FOCUS

PLANTS FOR POWER

Both food and fuel: while grains of barley and other cereals are regularly processed into food, the leftover straw or stubble can also be used to produce second-generation biofuels.

PHOTO: ISTOCK

FUEL FROM STRAW AND STUBBLE

TEXT: RALPH DIERMANN

Second generation biofuels could solve the food versus fuel conflict, because the energy crops involved do not need to be cultivated on arable land specifically reserved for them, which would then no longer be available for food production. Researchers around the world, including Ferdi Schüth, Director at the Max Planck Institute für Kohlenforschung, and Walter Leitner, Director at the Max Planck Institute for Chemical Energy Conversion, are working on the production of both economically viable and low-emission biofuels.

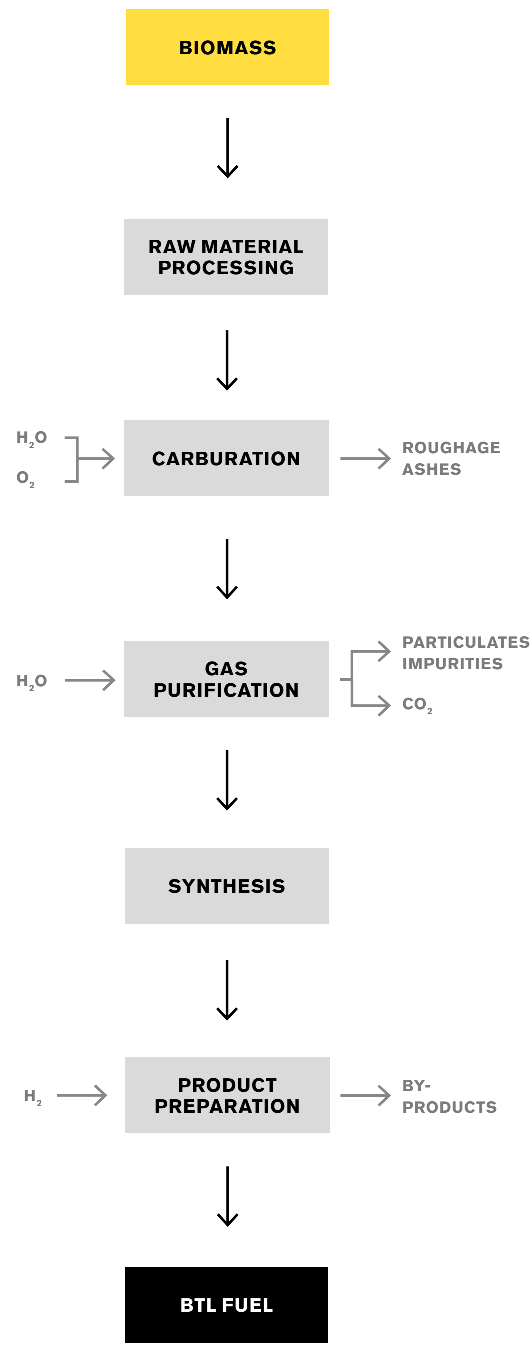
It took nature millions of years to create the raw material that allows us almost unrestricted mobility, namely crude oil formed from dead marine organisms buried under sedimentary rock where they were exposed to high pressure and high temperature over a vast period. So fuels, such as gasoline or diesel, are like a greeting from the deep history of the Earth.

But this process can also be accelerated: refineries are producing high-quality biofuels that are similar to gasoline and diesel from rapeseed, cereals, corn, sugar beet and sugarcane. These fuels can therefore be used in contemporary combustion engines without having to fundamentally change the engines. Biofuels can be distributed via the existing network of gas stations. Because their energy density is almost as high as that of fossil fuels, motorists can get about the same number of miles to the gallon. But, above all, they are much more climate-friendly than their fossil fuel counterparts, because the combustion process within the engine only releases the same amount of carbon dioxide as the plants had previously sequestered. Yet biofuels are by no means climate-neutral, because the cultivation and processing of the crops produces greenhouse gases.

Biopetroleum for fuel and chemical raw materials

Those of us currently filling our tanks with alternative fuels, such as biodiesel or bioethanol – whether in a pure form or as an admixture to gasoline (“E10”) or diesel – are filling them with so-called first-generation biofuels made from grain or seeds. What this means, however, is that these biofuels stand in direct competition with food production. Rapeseed, for example, can be used to produce both a fuel and a healthy edible oil. According to the Agency for Renewable Resources (Fachagentur Nachwachsende Rohstoffe – FNR), 800,000 hectares of energy crops are currently being cultivated for fuel in Germany, which corresponds to seven percent of the country’s total arable land. Given the continuously expanding global population and the scarcity of agriculturally usable land around the world, the production of first-generation biofuels is resulting in a so-called fuel-food conflict, a good reason for researchers around the world, including scientists at various Max Planck Institutes, to be working on biofuels that can be produced from other organic materials that are not suitable as foodstuffs. The objective is to defuse the fuel-food conflict by expanding the biomass supply for climate-friendly fuels, whereby the researchers are planning to use as many biomass components as possible. Their current focus is on lignocellulose,

FUEL FROM BIOMASS



Biomass is crushed and dried to obtain liquid fuels from straw or waste wood. With the aid of oxygen, it is then converted into synthesis gas, which primarily consists of carbon monoxide and hydrogen. After removing any impurities, the synthesis process produces liquid hydrocarbons which can then be used as fuels.

PHOTO: FRANK VINKEN | DWB

Sawdust as a raw material: wood mainly consists of lignocellulose, from which both biofuel and raw materials for the chemical industry can be derived.

which forms the structural framework of plants and consists of cellulose, hemicellulose and lignin. Its high proportion of carbon and hydrogen makes it an attractive raw material for alternatives to gasoline and diesel, which are nothing more than hydrocarbons. However, it can also be used to produce the substances from which chemical products, such as plastics, can be made. Either straw or agricultural waste can be used as raw material for both applications. Theoretically, the straw (or stubble) alone that is leftover in Germany each year could cover up to three percent of the country's primary energy demand.

Second generation biofuels can be produced in various ways. In the so-called Biomass to Liquids (BtL) process, the biomass is first subjected to heat to produce a synthesis gas consisting mainly of hydrogen and carbon monoxide, but which also includes sulfur and nitrogen compounds (the latter have to be removed, because they hinder further processing). The synthesis gas is then processed to form liquid hydrocarbons, for example by using the Fischer-Tropsch process, which was developed almost a hundred years ago to liquefy coal. Crude oil refinement processes are then used to transform the resulting mixture of various hydrocarbons into biofuels. "This process," explains Ferdi Schüth, Director at the Max Planck Institute für Kohlenforschung in Muelheim an der Ruhr in Germany, "makes it possible to produce so-called drop-in fuels, which can be used in modern combustion engines with no issues." The BtL process is also suitable for almost any type of biomass.

The process does, however, pose a logistical challenge: due to its relatively low energy content as measured by volume, enormous amounts of biomass are required to keep a production plant running at full capacity. This requires countless truck deliveries to

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Mixing makes all the difference: Ferdi Schüth and his team are working on making biofuels more competitive. In the laboratory, the researchers are searching for ways to use biomass not only to produce fuel but also costly raw materials for the chemical industry.

PHOTO: ANSGAR PUDENZ

bring sufficient straw and other biomass from the field to the production plant. This problem can be solved through a spatially separated pyrolysis process carried out upstream of the synthesis processes. Among other things, a so-called pyrolysis or bio-oil, consisting of various oxygenated organic compounds and water, is produced; which contains around three quarters of the energy content of the biomass, with a significantly reduced volume. "The bio-oil," Schüth explains, "is then transported by tanker or train to the BtL plant, where it is processed in the standard manner." However, this detour via the pyrolysis production process is not only attractive in terms of logistics; it also enables refineries to use the bio-oil to produce other chemical raw materials in addition to fuels.

SUMMARY

Whereas biofuels from plant waste such as straw do not compete with food production, they are still too expensive.

Biofuels are already being produced in pilot plants using either the biomass-to-liquids process or enzyms, and could cover around one tenth of the global energy demand for transport.

Max Planck researchers are attempting to make the use of lignocellulose more profitable, by using it to produce not only fuels but also rather costly basic materials for the chemical industry among other things.

Altering their molecular composition can reduce both soot and nitrogen oxide emissions from biofuels. In the case of fossil fuels, the emissions of either one of these pollutants can only be reduced at the cost of increasing the emissions of the other.

Enzymatic processes offer an alternative to the BtL concept. "These involve breaking down the biomass following a mechanical pre-treatment with the aid of special enzymes," Schüth explains. The challenge is to separate the lignin from the cellulose and hemicellulose, the latter of which can be fermented into ethanol. Biomass can also be chemically converted as an alternative to the enzymatic process, which enables the production of a wider range of potential fuel components, such as furan derivatives. One of the benefits of ethanol and furans is that they burn more cleanly than such things as BtL fuels.

According to a study by the German Environment Agency (UBA), second-generation biofuels could provide between 13 and 19 exajoules of energy globally by 2050. This is still far from enough to cover the entire mobility energy requirement, which the UBA estimates will be between 100 to 179 exajoules worldwide by 2050. However, in terms of climate protection within the transport system, they are a necessary adjunct to electric vehicles and other alternative fuels.

Work on biofuels by researchers in science and industry has already come a long way: major proof of concept plants for both BtL and enzymatic processes demonstrate that, from a technical perspective, these processes work well in principle. Yet the high costs involved are still an issue. "Currently," says Schüth, "all of these processes are still far too expensive for large-scale commercial use."

The purification of the synthesis gas from sulfur and nitrogen compounds in the BtL process, for example, is what drives up the cost. In the enzymatic processes, which themselves are anything but trivial, it is the enzymes in particular that are costly. The same applies to the chemically-based decomposition of biomass. Nor is the integration of these enzymatic and chemical processes into existing biorefinery processes particularly easy. "The main thing we need in this context," Schüth explains, "is to find the optimum balance between the production of fuel and chemical products."

So there is still a lot to be done by science and industry experts as well as researchers at the Max Planck Institutes, some of whom have been researching biofuels for many years. The Max Planck Institute für Kohlenforschung, for instance, is currently working on synthesis methods for refining bio-oil produced by biomass pyrolysis. "We want to help refineries to be able to produce rather costly chemical raw materials and fuels from bio-oil in the right ratio in an economically viable manner," says Schüth. In addition to water, bio-oil contains various compounds of carbon, hydrogen and oxygen, such as carboxylic acids, aldehydes and phenols. Processing the bio-oil into fuels and chemical raw materials requires the targeted removal of individual oxygen atoms from the compounds, which is where the Max Planck researchers come in: they are trying to find catalysts that enable such a selective deoxygenation, while minimizing the energy needed to achieve it.

Fewer pollutants

Researchers at the Institute have also developed a novel mechanochemical process which involves grinding cellulose in a ball mill to break it down. This process is faster than conventional methods and generates fewer worthless by-products. "However," Schüth cautions, "we have to be honest about the fact that nobody could currently apply this process in a commercial setting given the current market situation."

If the biopolymers are first split from the biomass and then assembled almost at will into new molecules for the production of second-generation biofuels, then it may also be possible to tackle another problem for which road traffic is repeatedly criticized, apart from its poor CO_2 performance, which is the pollu- →

tion mainly of city centers primarily with particulates and nitrogen oxides. This is because the BtL process could potentially be designed to produce a low-emission fuel.

Researchers at a cluster of excellence at RWTH Aachen University known as The Fuel Science Center, in which the Max Planck Institutes für Kohlenforschung and for Chemical Energy Conversion and the Forschungszentrum Jülich are involved, are pursuing this basic concept. The researchers are particularly interested in the soot-NOx conflict, which is a problem with all fuels derived from pure hydrocarbons, whether fossil or renewable. The term refers to a conflict of objectives during combustion: the less oxygen is present during combustion, the more soot is produced in the form of harmful particulates. However, the more oxygen is present, the more nitrogen oxides (NOx) the engine emits. "What this means," explains Walter Leitner, Director at the Max Planck Institute for Chemical Energy Conversion in Muelheim an der Ruhr, "is that the levels of either one or the other pollutant is increased in the exhaust gas."

Scientists at the Fuel Science Center have therefore modified the molecular composition of alternative fuels to reduce both soot and NOx emissions. "We've more or less tailored these fuels to reduce emissions," says Leitner. Not only are the researchers working with bio-based fuels, but also with synthetic, electrically-based fuels. This fuel, which is also known as e-fuel, is made of carbon dioxide and hydrogen, which is produced through electrolysis using electricity from wind turbines, photovoltaic plants or hydroelectric power stations. With fuels such as these, drivers do not have to sacrifice engine efficiency. "Their molecular composition," the researcher explains, "can even be beneficial, for example by increasing knock resistance and thus engine performance."

Yet the Cluster of Excellence's focus is not only on fuels, but also on engines. "Our colleagues from the engineering sciences are modifying traditional gasoline and diesel engines to make the best possible use of the benefits of the optimized fuels, in terms of both emissions and performance," Leitner explains. The researchers are working, for example, on engines fed by different fuels from two tanks, one of which contains a fuel that ignites particularly quickly therefore optimizing the combustion process, whilst the other supplies the actual operational fuel. But such conceptual engines are still far from being ready for series production. "This is not least due to the fact that the automotive industry is currently putting a lot of focus on other technologies," says Leitner.

It is quite possible that this may change if policymakers were to create the framework conditions to make this type of innovative engine concept more attractive to the automotive industry. The same applies to the use of fuels from renewable sources. "They will only win out if the market rewards their use," as Ferdi Schüth of the Max Planck Institute für Kohlenforschung explains: "And that requires a new course from politicians."

It is true that the Bundesimmissionsschutzgesetz (German Federal Immission Control Act) already provides an incentive to bring eco-fuel to the gas pumps, as it obliges the fuel industry to continuously reduce the CO_2 emissions of its products. However, to meet this requirement, the companies primarily mix first-generation biofuels, which are significantly cheaper than those made of cellulose, with gasoline and diesel. This is primarily because the industry has been producing fuels from grains and seeds such as rapeseed or sugar cane on an industrial scale over a long period, which keeps costs down in spite of the expensive raw materials.

To bring second-generation biofuels to market, demand must be stimulated to make it worthwhile for the industry to build up the requisite production capacities, as the greater the production volumes, the lower the costs will be. But at least the EU stipulated in the most recent version of the Renewable Energy Directive 2009/28/EC that the proportion of "advanced biofuels in the transport sector" – meaning all fuels made of biological waste and residual materials – should be at least one percent by 2025 and at least 3.5 percent by 2030. With a view to possible land use conflicts, the EU has limited the proportion of first-generation biofuels to seven percent. Yet because second-generation biofuels may be counted twice, the actual maximum target for these is only half as high.

"A CO_2 tax on fossil fuels could help to negate their current cost advantage."

FERDI SCHÜTH

However, rather than a quota, Schüth and his research colleague Leitner prefer a different instrument, namely CO_2 pricing. “An appropriately priced CO_2 tax on fossil fuels could help to ensure that they lose their current cost advantage over more climate-friendly alternatives,” says Schüth. Leitner, however, points out that this would only apply if blending bio-based or even synthetic, electrically-based fuels is recognized as an emission-reducing measure, “which,” says Leitner, “is not yet the case under current EU regulations. There is an urgent need for action in connection with the forthcoming amendment, so that not only CO_2 emissions from engines, but also CO_2 binding during production are taken account of. Initially,” he continues, “biofuels and e-fuels do use CO_2 to enable the utilization of renewable energy. They are, so to speak, putting sunshine in the tank.”

https://www.mpg.de/podcasts/biooekonomie (in German)

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GLOSSARY

BIOMASS-TO-LIQUIDS PROCESS (BTL)
This term refers to the thermochemical processes by which biomass is converted into liquid fuels. A synthesis gas, i.e., a mixture of carbon monoxide and hydrogen, is first produced from the biomass. This is then used to produce liquid hydrocarbons, for example using the Fischer-Tropsch synthesis process.

FISCHER-TROPSCH SYNTHESIS
Originally, this process was developed to produce liquid fuels from coal, but it can also be applied to biomass. The process involves the synthesis of liquid hydrocarbons from carbon monoxide and hydrogen, which are obtained from the solid raw material.

LIGNOCELLULOSE
Lignocellulose is the structural material of plants and consists of the polysaccharides cellulose and hemicellulose as well as lignin, a complex biopolymer.

An alternative to the alternative: as Walter Leitner sees it, biomass is not the only source of climate-neutral fuels. He is also making progress with the conversion of CO_2 and hydrogen from renewable sources into hydrocarbons and other chemical products.

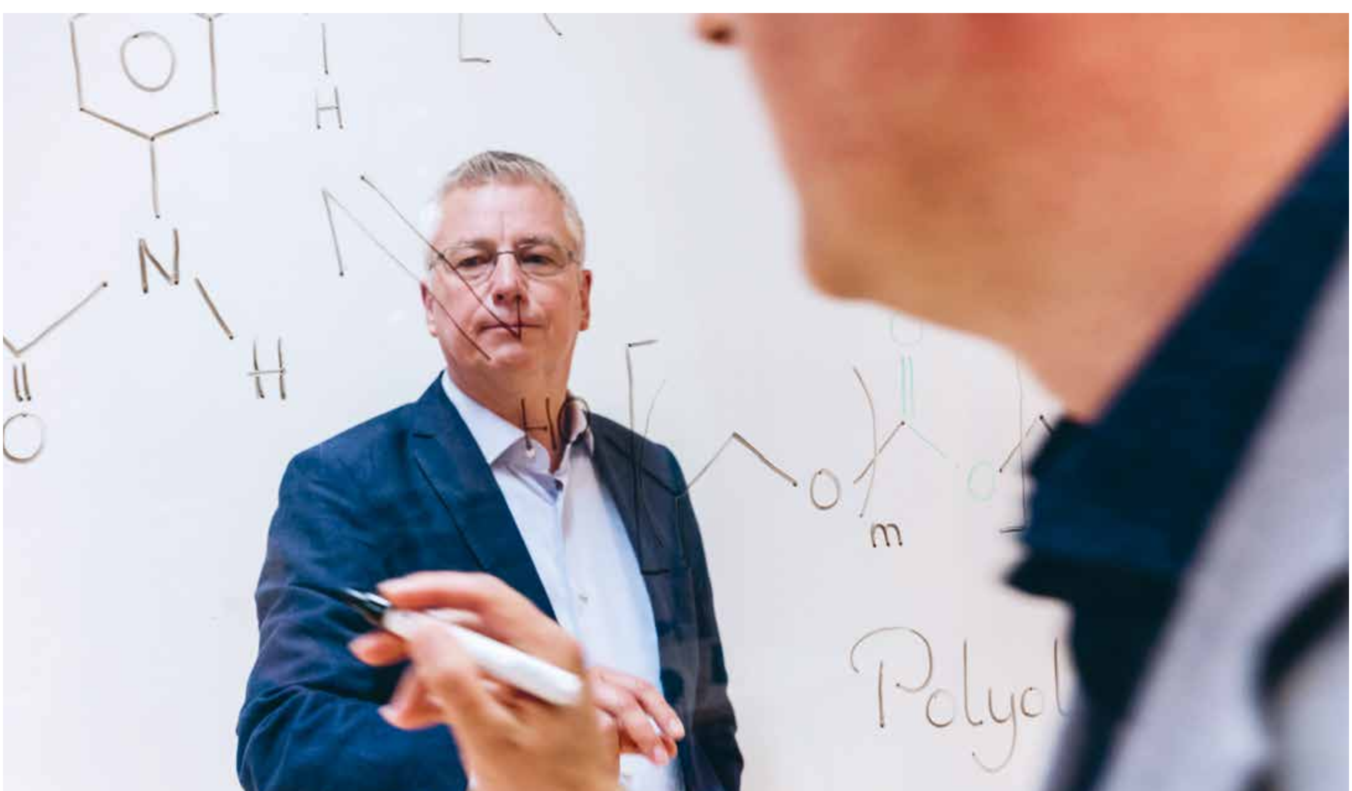

PHOTO: ANSGAR PUDENZ