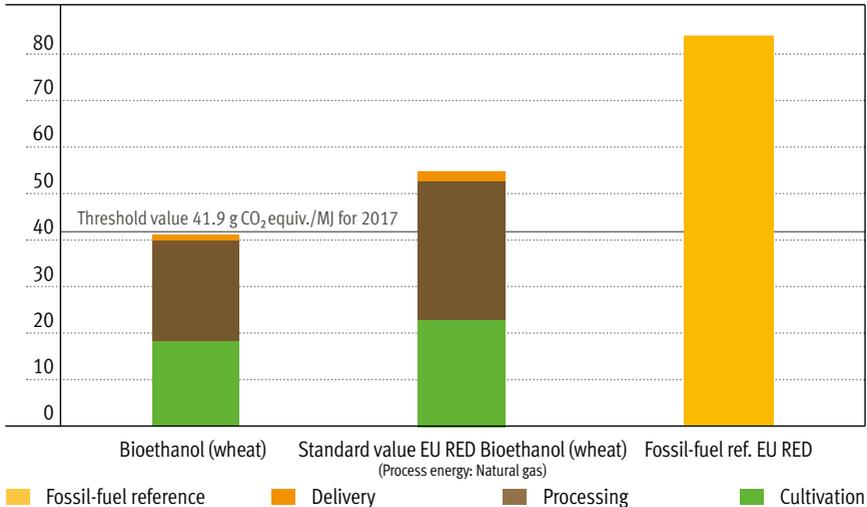
The quantity of ethanol sold in 2015, 1.2 m. tonnes, replaced around 1 bn. litres of petrol and reduced GHG emissions by around 1.2 m. tonnes.

The production of ethanol from cereal is very laborious in terms of energy. For instance, if this energy is obtained from coal, the EU Directive’s target value of 35 % GHG reduction cannot be met. That is why many German ethanol facilities adopted alternative energy concepts at an early stage. These range from combined-heat-and-power solutions based on natural gas, through to biogas facilities that make use of waste materials and simultaneously supply process energy. Further measures are needed

to reach the EU’s target value for GHG savings, namely 50 % from 2018. When growing the raw materials, an optimised use of fertiliser has a positive effect, as is the case with biodiesel, because the manufacture of artificial fertiliser is very energy-intensive. The lower its consumption, the more energy – and consequently the more CO₂ – that can be saved. The use of biofuels for the cultivation of fields also improves the balance in the statistics. With these measures and use of natural-gas as the energy source as prerequisites, DBFZ calculates that the required 50 % GHG reduction compared to petrol is achieved. If, beyond this, natural gas is replaced as the process energy by biogas (including use of waste materials), the emissions can be further reduced.

GHG EMISSIONS – ETHANOL FROM CEREALS

GHG emissions in g CO₂equiv./MJ



Source: FNR, based on DBFZ information

© FNR 2014

4.4 Biomethane

A precondition for use of biogas as a fuel is its processing to form biomethane (also known as bio natural gas). In chemical terms, biomethane is de-facto identical with natural gas and is fed into the natural-gas grid. This grid makes an outstandingly extensive infrastructure available: there are opportunities to link up to sources across large areas of Germany; at the same time the grid is connected with underground storage facilities. This enables stored biomethane to be deployed flexibly where the demand for energy is present. The biomethane can also be used not only for electricity and heating, but also as a fuel.

The quantity of biogas facilities in Germany has by now risen to 8,100, more than 180 of which produce biomethane (status: end of 2016). However, the treatment of the biogas, so as to form methane, involves resource commitment in terms of technology and energy. This is worth it, for instance, in those cases where there are not enough takers for the energy produced at the biogas facility's location. A methane-producer can conclude an agreement for supply of product with a mineral-oil trader or a fuel station operator. It is not necessary to be neighbours in terms of location, the fuel station operator obtains normal (bio-)natural gas from its grid, yet pays the biomethane producer that feeds-in the corresponding quantity of biomethane at its specific location.

KEY NOTES: BIOMETHANE

Raw materials: Energy plants, manure and organic recycled material

Yield per hectares: 4,945 m³ or respectively 3,560 kg*

Fuel equivalent: 1 kg biomethane replaces circa 1.5 l of petrol or 1.3 l of diesel

GHG emissions:** 16 g of CO₂equiv./MJ for biomethane from liquid manure (fuel used as comparison = petrol: 83,8 g of CO₂equiv./MJ), GHG reduction: 81 %

techn. information: Biomethane (bio natural gas) is used in natural-gas vehicles, with no further need for adaptation, DIN 51624

* *Basis: Area yield of maize 50 (t/ha • a); biogas yield 220 (m³/t); methane content 53 %.*

** *Standard values for GHG emissions according to EU Directive 2009/28/EC.*

The Federal Government has anchored the Gas Grid Access Ordinance (Gasnetz-zugangsverordnung) in legislation, as a prerequisite for feeding biomethane into the natural-gas grid. This ordinance not only created the legislative framework but also defined goals. It provides for the feeding-in of biomethane to rise to 6 bn. m³ annually by 2020. As a comparison: in 2013 over 50 m. m³ were used as fuel.



Maize silage fodder is one of the most important raw materials for biogas production.

4.4.1 Raw materials

The starting substance for biomethane is biogas: in Germany this is mainly obtained by fermentation of energy plants, liquid manure and solid manure, but also from organic waste material sourced from industry and private households. Around a half of the substrates used are renewable substances (52 %), followed by animal excrement, at 43 %, and biogenic waste and recycled material, at 5 %. Maize dominates among the renewable resources, at 73 %. The Federal Ministry of Agriculture is providing support to the search for sustainable

alternatives to maize, in various projects (<http://energiepflanzen.fnr.de>). Scientists are examining new systems of cultivation and crop rotation, and also numerous interesting old and new energy crops. In plant-breeding projects, highly-promising candidates are made ready, in terms of cultivation, for their task as energy supplier.

For the production of biomethane as a fuel, the use of waste materials and recycled materials is particularly interesting. Low GHG emissions make a case that favours this source as an option.

TAB. 4: YIELD OF RAW MATERIALS, ANNUAL YIELD OF BIOGAS AND METHANE

Raw mats.-yield [t/ha] FM	Biogas yield [Nm ³ /t]	Methane content [%]	Methane yield	
			[Nm ³ /ha]	[kg/ha]
ca. 50*	ca. 200*	53	4,945	3,560

Source: FNR, using KTBLinformation (2014)

* Based on silo maize, medium level of yield, 12 % losses in storage;
Density of biomethane: 0.72 kg/m³

4.4.2 Manufacture

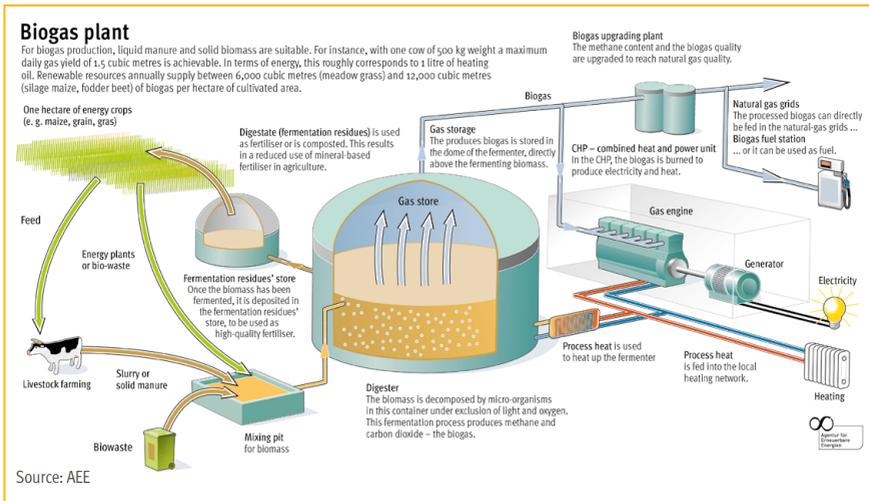
The biogas produced by fermentation contains a substantial proportion of carbon dioxide, alongside a methane content of 50–75 %. Added to this are small quantities of hydrogen sulphide and other trace gases. Yet it is only the methane (CH_4) that is usable as a fuel: in chemical terms it is identical with natural gas. Thus separation of the methane from other constituent elements of biogas is decisive.

In Germany there are currently five different treatment procedures used in practice. These include PSA (pressure swing adsorption), compressed water washing, physical and chemical washing (e.g. amine washing), and the membrane separation procedure. More extensive information is available at <http://biogas.fnr.de>.

These procedures allow the methane content in the biogas to be increased to up to 98 %. The orientation point for this level of methane content is the respective methane concentration in the gas grid at the place where the product is fed-in. The degrees of concentration range from 80 % (so-called L-Gas from Lower Saxony, the Netherlands and the North Sea) up to 98 % (H-Gas sourced from Russia).

4.4.3 Properties and quality of the fuel

Biomethane or natural gas are stored in a pressurised tank at 200 bar and sold at specialised fuel pumps. It is a mandatory requirement to state natural gas prices and biomethane prices at fuel-stations, based on mass and denominated in kg. The energy-content of a kilogram of methane approximately corresponds to that of 1.5 l of petrol or 1.3 l of diesel.



Manufacturing process: biogas/biomethane to produce electricity, heating and fuel

To guarantee uniform quality, bringing biomethane and natural gas into circulation as a fuel is tied to compliance with the norm DIN 51624. Subject to this prerequisite, natural gas and biomethane can be mixed in any ratio.

New natural-gas vehicles are usually bivalent, i. e. equipped with an additional petrol tank, so that there are no losses sustained in terms of vehicle range or problems arising from a lack of gas fuel stations.

4.4.4 Market presence/use

In the year 2015, biomethane-natural-gas mixtures were able to be tanked throughout Germany in various mix ratios at over 300 fuel stations. Of these, 150 fuel stations were already offering pure biomethane. In 2015, sales rose to 38 m. kg or respectively 53 m. m³.

Thanks to politicians' efforts and to initiatives by the industry, in future natural gas and biomethane are to play a larger role in the mobility sector; the aim is a 4 % share for natural gas and biomethane in German fuel consumption. This goal is ambitious because it amounts to a factor-of-10 increase

compared to the figure for 2015. The aim is also for the number of suitable vehicles in use to grow, to a total of 1.4 m. vehicles. At present there are no more than 98,000 natural-gas-powered vehicles on German roads, of which 80,000 are cars. They have a network of more than 900 natural-gas fuel stations available to them. Yet biomethane is obtainable not only at the network of natural-gas fuel stations; there are also biomethane service stations directly at biogas facilities. In 2006 the first of these biomethane fuel stations was established in Wendland.

A reduced energy-tax rate applies to natural gas and biomethane until the end of 2018, namely 1.39 EUR-ct per kilowatt-hour. If biomethane is credited against the biofuels quota, however, the full tax rate must be paid. Yet because the prices for biomethane are still above the natural-gas prices, quota-trading for biomethane sourced from recycled material is an important mechanism used for biomethane sales.

Biomethane is an alternative, not solely for cars and small transporters; to an increasing degree, urban buses, vehicle fleets serving municipalities and also commercial vehicles

TAB. 5: SALES OF BIOMETHANE AS FUEL

	2010	2011	2012	2013	2014	2015
Sales in GWh	162	190	404	557	580	530

Source: AGEES-Stat (Juli 2016)

Sales of methane as fuel: 2,300 GWh in 2014

are gas-powered. While the comparatively low vehicle range is problematic in the transport sector, buses and municipal vehicles can typically use the company-internal fuel-station at their operational base. First concepts tested in agriculture show that combined diesel-biomethane operation is possible with tractors. A two-tank system, similar to that used for vegetable-oil fuel, serves for starting up and switching off the vehicle using diesel fuel. The degree to which these concepts can be economically viable for farmers in the future, depends on the tractor's area of operation and on the financial support provided.

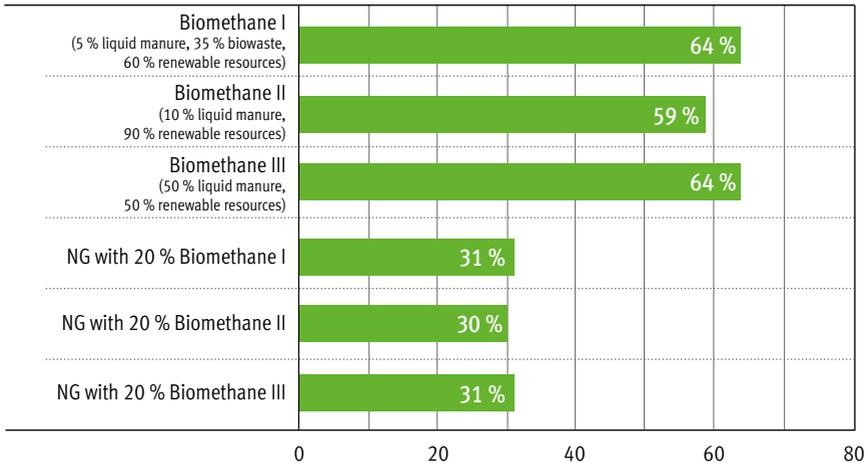
4.4.5 Environmental aspects

A key advantage of biomethane compared to diesel and petrol is the reduced level of pollutant emissions. By using bio natural gas in buses and municipal vehicle fleets, emissions of soot and particles attributable to transport can be substantially reduced in our inner urban areas.

Depending on the raw material used, the GHG emissions for biomethane vary. The use of recycled and waste material has a positive effect because only emissions from transport and from processing are included in the balance. Overall, GHG savings of 60–80 % are possible. On this basis, even

GHG REDUCTION POTENTIAL USING BIOMETHANE & BIOMETHANE-NATURAL GAS (NG) MIXTURES

GHG reductions in %



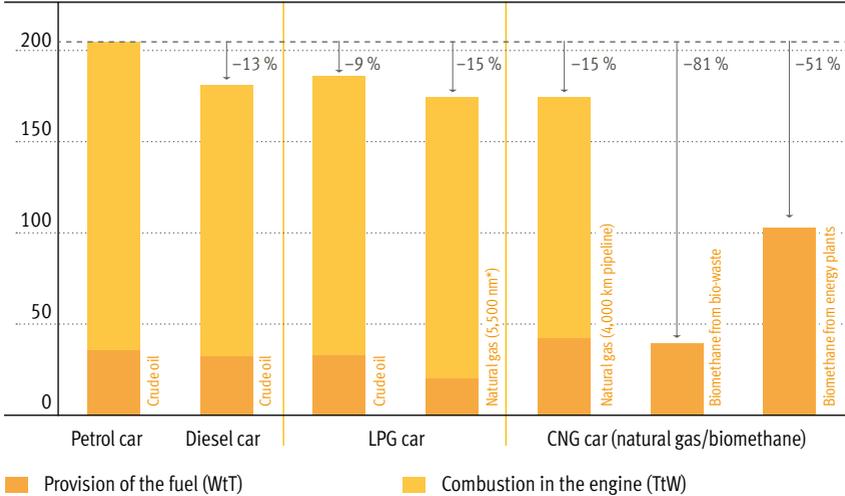
Fossil-fuel reference petrol/diesel according to Biofuels Sustainability Ordinance (BiotkraftNachV) value = 0 %.

Source: FNR, using dena information

© FNR 2014

WTW GREENHOUSE-GAS EMISSIONS – CARS: 2012

GHG emissions in g CO₂equiv./km



*WtW: Well-to-Wheel, * LPG from natural gas by ship-transport corresponds to 10,186 km*

Source: FNR, using information from BMVBS/ifeu

© FNR 2014

taking into account various mixtures of substrate, the target value of 50 % GHG saving for 2018 can be reached. After all, for natural-gas-biomethane mixtures (80:20), the GHG saving still amounts to 30 % compared to petrol fuels or diesel fuels.

At present, the Biofuels Sustainability Ordinance includes no standard value for GHG saving attained by biomethane sourced from energy plants; accordingly, in this case the producers must make their own calculation, using the predetermined methodology. However, the European Commission has already announced a corresponding addition to the list of standard values. The two graphics (see Pages 39 and 40), based on various studies, give points of reference on the GHG savings.

4.5 Hydrogenated vegetable oils (HVO)

For hydrogenated vegetable oils (HVO), vegetable oil is converted into hydrocarbons by means of a catalytic reaction involving addition of hydrogen. No adaptation of the engine is necessary and the fuel can be used in any mixture and even as a pure fuel. These properties draw the interest of the oil companies and the automotive industry. In Germany, HVO is an admixture inserted into petrol.

Yet the greatest interest comes from the aviation industry, a sector growing worldwide and with huge goals in terms of CO₂ savings. Accordingly, biofuels and specially hydrogenated vegetable oils play a decisive role in that sector's strategic deliberations. After all, in 2014, HVO sales in Germany amounted to no less than 340,000 tonnes.

4.5.1 Raw materials

Hydrogenated vegetable oils (HVO's) can be produced from vegetable oils but also from vegetable fats or animal fats – even such exotic sources as oil from camelina sativa, jatropha or algae have already been tested. As the raw materials do not significantly influence the characteristics, the option selected is usually the cheapest raw material. Thus, in the few industrial facilities in operation, the preferred ingredients are palm oil and used edible oils. The precondition for being credited against the biofuels quota in this country is that the raw materials comply with sustainability standards.

KEY NOTES: HYDROGENATED VEGETABLE OIL (HVO)

Raw materials: Plant oils, vegetable fats and animal fats

Yield per hectare: 3.5 t of rapeseed oil produce around 1.200 l HVO (and 2 t of feed)

Fuel equivalent: 1 l HVO replaces 0,96 l of diesel

GHG emissions*: 44 g of CO₂equiv./MJ for HVO made from rapeseed oil (fuel used for comparison – diesel: 83,8 g of CO₂equiv./MJ), GHG reduction: 48 %

techn. information: DIN 590 for diesel fuel

** Standard values for GHG emissions according to Dir. 2009/28/EC.*



Thus, for palm oil (for example) traceability back to the plantation is necessary. The certified oil mills in Malaysia or Indonesia are solely permitted to process sustainable products from registered plantations.

4.5.2 Manufacture

For the manufacture of hydrogenated vegetable oils, a distinction based on principle is made between two procedures: firstly, direct integrated treatment in the refinery process, also known as co-processing, and secondly production in stand-alone facilities.

For hydrogenation of vegetable oils in the petroleum refinery, in so-called co-processing, individual process parameters need to be adapted but the procedural steps to go through are the same as in classic processing in a refinery. The first step entails admixture of the vegetable oil to the vacuum gas oil, i. e. an interim product generated in the refining of petroleum. So as to produce pure hydrocarbons from this mixture, it is essential to remove sulphur, oxygen and nitrogen – the so-called hetero-atoms – by means of hydro-treating. Mixed with hydrogen and then heated up, these unwanted compounds are then catalytically separated off. What remains is pure, long-chain hydrocarbons. To achieve the desired shorter chain-lengths that characterise diesel, kerosene or petrol, the hydrocarbon chains must be split or respectively cracked. An established procedure from refining of petrol is hydrocracking; by means of catalysts, this sets the shorter chain-lengths, subject to addition of hydrogen. The manufacture of HVO in a stand-alone facility proceeds

in a similar way. In advance, the vegetable oil must be cleaned: this usually happens according to familiar procedures used in vegetable-oil refining. After this, the vegetable oil is hydrogenated. At temperatures of 350–450 °C, with hydrogen partial pressure at 45–152 bar, and using a catalyst, what emerges is hydrocarbons with properties typical for diesel. However, in contrast to co-processing, these are entirely of biogenic origin.

4.5.3 Properties and quality of the fuel

Hydrogenated vegetable oils are usually adapted to diesel fuel and exhibit the fuel characteristics required by the diesel-fuel norm DIN 590. Thus a mixture with diesel-fuel does not constitute a problem, regardless of the ratio. An exception is the density; at 0.78 kg/l this is slightly below that of diesel fuel (0.83 kg/l). The resulting disadvantage with regard to storage and vehicle range per tank-filling is almost compensated for by a higher energy content. Advantages in relation to diesel fuel emerge due to the high cetane number, at up to 99 per ignition delay. The ignition delay corresponds to the time that elapses from the fuel injection to the automatic ignition. A high cetane number indicates a short ignition delay. For the use of exhaust-gas treatment systems, no limitations apply in relation to the use of hydrogenated vegetable oils. It generally holds true that the fuel properties of HVO are comparable with those of GtL and BtL fuels.

4.5.4 Market presence/use

Hydrogenated vegetable-oils manufactured in stand-alone facilities can be credited against biofuels quotas in their entirety. It is to be assumed that the quantities sold in Germany originate exclusively from these facilities. In the future HVO from co-refining can be credited against the GHG quota.

Currently there are no stand-alone facilities in Germany for production of hydrogenated vegetable oils. Their largest European manufacturer is the Finnish company, Neste Oil AG. Following a facility in Singapore and two facilities in Porvoo (Finland), a 800,000 tonne facility in Rotterdam commenced operations in 2011. This brings the total processing capacity of Neste Oil to around 2 m. tonnes of HVO.

HVO FOR AVIATION

With the aviation sector recording annual global growth of 4–5 %, the search for suitable alternatives to fossil-based kerosene has long since begun. Biofuels are an option of substantial significance in this regard. because current environmental goals pursued by the aviation sector cannot be reached entirely by means of new aircraft geometries, materials or the optimisation of global flying routes.

The aviation industry's environmental goals (Source: IATA):

- Reduction of the specific fuel consumption up to 2020 by 1.5 % annually
- CO₂-neutral growth in volume of operations from 2020 onwards
- Halving of CO₂-emissions in 2050, using 2005 as base year

A precondition for the use of biofuels in aviation is the availability of 'drop-in fuels'. These are fuels that can be deployed in the engine systems without adaptation of engine systems and yet that simultaneously do not cause any disadvantages in terms of their flying range. Of the biofuels currently available on the market, interest is primarily directed at hydrogenated vegetable oils; this is because biodiesel and ethanol cannot match the specifications of the currently-relevant JET A-1 fuel. Yet even with regard to HVO there remains a need for adaptation, primarily in connection with meeting the -47 °C freezing-point requirement.

Worldwide, biofuels based on vegetable oils are being tested in practice. Accordingly, Lufthansa was the first company worldwide to deploy biofuels in daily flight operations, as early as 2011. An Airbus A321 flew the Hamburg – Frankfurt return journey, four times daily. This test spanned six months in all: one engine successfully used biofuels based on hydrogenated vegetable oils for 50 % of its fuel needs.

4.5.5 Environmental aspects

Hydrogenated vegetable oils are available as pure hydrocarbons and are free of aromates, sulphur, nitrogen and oxygen. The exhaust-gas emissions are correspondingly low. Above all, particle emissions and NO_x emissions are below those of diesel fuel. Yet in contrast to the starting substance – vegetable oils – HVO's are no longer biologically degradable.

The HVO quantities sold in Germany are traded in the context of the biofuels quota. Accordingly, predefined sustainability standards must be adhered to and greenhouse gases must be reduced. Because hydrogenated vegetable oils take traditional vegetable oils as their starting material, the emissions involved in their manufacture are transferable. Emissions for transport and processing must be added to this. However, to match the more demanding GHG reduction requirements set for 'stand-alone facilities', taking effect from 2018, certain measures must be taken. As is the case with biodiesel and vegetable oil, the improvements with regard to rapeseed are to be made in the optimisation of use of fertiliser and, with regard to palm oil, in the adaptation of oil pressing. To reduce GHG emissions in the stand-alone facility, the decisive factors are the hydrogen requirement and the hydrogen production, in addition to the use of the by-products, such as propane for making process energy available.

It is raw-materials costs and also the political framework that will decide whether it is German or other European-sourced rapeseed, palm oil or used edible oils that, via

the hydrogenation route, contribute to the fulfilment of Germany's fuel-related goals. Similarly, the aviation sector's strategic decision to use HVO as its transitional technology takes on a particular significance.

4.6 Electro-mobility and biofuels

In the public debate, electro-mobility using self-regenerating sources is often discussed as the transport sector's only renewable solution. Yet some factors indicate that, alongside electric engines, combustion engines retain their *raison d'être* in certain activity areas, and are operated with biofuels as a renewable alternative to fossil fuels. Now more than ever, well-known manufacturers and research institutes are currently investing in the further development of combustion-engine concepts. Because of its characteristics, the combustion engine is particularly suited both to lorry-based goods transport (independent of a power-grid), to agricultural and forestry work and also to marine and aviation transport; in these sectors it will retain its right to exist for a long time yet. The transitional solutions to make the switch into the era of electro-mobility – hybrid vehicles and electric vehicles with "range extenders" – need the combustion engine and corresponding fuels.

Electro-mobility powered by biomass

Today, without any further ado, it is possible to select an energy supplier who offers electricity exclusively from renewable energies. If the electro-vehicle is tanked using such

'eco-electricity', renewable, emission-free driving is already possible to a large extent. Around 30 % of the electricity from renewable energies used in Germany in 2015 was sourced from biomass (e. g. in biogas facilities or in wood-fuelled heat-and-power plants; consequently, renewable electro-mo-

bility is also based on bioenergy to a proportional degree. Yet in practice many eco-electricity suppliers offer electricity sourced from water-power obtained in European neighbouring countries, who are able to produce this particularly cheaply because of specific geographical features.

PROS AND CONS AT A GLANCE

Combustion engine

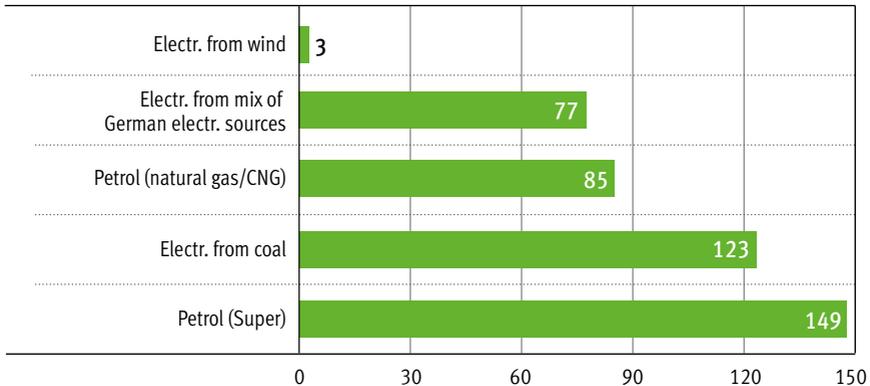
- + Liquid fuels store a lot of energy in a small volume; thus enabling a lot of range and performance to be provided
- Complicated and heavy mode of construction
- Low degree of energy-effectiveness
- Emissions

Electro-engine

- + Light and simple mode of construction
- + High degree of energy-effectiveness
- + When using electricity sourced from renewable energies, few emissions or indeed zero emissions
- Batteries store little energy in relation to volume. High-performance batteries are correspondingly heavy. This results in more limited range and performance.

COMPARISON/CO₂-EMISSIONS: EXAMPLE VW E-UP VS. PETROL ENGINE

CO₂-emissions g/km



Source: FNR using ADAC information

© FNR 2014

5 FUTURE BIOFUEL OPTIONS

5.1 BtL fuels

BtL stands for 'Biomass to liquid'. BtL liquids are to be understood as meaning synthetic fluids made from biomass. These fuels are not yet available on the market. The challenge is to transfer the manufacture of fuel, as is already familiar from coal and natural gas, to biomass as a raw material. The overarching term 'XtL fuels' summarises procedures that produce synthetic fuels obtained, for example, from coal (CTL: Coal to liquid), gas (GtL: gas to Liquid) or biomass (BTL: Biomass to Liquid).

Specialists regard BTL fuels as having advantages among the spectrum of broadly and efficiently usable raw materials, but also primarily in the fuel quality, even matching the more exacting requirements of the automotive and aviation industries. The whole manufacturing process is currently being tested out in the context of a pilot production line at Karlsruhe Institute for Technology (KIT).

KEY NOTES: BIOMETHANE

Raw materials: various dry types of biomass (straw, wood, recycled materials)

Yield per hectare: ca. 4,000 l

Fuel equivalent: 1 l of BtL replaces 0.94 l of diesel fuel

GHG emissions*: 6 g of CO₂equiv./MJ (fuel used as comparison = diesel: 83,8 g of CO₂equiv./MJ),
GHG reduction: > 90 %

techn. information: DIN 590

** on the basis of cultivated wood according to standard values for GHG emissions referred to in European Directive 2009/28/EC.*

DEFINITION: BTL FUEL

"Biomass to liquid" characterises a chain of processes by means of which biomass is converted into synthetic gas via thermochemical gasification and is subsequently synthesized to form liquid hydrocarbons. The biogenic hydrocarbons produced in this way can be treated to form marketable fuels, such as diesel complying with the EN590 norm or petrol complying with the EN228 norm.



Straw as a raw material for the bioliq process

5.1.1 Raw materials

While with traditional fuels it is often only parts of the plant – mostly the seeds – that serve as the raw materials, with the manufacture of BtL fuels it is the whole plant that can be used.

Various types of biomass can serve as raw material. The portfolio ranges from natural waste materials that emerge in any case, such as straw and remnants of wood, right through to energy plants. For instance, in the case of plants cultivated specifically for fuel manufacture, a yield of up to 4,000 l per hectare is expected. Estimates work on the basis that BtL fuels from domestic cultivation have the potential to replace 20–25 % of Germany's fuel demand, and Europe-wide even a much higher percentage. With this performance capacity, BTL fuels can hugely contribute to substitution of use of finite fossil fuels.

5.1.2 Manufacture

At present there are various procedures in development worldwide for manufacture of BTL fuels, mostly in the research project and

pilot project stages. In principle the manufacturing process can be divided into the following process steps: biomass processing, gasification, gas purification, synthesis and fuel processing.

KIT in Karlsruhe is pursuing the concept of decentralised pre-treatment of the biomass, in order to simplify the logistics. As biomass is produced on a decentralised basis with a low energy density, via the path of fast pyrolysis it is initially converted into an energy-dense intermediate product – Syncrudeoil or bioliqSynCrude®. This is able to be transported more efficiently for further processing in central and industrial large-scale facilities.

What follows there is initially the task of manufacture of synthetic gas. In a reactor, the Syncrudeoil is converted into a gaseous state at temperatures above 1,200 °C and pressure of up to 80 bar, involving use of a gasification agent (e. g. oxygen). The process is also characterised as thermochemical gasification. The raw synthesis gas consists of hydrogen (H₂), carbon monoxide (CO) and

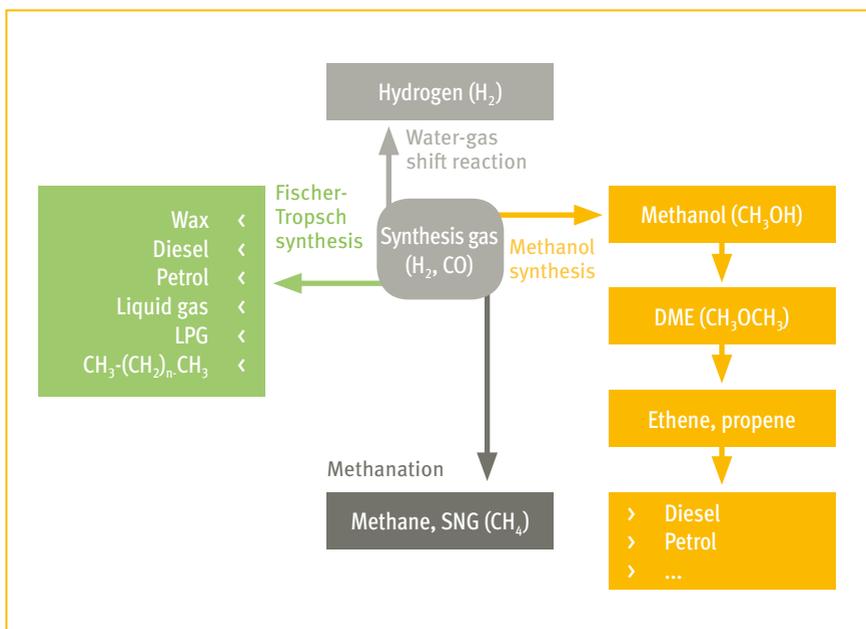
carbon dioxide (CO_2), sulphur compounds and nitrogen compounds, and also further components. For the subsequent synthesis it is essential to make the raw synthesis gas free of various harmful components (e.g. sulphur compounds and nitrogen compounds).

At the synthesis stage, the gaseous mix is processed so as to form liquid hydrocarbons. The Fischer-Tropsch (FT) synthesis is often named in this context, but methanol synthesis is also a possible option, in particular the Methanol-to-Gasoline[®] procedure (MTG) generating dimethyl ether (DME) as an intermediate product.

In the fuel processing, a selection takes place, making a subdivision into heavy, medium and light fragments. These are then refined in a targeted way and adapted to suit the desired fuel characteristics. Depending on the procedure, final products are diesel, kerosene or petrol. Apart from fuels, base chemical products are also produced – but electricity and heat are also generated and these can cover the bulk of the necessary process energy.

5.1.3 Properties and quality of the fuel

BtL fuels are manufactured synthetically; thus their properties can be influenced in



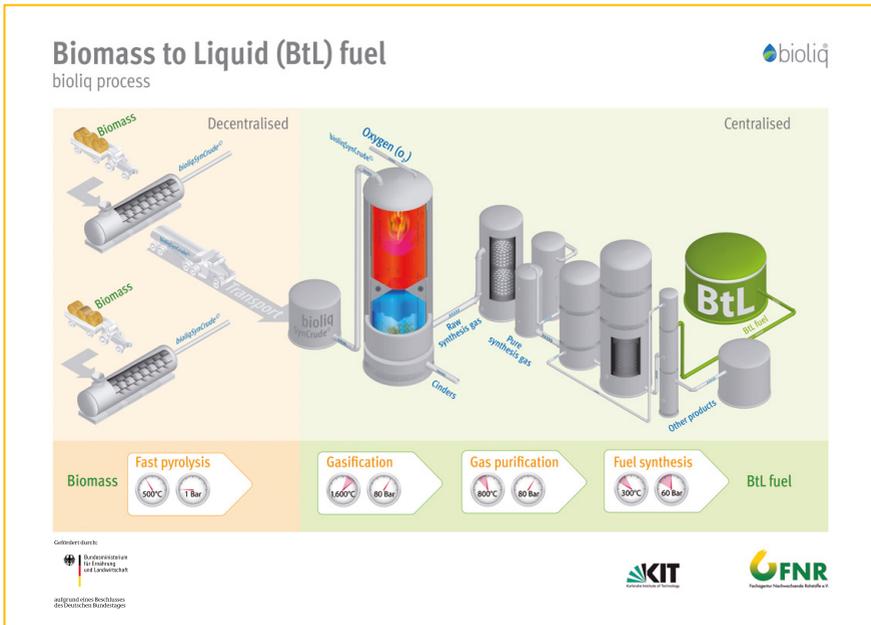
Paths to BtL fuels and chemical elements

a targeted way and optimised to match particular applications and combustion procedures. The term ‘designer fuels’ is also used. The current state of knowledge indicates that, via a corresponding process management, these products will be able to fulfil requirements from aviation applications and for future developments in engine technology. Because BtL fuels comply with threshold-value requirements for relevant fuel norms, it is possible to mix them with fossil fuels in any desired ratio. Features common to all BTL fuels are a high cetane number, an absence of sulphur and aromates and significantly reduced emissions of pollutants (e. g. nitrogen oxide, NO_x and

particles). As is the case with HVO, BtL fuel also has a lower density than diesel but a higher energy content that balances out the possible disadvantage in terms of the range.

5.1.4 Market presence/use

BtL fuels are not available now in quantities that have market-relevance. In this country, the whole process chain is currently set up and operated at KIT in the form of a pilot facility. Experts expect relevant fuel quantities from industrial facilities to be on the market in 5–10 years.



Schematic overview of a BTL manufacturing process

5.1.5 Environmental aspects

BTL fuels make avail of a wide range of raw materials; only to a small extent, if at all, do they compete with food production. Particularly in the use of recycled materials, the savings in GHG emissions (savings of over 90 % compared to diesel seem possible) go so far beyond the current minimum requirements that even future, more demanding requirements (50 % from 2018)⁵ are fulfillable. Biomass cultivated directly for BtL production, e. g. in short-rotation forestry facilities, also exhibits greater area efficiency than the biofuels hitherto introduced to the market, at up to 4,000 l per hectare. By means of the conversion of the biofuels quota to a greenhouse-gas (GHG) quota, starting in 2015, BtL fuels can particularly gain because of their potential for GHG reduction.

5.2 Bioethanol made from lignocellulose

Bioethanol is currently the most significant biofuel worldwide, with an annual production of around 70m. tonnes. It is obtained through fermentation of alcohol in sugars that are contained in plants, using yeast cells. While cereal, maize, sugar-beet and sugar-cane have already been converted for decades to form ethanol, the use of biomass in solid form is a new development.

Solid biomass contains a particularly high amount of lignocellulose, that in turn consists of cellulose, hemicellulose and lignin; this forms the cell walls and thus the structure of our plants. Solid biomass includes wood, straw, large grasses such as *Miscanthus sinensis* (also known as Chinese silver grass), cereal, including the stalks (so-called whole-plant cereal) and material from landscape cultivation, for instance the cuttings from hedges, trees and shrubs in streets or public greenery. Triggered off by the ‘food versus fuel-tank discussion’, the use of these raw materials for fuel products has been much discussed recently, because they do not compete directly with food production, or at least do so less directly. Simultaneously they have a high potential for GHG reduction.

A range of pilot facilities and demonstration facilities was set up worldwide for the manufacture of ethanol sourced from lignocellulose. Yet there is far to go before industrial-scale manufacture is an option. To produce ethanol from biomass containing lignocellulose, the raw material must be pre-treated and converted into sugar; this sugar makes possible the subsequent fermentation so as to produce ethanol. The problem: when processing lignocellulose, alongside the familiar hexoses (mostly glucose), what is also produced is sugar with five carbon atoms – so-called pentoses

⁵ *New facilities built after the 5th of October 2015 it must achieve a GHG saving 60%.*

(C₅ sugars). These sugars cannot be converted into ethanol using yeast from traditional ethanol production. This is why the optimisation of yeast types and micro-organisms is currently being researched in the most diverse projects worldwide. At laboratory level the results are promising but the processes also have to function efficiently in large-scale industrial facilities. To be added to this are high enzyme costs that still need to be invested to run the process viably in economic terms.

Despite all challenges faced, lignocellulose indisputably offers positive effects with regard to availability of raw materials and also GHG emissions. In chemical terms, lignocellulose-ethanol is identical with ethanol sourced from cereal. Thus the familiar usage options are open in Germany.

5.3 Bio-butanol

Butanol (C₄H₁₀OH) is predominantly used as a solvent in the varnish industry; on an industrial scale it is mostly produced by petrochemical process, using fossil-based resources. Up to now, its manufacture as a fuel is not economically viable, yet various companies see it as an alternative rich in potential. Like ethanol, butanol ranks among the alcohols. Plant material containing starch or sugar, for example, can be fermented to form bio-butanol. Compared to ethanol, bio-butanol is a fuel with certain advantages. The higher energy content leads to an increased range and the product's limited capacity to mix with water brings about

advantages regarding storage and mixing with petrol. The primary difference to ethanol production is in the fermentation, and the bacteria and enzymes responsible for this. To produce butanol, certain types of clostridia are needed. By nature, they are capable of producing butanol by means of a so-called ABE fermentation. What emerges from this is a mixture of acetone, butanol and ethanol. Yet so far the butanol yield is insufficient for fuel manufacture on a large technical scale. Because butanol even has a toxic effect on the micro-organisms when concentration levels increase, commercial production procedures require new approaches to solutions; there remains a need to conduct more research on this.

5.4 Hydrogen

The idea of using hydrogen as the drive for vehicles dates back almost as far as the invention of the automobile itself. Hydrogen combusts in the fuel cell free of emissions, all that emerges is water or respectively water vapour. Used in the combustion engine, it also causes limited quantities of nitrogen oxides. From the emissions viewpoint, hydrogen is thus (almost) an ideal fuel.

The automotive industry and politicians have both intensified their efforts in this regard and the 21 fuel-stations currently available in Germany (source: CEP; 2016) are set to be 400 by 2023; yet to this day hydrogen as a fuel source remains the preserve of test vehicles.



Hydrogen fuel-station in Berlin

The manufacture per se matches the state of the art, for the most part it is done by means of steam reforming, by similar thermochemical processes, or by electrolysis. Today the starting substance for steam reforming is primarily natural gas (CH_4). In the reforming of biomethane or raw glycerine it is also possible to produce bio-hydrogen on an environmentally neutral basis, from renewable resources. In a pilot facility at its Leuna site, Linde AG is demonstrating the production of hydrogen sourced from glycerine. Through a pyro-reforming process developed by Linde, the hydrogen-rich glycerine emerging as a by-product of biodiesel production is converted into pyrolysis gas and then, through a process of reshaping, converted into hydrogen.

In electrolysis, by contrast, water (H_2O) is broken down into its constituent parts, hydrogen (H_2) and oxygen (O_2). Accordingly, if the electricity comes from renewable sources the hydrogen is environmentally-neutral.

The challenges involved in expanding this fuel option lie in the fuel logistics, in storage the product without incurring losses, and in cost reduction. As regards the engine, two concepts are available: the combustion engine and the fuel cell. Both are currently operating in tests under live conditions. For use in the combustion engine, the hydrogen needs to be converted into fluid by cooling it down to -253°C . By contrast, with fuel cells, the hydrogen is compressed, hitherto using the pressure levels 350 bar and 700 bar. In the opposite process to electrolysis, fuel cells convert hydrogen and oxygen into water. Using the energy of the hydrogen, the fuel cell produces electricity and heat, driving the vehicle by using an electric motor. Fuel-cell vehicles are particularly low in emissions and in the noise level generated.

Both the cooling and the compression of the hydrogen are expensive in terms of cost and energy; they also require their own transport infrastructure and fuel-station infrastructure. By contrast, questions of safety and of comfort are by now deemed to be solved. Tanking-up is easy and is completed in just a few minutes. Compared to pure electrical drives, fuel-cell vehicles even have advantages in terms of range. Yet up to now vehicle manufacturers in Europe are not yet offering any vehicles produced in series.

Hydrogen's future remains uncertain. What is certain is that its manufacture for use in sustainable provision of energy must be based on self-regenerating sources.

5.5 Biofuels from algae

Microalgae are a still comparatively distant option for generation of biofuel but a particularly interesting one. A favourable factor is these water organisms' enormous potential for biomass formation; per unit of area, the yields can theoretically be 30 times the current yield of rapeseed. Algae production would also be largely independent of agricultural areas. Yet the disadvantage is a level of economic viability that remains low: the kilo price for algae oils is above € 10, while plant oils and other biomass resources are available for less than € 1 per kilo.

Of the circa 300,000 varieties in the world, up to now only a fraction has been researched. Above all, it is those species from which oils can be extracted that are deemed as highly-promising. The technologies for their further processing are familiar, whether it is via esterification to form biodiesel or the production of hydrocarbons (see Chapters: 'Biodiesel' and 'HVO'). Ethanol, methane or hydrogen sourced from algae would also be conceivable.

Above all, the challenge consists in selecting from the many algae varieties the one best suited for commercial use, and to further optimise its cultivation, because this is where the high costs emerge. In principle, open and closed systems of cultivation are the respective options. So-called "open ponds" are open receptacles that have hitherto dominated use because of lower costs of acquisition. However, optimum growth of the algae and the degree of incidence of de-



Algae-cultivation facility consisting of plastic tubes

sired properties require special conditions that can only to a limited degree be created in open ponds. That is why photobioreactors were developed. These are closed systems consisting of a network of glass pipes or transparent plastic tubes. They make it possible to increase yields of light and also to optimise supply of CO₂ and nutrients.

Constant levels of light and temperature provide the best starting conditions for good growth of algae, so Central Europe is not an optimum location. Yet it is particularly in the industrial countries that operators of coal-fired, gas-fired or recycled-material-fired power stations are hoping to improve their CO₂ performance by directing the power stations' smoke gases into neighbouring facilities for algae cultivation. There the algae convert this environmentally-harmful gas into carbon compounds – a win-win situation for power-station operators, for cultivators of algae and for the environment.

Yet at present a great deal of research remains to be done on all aspects of algae production.

6 FUTURE PROSPECTS

So what force will drive us in the future? At present this question cannot be answered without some ifs and buts and eludes any standard, off-the-shelf solution. But one thing is sure: the foreseeable increasing shortages of fossil-based resources urgently demand an energy supply that, over the short to medium term, requires less and less petrol, diesel, heavy oil, etc., and over the long term dispenses with them altogether, it must also significantly reduce the emission of environmentally-relevant gases. This presents mobility, today almost exclusively dependent on petrol products, with very specific challenges.

Yet there is no shortage of options for renewable drive concepts – above all, for individual mobility in private cars – and likewise no shortage of engineering know-how for converting these options into realities. Nevertheless some technical hurdles still have to be overcome.

Biofuels offer one prospect for the mobility of the future but absolutely not the only one. Fuels sourced from biomass are not only highly-concentrated energy carriers; they are also the most important alternative form of drive technology today. While many of the new options for drive technology still need some more time to reach the necessary market-readiness, biofuels are already playing a significant role today. They are largely compatible with the current combustion engines and those in the

development stage; they lend themselves to being integrated successively into the market as admixtures to fuels currently in use, stage-by-stage, and they make avail of the existing infrastructure and logistics systems without fundamental adjustments. Biofuels bring their advantages to bear in combination with the combustion engine, above all in those applications for which alternative solutions demand a much higher commitment of resources. This can have a certain role to play in the electrically-powered car – e. g. in the form of the Range Extender. Yet what this primarily refers to is all those areas of mobility that demand large quantities of energy over longer periods, without being able to make avail of infrastructural support, in the form of conductor rails, battery-charging stations etc. Above all, this includes agriculture and forestry, demanding the maximum of performance from their tractors and working machinery out on active service. Here it is worth recalling the vast amount of energy used by aircraft, especially for the initial thrust at take-off. Yet the prospect is that biofuels can also drive ships' engines and the transportation of goods on the roads.

Primarily in these segments, biofuels are in a position to replace fossil fuels in the future and to assume a significant position both in Germany and globally. The potential for this is readily to hand; after all, alongside economic costs many other factors – not least societal acceptance – determine



which concepts establish themselves in which segments.

Biofuels need biomass for their manufacture. Therefore, in the long term they will only be able to prove their worth in one way: if, on a lasting and secured basis, biofuels can plausibly defuse the competition for land areas used for its production, because biomass is especially likely to find itself competing against food production.

In this context, biofuels' competition among one another advances those concepts that can be implemented with the minimum resource commitment in terms of area and energy. This competition also lends support to the search for solutions that are particularly sparing on the environment and make the largest greenhouse-gas savings. On these issues, the approaches described in the brochure exhibit significant differences in some respects. It also holds true, especially for this reason, that biofuels are not good or bad per se.

Research and development efforts face the challenge of attaining the necessary improvements in biofuels' energy efficiency while simultaneously minimising the emission of pollutants. This is not solely an engine-related matter, and focus also continues to be directed on the following: the whole chain of activities involving the cultivation of energy plants; making other recycled materials and waste materials useful; logistics, and concepts for powering vehicle engines.

The matter in hand is to exercise due care in producing the next stage of strategic guidelines for the development both of alternative mobility concepts in general and also of biofuels in particular. In doing this, there is a need to keep in view the challenges of global nutrition, but also the requirements of our highly-developed economic systems, greatly dependent on mobility that has a future. Biofuels offer usable solutions to meet this need.

7 MORE DETAILED INFORMATION

Information from the Fachagentur Nachwachsende Rohstoffe e.V. (FNR) at
<http://biokraftstoffe.fnr.de>

Other information

Agentur für Erneuerbare Energien (AEE):
www.unendlich-viel-energie.de

Bundesministerium für Ernährung und Landwirtschaft (BMEL):
www.bmel.de

Bundesministerium für Wirtschaft und Energie (BMWi):
www.bmwi.de

Bundesverband der deutschen Bioethanolwirtschaft e.V. (BDBe):
www.bdbe.de

Clean Energy Partnership (CEP):
www.cleanenergypartnership.de

Deutsches Biomasseforschungszentrum gGmbH (DBFZ):
www.dbfz.de

Karlsruher Institut für Technologie (KIT) – bioliq-Verfahren:
www.bioliq.de

Technologie- und Förderzentrum TFZ:
www.tfz.bayern.de

Union zur Förderung von Oel- und Proteinpflanzen e.V. (UFOP):
www.ufop.de

Verband der Deutschen Biokraftstoffindustrie e.V. (VDB):
www.biokraftstoffverband.de

Verband der ölsaatenverarbeitenden Industrie in Deutschland e.V. (OVID):
www.ovid-verband.de

Fachagentur Nachhaltige Rohstoffe e. V. (FNR)
Agency for Renewable Resources
OT Gülzow, Hofplatz 1
18276 Gülzow-Prüzen
Tel.: +49 3843/6930-0
Fax: +49 3843/6930-102
info@fnr.de
www.fnr.de

Printed on 100 % recycling paper
using vegetable oil-based colours

Order no. 230
FNR 2016