PhotoBionicCell

Automated cultivation of biomass

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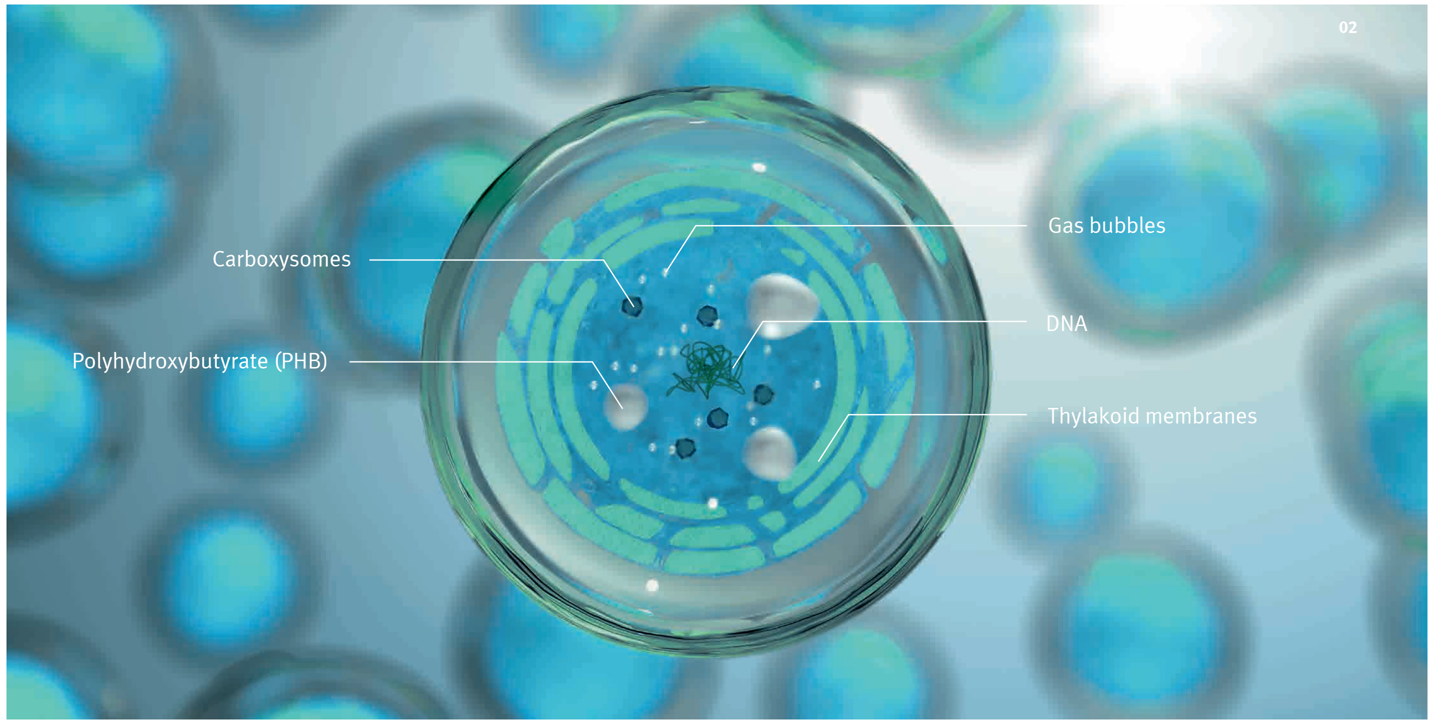
01: **Automated bioreactor:** photosynthesis of algae in a closed circuit

02: **Structure of the algae cell:** extracting PHB for bioplastics



Our world is changing at an unprecedented rate. The global population is growing rapidly and the impacts of climate change are marked. We can only maintain a future worth living if people, the animal kingdom and the plant world live together in harmony. This is why we at Festo believe the bio-economy will be the economic system of the future. We aspire to make a decisive contribution to improving the quality of life of present and future generations – by cultivating biomass on a large scale using our automation technology.

Sustainability thanks to a circular economy
If we can live in a circular manner, innovative spaces pop up from which both people and the environment benefit at the same time.

A circular economy is defined by producing in a carbon-neutral way while using as few resources as possible. The idea behind this is to cultivate living matter as a biological basis in an energy-efficient way so that raw materials can be extracted from it and processed into products. Ultimately, these will be returned to the natural cycle.

At the Festo learning company, we have considered biology to be a source of inspiration and even a teacher for decades. Over the years, our bionics experts have developed a multitude of technological innovations. The PhotoBionicCell research project demonstrates a possible approach for the industrial biologisation of tomorrow.

Efficient photosynthesis in a high-tech bioreactor
Using the bioreactor, algae can be cultivated automatically and their growth controlled. For this purpose, the algae liquid is pumped upwards into the surface collectors, where it is distributed evenly before flowing back into the cultivator. During this circulation loop, the algae's chloroplast cells photosynthesise to convert sunlight, carbon dioxide and water into oxygen and chemical energy sources – or valuable organic matter. As such, the biomass is cultivated in a closed circuit in a highly efficient and resource-saving way. Compared to systems commonly used today, such as open basins and foil bioreactors, over ten times more biomass can be produced with PhotoBionicCell.

Biological recyclable materials for climate-neutral end products
Depending on the nutrients supplied to the algal biomass, fatty acids, colour pigments and surfactants are formed as products of their metabolic processes. These serve as base materials for the production of medicines, foodstuffs, plastics, cosmetics and fuels. Unlike petroleum-based products, bio-based end products usually biodegrade and – in keeping with an overall circular economy – can always be recycled in a climate-neutral manner.

As part of their work on PhotoBionicCell, our researchers focused on cultivating the blue-green algae Synechocystis, which produces colour pigments, omega-3 fatty acids and polyhydroxybutyrate (PHB). The PHB that is extracted can be processed into a filament for 3D printing by adding other substances. Thanks to this modern production technology, complex shapes of sustainable plastic components or packaging can be produced in a short time. As part of PhotoBionicCell, certain grooved mounting pins can be manufactured from this bioplastic.

Intelligent control technology
To create the best possible conditions for the micro-organisms, proven control technology is combined with the latest automation component. A holistic gassing concept ensures that the carbon dioxide extracted from the air is evenly distributed in the circulating biofluid.

Innovative quantum sensor technology
A significant challenge relating to bioreactors is precisely determining the quantity of biomass. To do so, our developers rely on a quantum-technology sensor manufactured by the start-up Q.ANT. This sensor provides precise, real-time information about the organisms' growth. The algae are fed to it automatically and continuously using microfluidics from Festo. The quantum sensor is able to optically detect individual cells so that the amount of biomass can be determined exactly. Moreover, the sensor can investigate the cell vitality. Only then is it possible to react to process events with foresight and to intervene in a regulatory manner.

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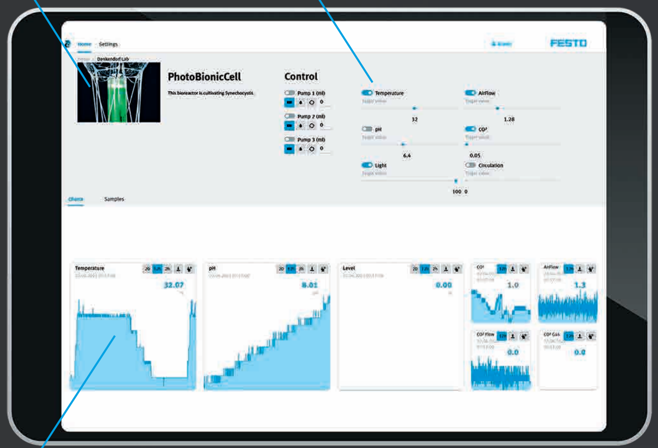
Efficient photosynthesis

Bioreactors that work with algae cells as miniature factories offer considerable potential for a climate-neutral circular economy. Algae living in the water are already extremely efficient in their natural photosynthesis outdoors: they absorb ten times more carbon dioxide (CO_2) than rooted plants. When combined with the right sensor technology, closed-loop control technology and automation, the efficiency of the algae can be increased to one hundred times that of rooted plants. Moreover, they require significantly less space and less water.

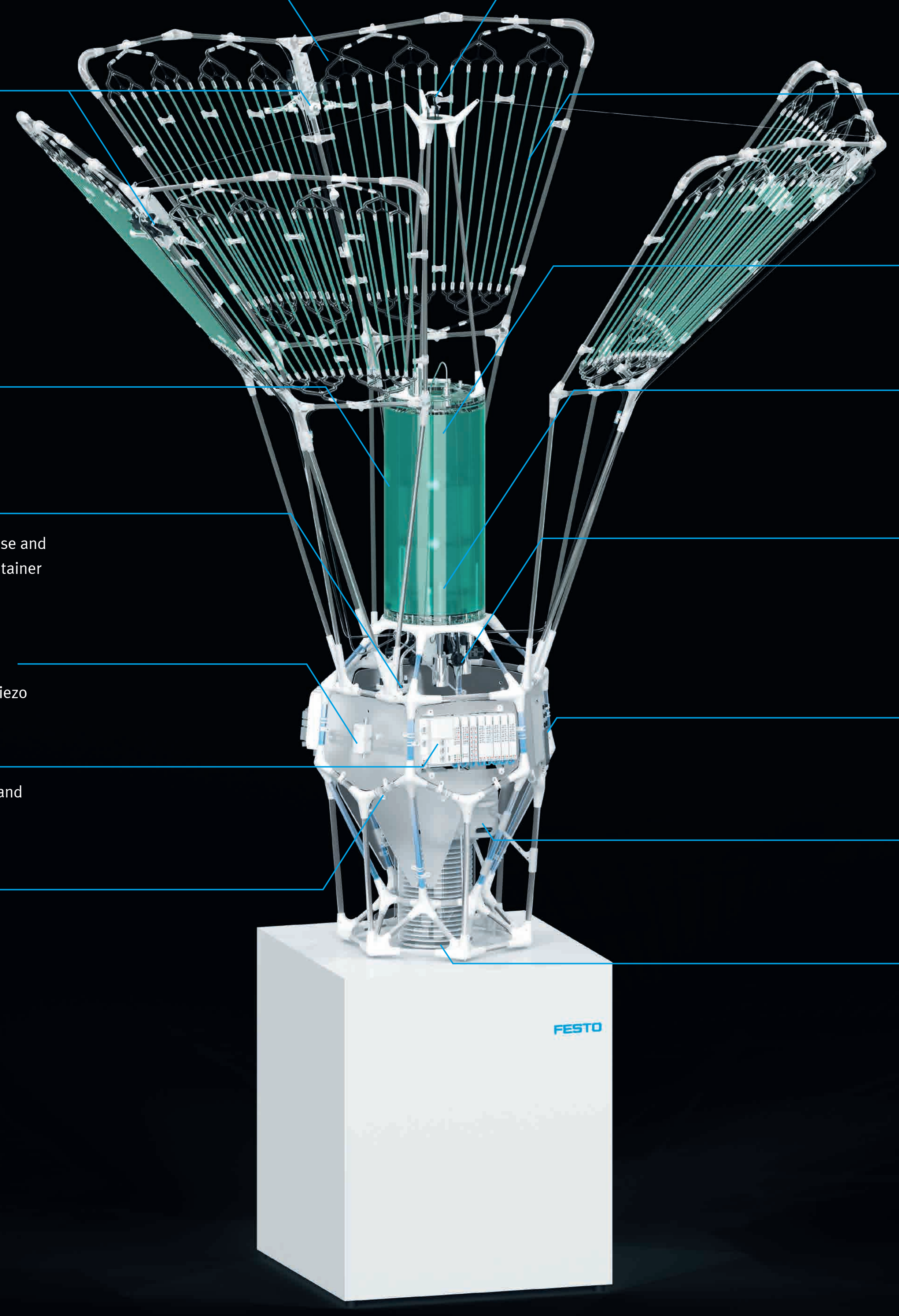
Laboratory software with cloud connection

Live images
refreshed every 30 seconds

Remote control
of parameters such as:
- pH value
- temperature
- light intensity
- air supply
- recirculation
- CO_2 content



Monitoring
Time and sample collection of:
- interior temperature
- surrounding temperature
- pH value
- air supply



Sail-shaped surface collectors
3 pieces for optimised light absorption and to regulate heat balance

Valve sensor units
3 pieces for sequence control of the circulation in the surface collectors

Cultivator
acrylic glass container for an algae volume of up to 15 litres

Peristaltic pumps
3 pieces to supply nutrient solution, base and acid to regulate the pH value in the container

VEMD proportional flow control valve
precisely dosed fumigation thanks to piezo technology

CPX-E automation system
controls all processes in the container and communication to the cloud

Connecting pins
3D-printed from PHB bioplastic

Multi-sensor
for measuring ambient temperature, light intensity and light incidence angle

Transparent acrylic tubes
with circulating algae fluid for optimised light absorption and heat exchange

Lighting elements
for optimum light intensity at all times

Ceramic gassing elements
gas supplied in the smallest possible bubbles for optimal absorption in the liquid

Circulating pumps
3 pieces to continuously mix the liquid in the container
3 pieces to transport the liquid to the collectors

CPX-AP-I-EC-M12 bus interface
to communicate with the valve sensor units

Quantum sensor
optical real-time determination of biomass

CO_2 absorber
converting ambient air into compressed carbon dioxide

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Automated cultivation of biomass

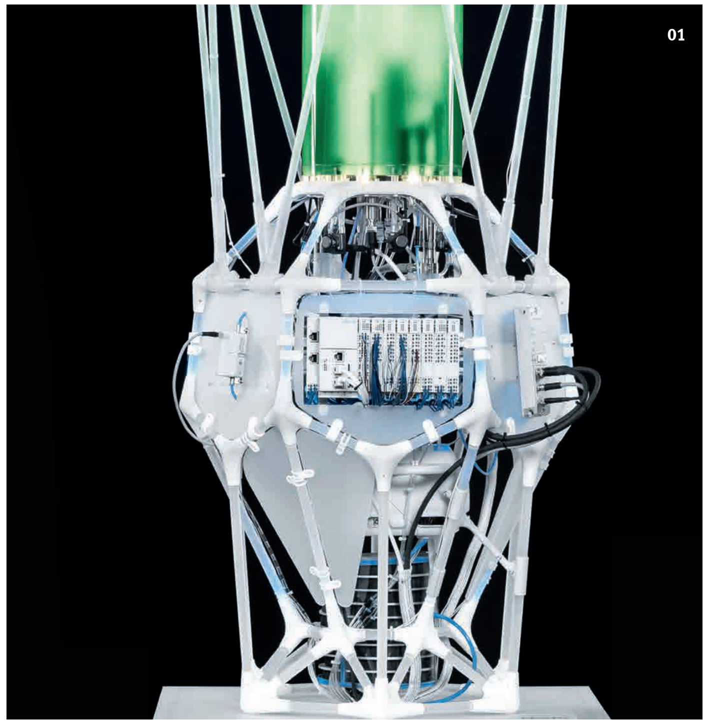
01: **Automated bioreactor:** best possible conditions for algae growth

02: **Optimum process stability:** permanent monitoring of multiple bioreactors from anywhere

03: **Artificial photosynthesis:** cultivating the droplets in a second bioreactor

04: **Specially developed automatic dispenser:** thousands of tests to improve enzymes

05: **On an industrial scale:** a solution for the climate-neutral circular economy of tomorrow



Software solutions for a digitalised laboratory
In laboratories, many analyses have been done manually up to now. This not only takes a great deal of time and effort, but can also lead to errors. By automating such laboratory facilities, all necessary data could be read directly and in real time in the future, thereby allowing researchers to better concentrate on their key tasks.

PhotoBionicCell is complemented by specially developed software. The dashboard allows multiple photo-bioreactors to be mapped with current data and live recordings. This means that manual parameter changes and subsequent evaluations can be made around the clock, even remotely. This allows users to react to changes in the bioreactor at any time and start harvesting products at the most suitable time, for example. The digitalised laboratory is enhanced by an augmented-reality application. Using a tablet, reality can be extended to visualise technical processes, process parameters and information about processes within the bioreactor.

Artificial intelligence and digital twins
Our developers also use artificial intelligence (AI) methods to evaluate data. This allows the bioreactor to be optimised either to propagate the algae cultures or to maintain predefined growth parameters with minimal energy input. It could also be used to predict the durability of valves and other components.

The use of digital twins created with the help of AI would also be conceivable. In future, they could be used to simulate and virtually map complete life cycles for bioreactors. The expected cell growth of a wide variety of microorganisms could then also be accurately estimated, even before a real system is physically constructed.

Further optimisation through artificial photosynthesis
In addition to optimising laboratory facilities through automation and digitalisation, artificial photosynthesis offers another promising perspective to cultivate biomass even more efficiently.

Automated dispensing as a basis
With our project partner, the Max Planck Institute for Terrestrial Microbiology, we have developed an automatic dispenser to improve individual photosynthesis enzymes. To do so, thousands of variants of an enzyme have to be tested. Compared to manual pipetting, the newly developed automatic dispenser does this much faster and without errors. In addition, the automatic machine can be adapted to new tasks in seconds.

Synthetic biology for maximum efficiency
But not only can individual photosynthesis modules be optimised. Scientists are now working on digitally optimising entire metabolic pathways. This approach is known as synthetic biology. A metabolic pathway optimised on the computer is packaged in synthetically produced cells, also known as droplets. These have a diameter of around 90 micrometres and contain all the necessary enzymes and biocatalysts. This enables them – just like their biological models – to lock in carbon dioxide by means of light energy.

Fundamental research meets automation
Even though we are still in the middle of the development process, we can already see future potential: if expertise in automation and fundamental research is combined, it will be possible to achieve industrial-scale carbon-neutral production more quickly.

Sustainability in the future
To cultivate the desired amounts of biomass with controlled cell growth in the future, systems such as PhotoBionicCell would have to be scaled up significantly. If chemical processes were replaced by biological processes, there would be no need for high temperatures, aggressive chemicals or fossil raw materials. Production will become both energy efficient and sustainable – benefiting people and the environment at the same time.

We are making a significant contribution to this change towards a climate-neutral circular economy through innovative technologies and by continually learning from nature.

Technical data

- Overall height: .... 3.0 m
- Surface collectors: .... 5.0 m^2
- Collector radius: .... 1.6-2.7 m

Cultivator:

- Height: .... 57.0 cm
- Diameter: .... 25.0 cm
- Capacity: .... 15.0 l
- Algae thickness: .... 5.5 cm

Materials:

- Cultivator: .... Acrylic glass
- Connecting pins: .... Polyhydroxybutyrate (PHB)
- Nodes: .... Quickgen 500 (3D-printed material)
- Connecting rods: .... Acrylic glass (glass-bead-blasted)
- Distribution elements: .... e-Clear (3D-printed material)

Integrated components:

- CPX-E automation system: 1
- VEMD proportional flow control valves: 2
- CMMT-ST motor controllers: 3
- CPX-AP-I-EC-M12 bus interface: 1
- CPX-AP-I-4DI4DO-M12-5P digital input/output modules: 3
- VYKB media-separated solenoid valves: 6
- CPX electric terminal: 1
- Sensors in the cultivator: 14
  Capacitive sensors for collectors: 6
  Capacitive sensors for fill level in the cultivator: 2
  Flow sensors: 2
  Sensors for temperature, pH value and CO_2 content: .... 1 each
  Quantum sensor: 1
- Multi-sensor for collectors: 1
- Total number of pumps: 11

Project participants

Project initiator:
Dr Wilfried Stoll, Managing Director
Festo Holding GmbH

Project management:
Karoline von Häfen, Dr Elias Knubben, Festo SE & Co. KG

Project team:
Sebastian Schrof, Michael Jakob, Timo Schwarzer, Nenja Rieskamp, Dominic Micha, Esmeralda Kramer, Philipp Steck, Ralf Kapfhamer, Ferdinand Glass, Dr Nina Gaißert, Charlotte Tesch, Francis Goh, Duc Thang Vu, Florian Zieker, Christian Stich, Vanessa Bader, Alexander Müller, Philipp Eberl, Festo SE & Co. KG

Prof. Dr Tobias Erb, Pascal Pfister, Maren Nattermann,
Max Planck Institute for Terrestrial Microbiology, Marburg

Dr Michael Förtsch, Dr Helge Hattermann,
Q.ANT GmbH, Stuttgart

Caspar Jacob,
Steinbeis Embedded Systems Technologies GmbH, Esslingen

Image 05, page 7: University of Hohenheim, photograph Manfred Zentsch

Festo SE & Co. KG

Ruiter Strasse 82
73734 Esslingen
Germany
Phone +49 711 347-0
Fax +49 711 347-21 55
cc@de.festo.com
→ **www.festo.com/bionics**

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