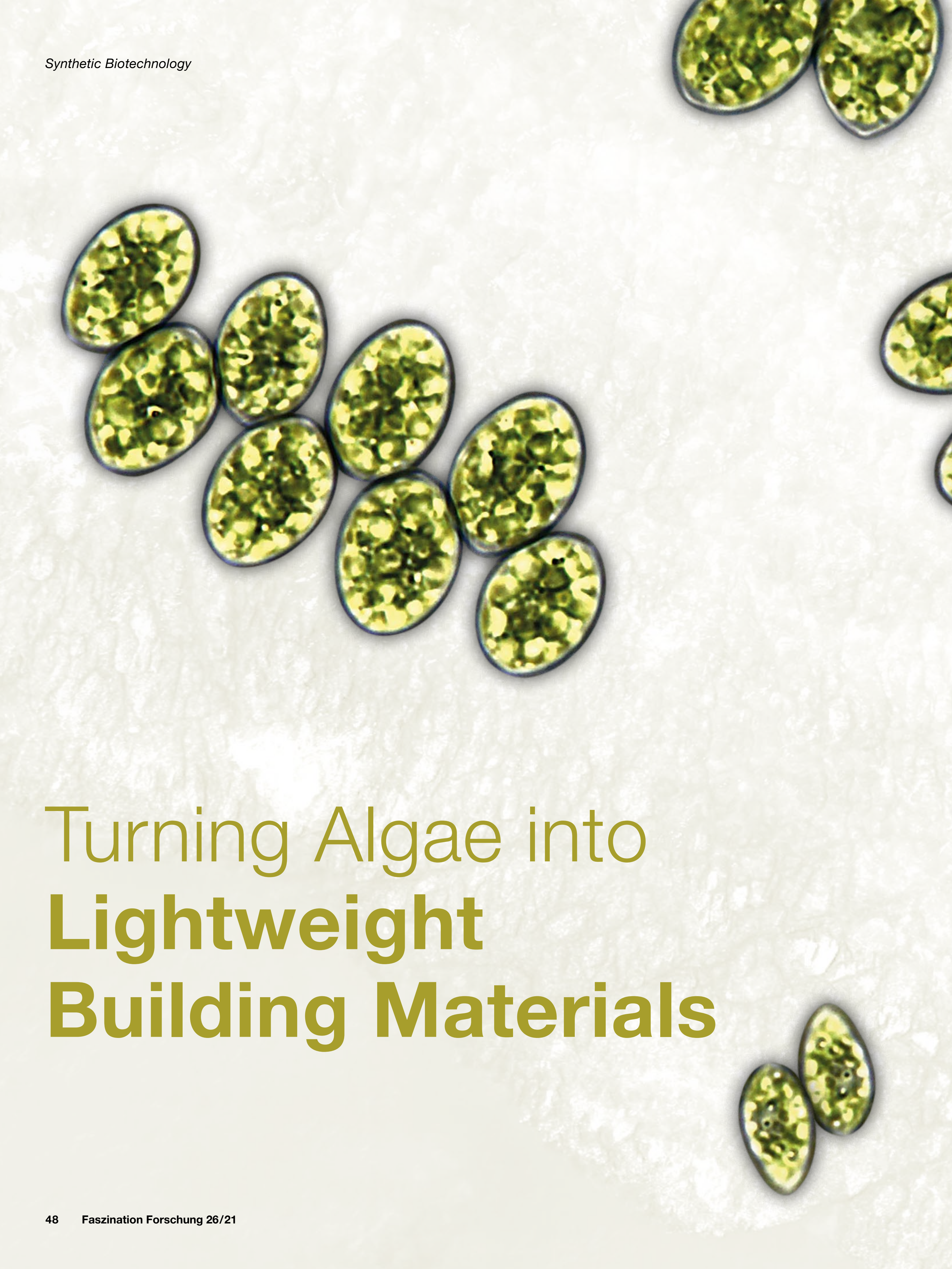
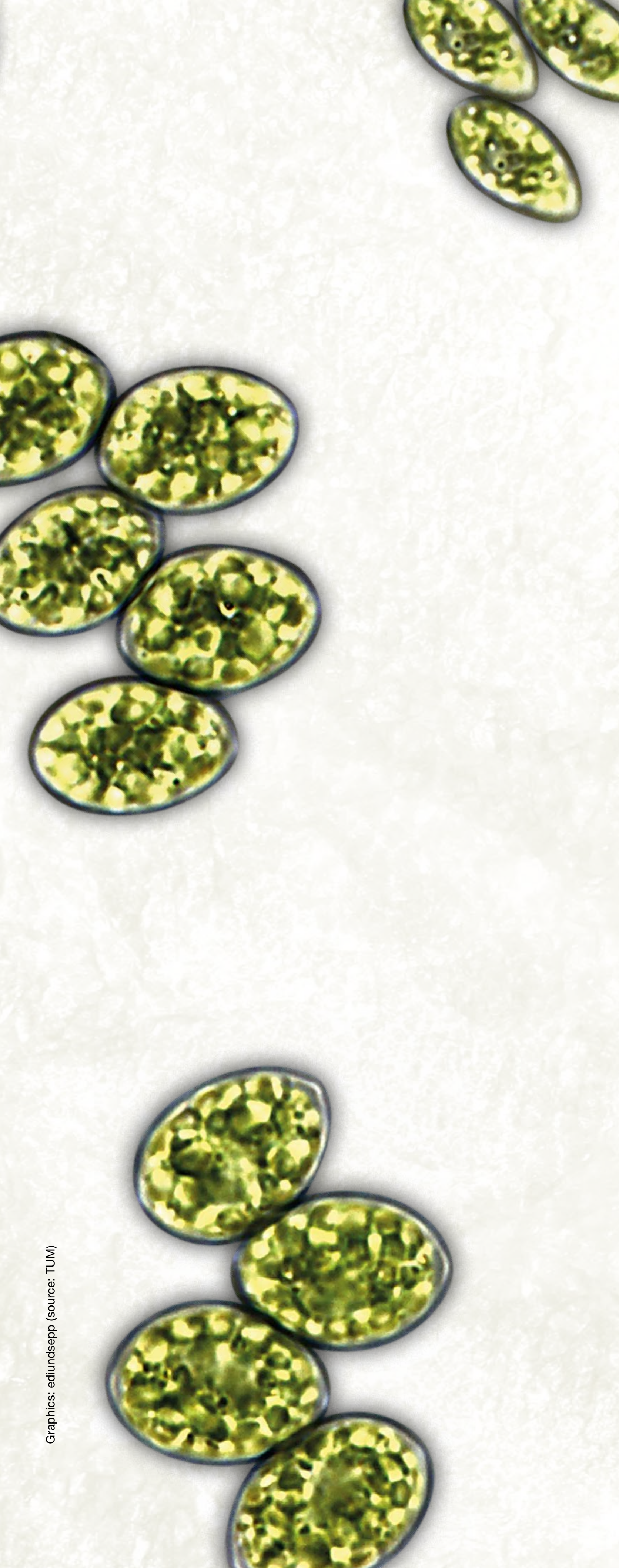


Turning Algae into **Lightweight Building Materials**



Graphics: ediundsepp (source: TUM)

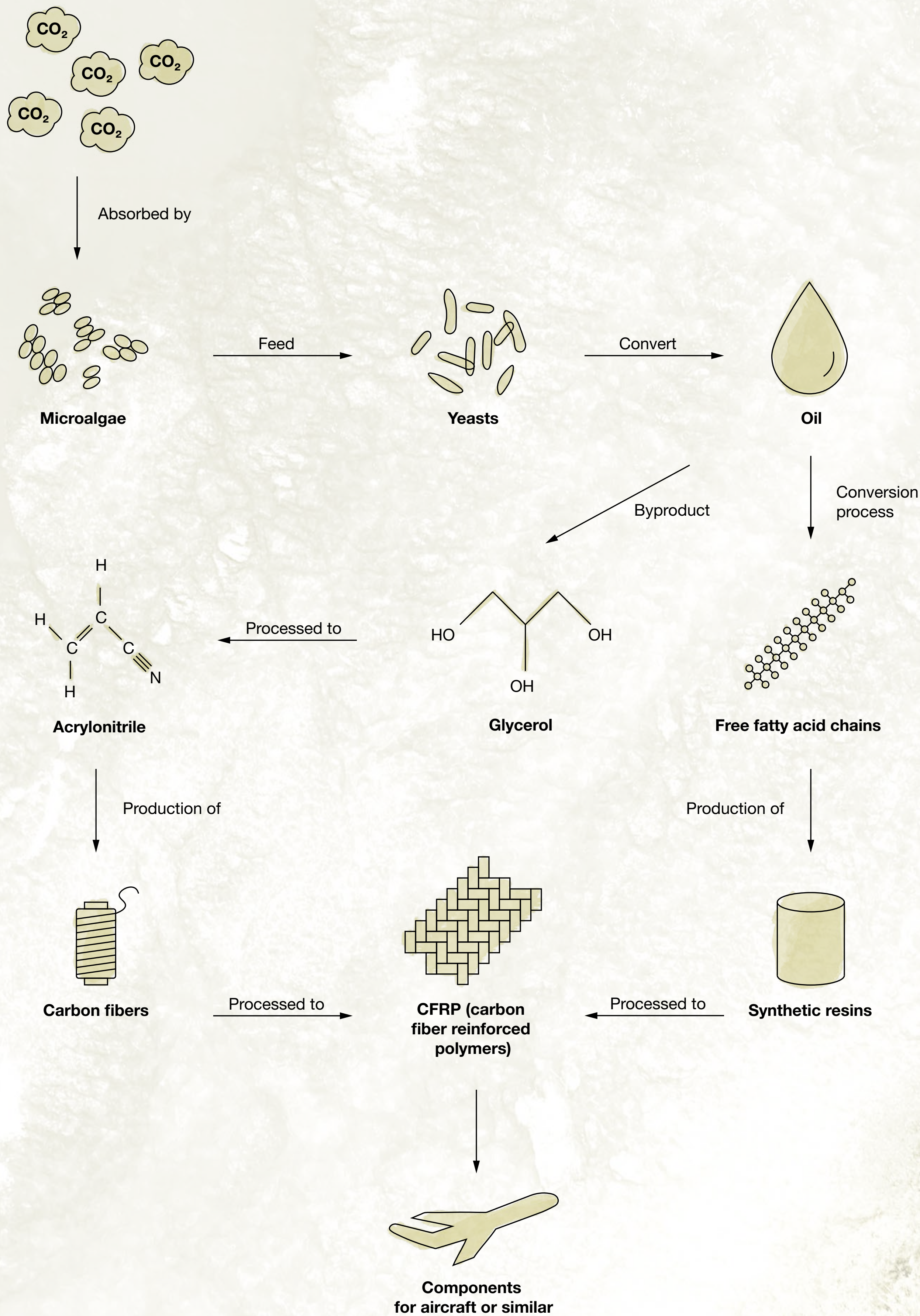
Carbon-fiber components are very light and extremely strong. At present they are manufactured from oil. In a project by the name of Green Carbon, the Werner Siemens Chair of Synthetic Biotechnology at TUM is now working with partner businesses to manufacture sustainable carbon fiber drawing on algae and yeast. A key focus is on scaling up the technology for industrial use.

Kurzfassung · Langfassung: www.tum.de/faszination-forschung-26

Freunde zu Verbündeten gemacht D

Leichte Bauteile aus Carbonfaser-Verbundwerkstoffen werden normalerweise aus Erdöl hergestellt. Der TUM Biotechnologe Prof. Thomas Brück arbeitet im Projekt Green Carbon jetzt daran, die benötigten Rohstoffe erstmals gänzlich aus Algen und Hefen zu gewinnen. In einem an der TUM entwickelten Prozess werden Algen gezüchtet, deren Biomasse anschließend an spezielle Hefen verfüttert wird, die Öl produzieren. Das Öl wird dann in seine Bestandteile aufgespalten – in Glycerin und lange Fettsäureketten. Das Projekt Green Carbon nutzt beide für die Herstellung von grünen Carbonfaserverbunden. Das Glycerin wird in den Werkstoff Acrylnitril gewandelt, aus dem Carbonfasern hergestellt werden. Die Fettsäuren werden zu Kunststoffharzen verarbeitet, mit denen die Carbonfasern zu einem Bauteil verklebt werden. Ferner werden im Projekt Green Carbon erstmals dünne Schichten aus Carbonfaserverbunden mit dünnen Lagen aus Stein kombiniert. Diese leichten und sehr stabilen Carbonfasersteinkomposite eignen sich insbesondere für den Hausbau. Sie können beispielsweise schwere Stahlträger ersetzen. □

Link
www.department.ch.tum.de/wssb


CO2
Absorbed by
Microalgae
Feed
Yeasts
Convert
Oil
Byproduct
Conversion process
H
H
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N
H
Processed to
HO
OH
OH
Acrylonitrile
Glycerol
Free fatty acid chains
Production of
Production of
Carbon fibers
Processed to
CFRP (carbon fiber reinforced polymers)
Processed to
Synthetic resins
Components for aircraft or similar

Sometimes research projects take surprising turns. Especially when you're not afraid to strike out in new, sometimes speculative directions. When Prof. Thomas Brück started cultivating algae seven years ago, his aim was to use them to produce high-quality aviation biofuel. His plan was based on an audacious-sounding idea. The idea was to cultivate algae and use the algal biomass as food for special oil-producing (oleaginous) yeast. The oil produced by the yeast would then be processed into aviation biofuel. So, over the next few years, on TUM's Ottobrunn campus he built what amounted to a high-tech greenhouse for growing algae in large tanks. The greenhouse was lit by a unique lighting system that mimicked sunlight in different geographical regions and climate zones. His experiments proved highly successful. After a lengthy series of tests, Brück and his team succeeded in determining the ideal growing conditions for both algae and yeast. "We developed a process in which the oleaginous yeast convert algal biomass into oil in four to five days," explains Brück. "We were then able to process the oil to produce high-quality aviation fuel."

Glycerol as feedstock

Algae absorb carbon dioxide from the atmosphere and process it to produce a biomass rich in energy-dense sugars. The yeast converts this biomass into oil. It's an extremely sustainable process. Brück could have left it at that, but there was one thing that bothered him. The process of turning the oil into aviation fuel produced a byproduct – glycerol. If the oil industry really were to one day start producing aviation biofuel at scale, Brück realized that this would result in the production of huge amounts of glycerol. Every ton of biofuel produced also yields around 100 kg of glycerol. "But there just isn't any demand for that much glycerol," he says. "Glycerol is used in the cosmetics and pharmaceutical industries, but by no means in the kind of quantities that would be produced by large-scale aviation biofuel production." So what to do with all that excess glycerol? Thomas Brück, who holds the Werner Siemens Chair of Synthetic Biotechnology, came up with a brilliant idea. Via a short series of chemical reactions, glycerol can be transformed into acrylonitrile – an extremely useful chemical compound that happens to be utilized in making carbon fibers. They are a material with a very bright future. Processing these fibers with synthetic resins produces very durable, very lightweight carbon fiber reinforced polymers (CFRP) – more commonly known simply as carbon fiber. The process has been around for some years. CFRPs are used in particular for manufacturing wind turbine blades and in aviation – the Airbus A350, for example, is more than 50 percent CFRP. Thanks to lightweight CFRP, aircraft fuel consumption is significantly reduced. It would take 9.7 tons of glycerol to make one ton of carbon fibers. ▷

"The result [of this process] is 100% biologically produced carbon fiber composites entirely from CO_2."

Thomas Brück

Graphics: ediundsepp

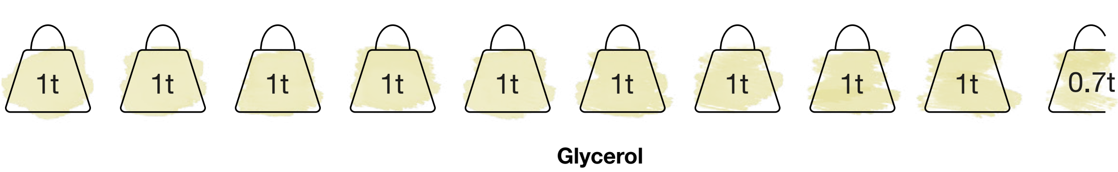
100% green components

Brück has since largely moved on from his original idea of producing aviation fuel to focus almost completely on CFRP. That's because it's not just the glycerol that can be used for this purpose – it's all of the oil produced by the yeast. This oil consists of fatty acid chains attached to a glycerol molecule like long pieces of string. The fatty acids can be separated from the glycerol chemically. Thomas Brück's original plan was to use these fatty acids to produce aviation fuel. “But fatty acids can also be chemically modified and made into plastics,” he says. “For example, the synthetic resins involved in manufacturing carbon fiber reinforced polymers.” So Brück's algae can, via the medium of oleaginous yeasts, not only be used to produce carbon fibers, but also the resins needed to produce CFRP. “The result is 100% biologically produced carbon fiber composites entirely from CO_2.” To be able to produce green, and in particular economically viable CFRP on an industrial scale, generously dimensioned algae farms would be required. Such farms would be best built in sunny Mediterranean regions. Brück estimates that these algae farms would need to cover an area of at least four square kilometers.

EUR 12 million grant for the industrial-scale Green Carbon project

The Green Carbon project is paving the way to industrial-scale production. Working with industry partners, Brück will further develop the process for producing carbon fiber components from algae until it is ready for mature industrial processes. The project has received a EUR 12 million

Laboratory scaling of algae cultivation in closed photobioreactors. The technical data generated here are the basis for the next process scale-up steps at the TUM AlgaeTech Center in Ottobrunn.

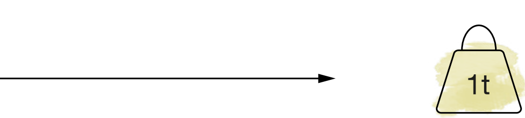


grant from the German Federal Ministry of Education and Research. The carbon fiber manufacturer SGL Carbon is also on board and will contribute its CFRP expertise. “The acrylonitrile we make from glycerol is the same molecule that’s normally produced from oil – which means it’s the same quality,” explains Brück.

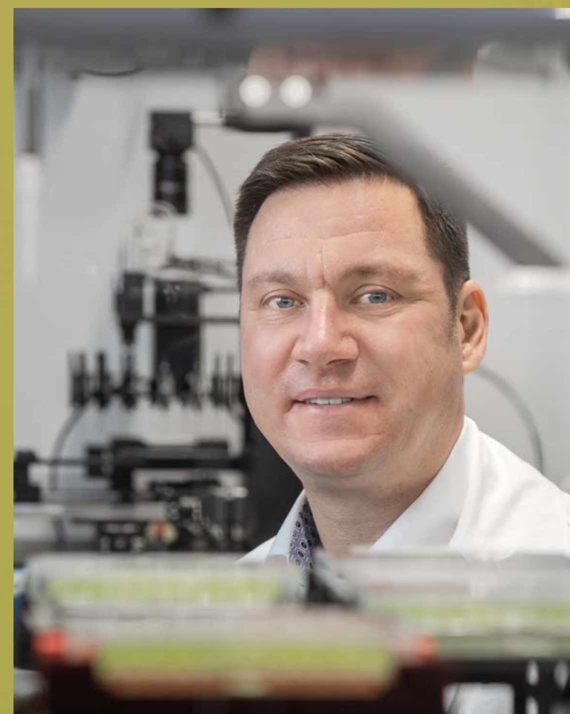
For the process to make the leap from university project to real-life application, from pilot project size to industrial scale, the facilities have to be bigger and process higher volumes of biomass – at least 50,000 to 100,000 times bigger. Consequently, one of the companies partnering in the Green Carbon project is consulting firm AHP. Their experts use computer models to analyze mass flow rates in industrial plants, as well as energy and space requirements. Their calculations are important when it comes to seeking finance for any future system. ▷

Picture credit: Andreas Heddergott; Graphics: ediundsepp

The next step in algae biotechnology developments. Accelerating selection of the best oil-producing algae strains using a robotic screening platform at the Werner Siemens Chair for Synthetic Biotechnology.



Carbon fibers



Prof. Thomas Brück

The practical relevance of his research is very important to Thomas Brück. That’s why he works on interdisciplinary projects involving industrial partners. Born in Cologne in 1972, he took his degree in chemistry, biochemistry and business administration in the UK. He then studied for a masters in molecular medicine at Keele University in Stoke-on-Trent. In 2002 he obtained a PhD from the University of Greenwich for his work on biochemical reactions of important enzymes. In 2006 he returned to Germany, where he moved into industry. In 2010 he was appointed head of the industrial biocatalysis research group at TUM. He has headed the Werner Siemens Chair of Synthetic Biotechnology since 2018.

Building new products from carbon fiber stone

In acknowledgement of his work, Brück has now been honored with the TUM's inaugural Sustainability Award. A while ago, Brück was also contacted by a company called TechnoCarbon Technologies (TCT). They had the surprising idea of combining carbon fiber composites with wafer-thin layers of hard rock such as granite. Initial experiments had demonstrated that the concept works in principle. Working with experts from TCT, Thomas Brück's team used resins produced from algae to bond thin slices of granite just a few millimeters thick with carbon fiber composite strips. This produced an extremely flexible and strong building material. The results were sufficiently promising that TCT has been signed up as a further partner in the Green Carbon project. The company has now manufactured a T-beam made of carbon fibers and Bavarian granite, which is half the weight of a standard steel beam. In house construction such beams are used to support floors. Depending on the applications and the load, carbon fiber stone can reduce the consumption of steel or cement by between one-half and three-quarters. After having the beams evaluated by experts, Brück has now, together with TCT, showcased the technology in a number of international journals. In one report, no less an authority than the Intergovernmental Panel on Climate Change describes carbon fiber stone composites as holding out great promise for reducing industrial CO_2 emissions. “The steel and cement industries are two of the biggest sources of industrial carbon emissions,” explains Thomas Brück. “If we can succeed in establishing carbon fiber stone composites as an alternative material, we could not just neutralize annual carbon emissions from the steel and cement industry, we could actually reverse them.”

Long-term carbon sequestration

The Green Carbon project's key goal is to remove carbon dioxide from the atmosphere, store it permanently in carbon fiber, and in doing so help to arrest climate change. The carbon will be stored in carbon fiber reinforced polymers for cars, aviation or wind turbines, or even in carbon fiber stone composites for buildings. The combustion of coal, natural gas and oil releases around 37 billion tons of carbon dioxide annually. Industrial CFRP production from algae could absorb between one and two billion tons a year – a far from negligible figure. “For me it's about long-term sequestration of atmospheric carbon dioxide. Only then does our process make a genuine contribution to climate protection,” says Thomas Brück. Carbon fiber stone composites could be used in buildings lasting 100 years or indeed far longer.

The lifespan of CFRPs in aircraft and similar applications is shorter, as aircraft and other vehicles are taken out of service much sooner. However, when an aircraft is scrapped after some 25 years, the carbon fibers can be recycled. The fibers can, however, only be recycled two to three times, as the recycling process breaks them and they end up being too short. Brück also has some ideas for solving this issue, adding, “Green carbon fiber components are an extremely sustainable, climate-friendly alternative. It's high time to get them out there in the real world.”

■ *Tim Schröder*

> *“Carbon fiber stone composites as an alternative material to steel and cement could more than neutralize the carbon emissions of that industry.”* Thomas Brück

Graphics: ediundsepp

Removing CO_2 from the atmosphere to store it permanently in carbon fiber is the idea behind green carbon. Green CFRP can be used for aircraft, automobiles or wind turbines, for instance. It can also be further processed into carbon fiber stone, offering a climate-friendly alternative to steel and cement.