THE BIOBATTERY
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The energy supply from renewable sources, such as the sun and wind, is subject to severe fluctuation. New technology is sought-after so that energy can be stored in a time-independent and transportable manner. Even for renewable energy sources, it is important to use them effectively and only incur a small amount of residue that requires cost-intensive disposal. At this point, the concept of the Biobattery takes hold, which was developed by the Sulzbach-Rosenberg branch of the Fraunhofer Institute for Environmental, Safety, and Energy Technology UMSICHT.

Energy storage through energy conversion

The Biobattery from Fraunhofer UMSICHT was developed in light of the use of bio-genous residues as cost-efficient energy sources. Currently on the market available conversion processes are faced with a variety of challenges: existing conditions, such as a high degree of capital commitment for production processes, high disposal costs and fluctuating market prices make sustained economic action difficult. In addition, existing conversion concepts of biomass find themselves facing low-lignocellulosic biomass, such as biogas, bioethanol, biodiesel, or white biotechnology, or are focused on dry lignocellulosic biomass such as combustion. Transportation of biomass is often a fundamental cost factor of these technologies. On the other hand, for stable, biomass-based intermediate products, there have been no efficient and economic production systems until now.

The Biobattery concept offers individual and, as such, optimal system solutions through the combination of different energy sources and processes. These processes can be combined with existing systems or installed as stand-alone units. The technology from Fraunhofer UMSICHT is suitable for a wide range of solid biomass. The energy-products are characterized by outstanding quality. The concept is based on the optimal interplay of different components such as Thermo-Catalytic Reforming TCR® and the associated motors for power production, concepts for biogas and biomethane production and thermal energy storage units. Through the optimal interplay of these components, the Biobattery concept successfully creates a robust and capital-efficient redesign or expansion of peripheral applications. The Biobattery is largely based, on the research and development work of Professor Dr. Andreas Hornung, head of the Sulzbach-Rosenberg institute branch of Fraunhofer UMSICHT.

Center for Energy Storage

The Biobattery concept is the result of more than 15 years of experience and R&D in the field of bioenergy conversion, which is transferred into practice through products and procedural solutions. The Center for Energy Storage assists customers in the specific implementation of energy conversion projects. The organization of the center – with the sites in Sulzbach-Rosenberg (Fraunhofer UMSICHT, Sulzbach-Rosenberg Branch) and Straubing (Fraunhofer IGB, Bio-, Electro- and Chemocatalysis Biocat, Straubing Branch) – is supported by the Free State of Bavaria. It has extensive technical centers, laboratories and test facilities in order to develop and test energy conversion and storage systems and prepare them for market introduction.
A fundamental prerequisite for a successful energy turnaround is the recognition of its complexity. Technologies cannot be considered in isolation. Instead, they must be complemented by socio-economic and ecological determinants. The focus of our system research is on integrating the respective storage technologies in different sectors and their effects on society and the economy. We are investigating the system environments and deducing recommendations for action for societal and economic stakeholders.

Thermo-Catalytic Reforming TCR®
Thermo-Catalytic Reforming TCR® is the main pillar of the Biobattery concept. High-quality, storable energy sources of various types are produced out of superfluous electricity from renewable sources and out of organic residues. The raw materials are initially subjected to pyrolytic decomposition during the process. By means of several integrated thermal process steps, products of unparalleled quality can be produced. In total, 75 percent of the energy content used is converted to biogenous products of the highest quality. By this process route, pure oil, product gas, and high-quality biochar are produced. The product gas is suitable for direct use in combined heat and power plants.

Increasing the efficiency of anaerobic digestion plants
Anaerobic digestion (AD) plants are potential locations for the components of the Biobattery, as large volumes of fermentation residue arise here, and this is particularly suitable for subsequent recycling in TCR® systems. The biochar produced as a result is suitable as an agricultural soil conditioner. Another field of use is in the further development of existing biogas technologies – many plants are now in need of technical improvement. For example, the scientists of Fraunhofer UMSICHT are working on a hydrolysis step to increase methane concentration.

Thermal energy storage
By using mobile and stationary heat storage technologies the efficiency of biomass conversion and industrial processes can be improved. Thermal energy storage is suitable to make use of waste heat, as for example in biogas plants. The goal is an efficient use and, where applicable, the appropriate transportation of waste heat from the heat source to the consumer, if the produced heat cannot be used at the source.
With the transformation of the energy supply, society as a whole, together with single industries, companies and municipalities, is confronted by precedent-setting decisions. The development and implementation of suitable storage technologies requires an analysis of all system-relevant factors. For example, the successful integration of chemical and thermal energy storage is affected by political framework conditions, societal acceptance, interdependencies with the environment, and demand pattern of the markets. The in-depth investigation of the individual storage technologies in the relevant sectors, such as industry, households, mobility or buildings, is at the core of our system research. As a result, the relevant factors are identified, evaluated and prioritized. Methodically, we apply multi-criteria analysis, simulation models, SWOT analysis, scenario technique, meta-analysis, standardized questionnaires, and techniques of relation and effect analysis. With the systems-analytical approach, we recognize system interrelations, making important contributions to support strategic decisions, such as specific recommendations for innovation management, with the objective of developing marketable technologies, evaluating optimal value chains, and being able to make sustainable decisions about facility locations.

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Globally, there is a major demand for sustainable and cost-efficient technologies for decentral energy supply from biomass. Biomass combustion and gasification tend to struggle with restrictions, with regards to the scope of possible input materials, compliance with emission standards and energy efficiency as a whole. In this context Fraunhofer UMSICHT in Sulzbach-Rosenberg has developed a market ready technology for the energetic conversion of biomass residues.

**Sustainable use of the potential of biomass residues**

The Thermo-Catalytic Reforming (TCR®) converts solid biomass to high-quality energy and nutrient rich in a multi-stage, thermal process. The process efficiently converts any type of biomass from a dry matter content of 70 percent or higher. Typical types of biomass residues are:

- Fermentation residues from biogas and bioethanol plants
- Wood residue and landscaping materials
- Industrial biomass residue, such as brewer grains or residues from paper recycling
- Biosolids
- Straw and other agricultural residues
- Animal excrement

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<th><strong>In a first step of the TCR® process, the biomass is cracked down to solid and liquid components at medium temperature (400 to 450 °C) followed by a simple but effective product processing to generate the following three high-quality products:</strong></th>
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<td>- Dust-free product gas consisting of hydrogen (up to 40 percent by volume), carbon monoxide, carbon dioxide and methane, together with a low proportion of higher hydrocarbons</td>
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<tr>
<td>- High-quality oil with a high heating value and a low acid number (comparable with vegetable oil)</td>
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<tr>
<td>- Biochar with a high level of carbon and high potential as a fertilizer substitute</td>
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The process stands out considerably in terms of technology from other thermo-chemical procedures:

- High operational stability by avoiding the formation of dust and tar
- Products with moisture content of up to 30 percent can be processed without any further drying
- In addition, in case of feedstock with moisture content higher than 50 percent, the process generates sufficient off heat to dry the feedstock to the required level
- About 75 percent of chemical energy of the feedstock is transferred to the products. Considering the heat provided for biomass drying, this figure rises up to 90 percent
- Through the robust, containerized system design, local plant sizes of about 200 to 300 kWel can be economically installed

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The high quality of the products facilitates attractive forms of usage:

**Product gas**
The product gas can be converted directly on-site by highly-efficient combined heat and power plants. The high hydrogen content opens up attractive routes for further processing. For example, Fraunhofer UMSICHT is working on projects in the field of fuel synthesis and the local production of green chemical preliminary products such as methanol.

**Product oil**
The product oil can also be converted directly on-site to a combined heat and power plant. Due to the storage properties of the oil, the electricity production can be economically adapted to demand. As a result, the Biobattery concept of Fraunhofer UMSICHT is significantly supported. Moreover, the high quality of the oil also opens up options for direct use as a sustainable fuel from biomass residues – without the laborious synthesis step for the first time. A program to investigate the engine suitability of the oil is currently being carried out with the University of Applied Sciences Amberg-Weiden.

**Biochar**
The produced biochar has very attractive properties. A nutrient-rich biochar is produced, which could be used as fertilizer.

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### Cost-effectiveness

Fraunhofer UMSICHT has already carried out extensive cost-effectiveness analyses for the TCR® process:

- Attractive profitability forecasts with returns of between 12 percent and 22 percent in many international application scenarios
- Major international market demand for the TCR®
- High capital efficiency with local plant sizes (expected investment volumes comparable with corresponding biogas plants)
- The easy conversion of systems to different raw biomass substances guarantees a high degree of flexibility on the volatile biomass markets
- By producing gas, oil and biochar, the plant’s profitability no longer depends on the market price of a single product
- Relocations are possible due to the containerized format of the plant

### Development of TCR® technology

Professor Dr. Andreas Hornung, director of the Sulzbach-Rosenberg Institute branch of Fraunhofer UMSICHT, has been researching intermediate pyrolysis for more than twenty years. During earlier research at the Universities of Technology of Karlsruhe and Kaiserslautern, he laid the foundations for today’s TCR® technology with the analysis and further development of pyrolysis processes. As the head of department at the Karlsruhe Research Centre, known today as the Karlsruhe Institute of Technology (KIT), he dealt with the conversion of biomass before founding the European Biomass Research Institute EBRI in Birmingham in 2007, where he was the director until 2013. Among other things, he worked intensively with the pyrolysis of biomass here. The breakthrough to today’s Thermo-Catalytic Reforming TCR®, which is characterized by a considerably better product quality, occurred in Sulzbach-Rosenberg at Fraunhofer UMSICHT.
INCREASING THE EFFICIENCY OF AD PLANTS

The situation of the AD plant industry is currently rather difficult. Even when the construction of new plants has decreased considerably, the potentials of existing plants are still far from being fully exploited. As part of the Biobattery, Fraunhofer UMSICHT offers numerous possibilities to increase the efficiency of existing AD plants. For example, the crude biogas produced must be treated before being fed into the natural gas grid, which is an energy-intensive process. If it is possible to reduce the carbon dioxide content of the crude biogas before the upgrading process, this can save energy and costs. In Sulzbach-Rosenberg, we are working on the development of a hydrolysis stage, which will do precisely this. The two-phase process allows separate collection of the CO$_2$-rich hydrolysis gas, leading to an increase in the methane content in the methane stage. We have already been able to successfully simulate this in our technical center and to achieve methane contents of up to 70 percent.

Increasing the efficiency using the TCR$^\text{®}$ process

In regions with a high density of livestock farms and AD plants, a recycling competition between the application of animal manure and digestate on arable land exists. The upcoming amendment of the German Fertilisers Ordinance intends to extend the maximum application limit of nitrogen to 170 kg per hectare to all organic fertilisers, including digestate from AD plants. As a result, the application of digestate might lead to considerable added financial burden in the future for AD plants operators. In this context, the TCR$^\text{®}$ process, developed by Fraunhofer UMSICHT, provides an alternative option to convert digestate into the products synthesis gas, oil, and biochar.

The biochar can be used for nitrogen removal from the separated liquid phase of the digestate and would ease the environmental burden of regions that have an excess of nutrients. Furthermore, it is possible to convert synthesis gas into electricity in combined heat and power plants (CHP) and the substrate usage can be reduced by up to 15 percent.

A prospective use of biochar as a high-carbon nutrient source produced by the TCR$^\text{®}$ fulfills the limits and the nutrient requirements for intended fertiliser uses.

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The storage of waste heat improves the efficiency of biomass conversion and industrial processes. The consumption of fossil fuels is reduced and the operational costs are lowered. Concepts tailored to the customer’s needs allow temporal and local decoupling of heat generation and usage. In addition, Fraunhofer UMSICHT is developing new processes up to their marketability in cooperation with industry and research partners. At Fraunhofer UMSICHT in Sulzbach-Rosenberg, storage technologies are investigated holistically. We are able to develop and provide thermal energy storage in a wide temperature range for a multitude of different applications. Therefore sensible, latent and thermochemical heat storage are used. The field of application for sensible heat storage goes up to 1 400 °C. In this high temperature range various bulk goods are used as storage material. Increasing the flexibility of cogeneration plants by combining them with thermal energy storage is the main focus of the developments. Another topic is the subsequent conversion of the stored waste heat into electricity.

The use of innovative latent heat storage systems allows heat discharge at a constant temperature level in the low to mid temperature range over a longer period of time. Our research is focusing on the procedural optimizing of the storage system. This includes a flexible design of the storage system and the development of new storage materials in order to cover preferably wide temperature ranges, for both stationary and mobile applications. One possible field of application is the heating of municipal buildings with waste heat from a nearby biogas plant. Thus, the heat generation and consumption are decoupled in terms of time and location. A further research topic is thermochemical heat storage, which is suitable for the temperature range of approx. 200 to 450 °C. We are focusing on the development of a demonstrator close to the application and based on the reaction system of magnesium oxide / hydroxide. The optimization of the process is amended by chemical and thermal analysis as well as the modification of the used storage materials. In addition, we are dealing with custom-designed storage integration. For this reason, we are determining the technical, energetic, economic and ecological framework parameters of heat sources and sinks, previously. Based on this detailed analyses, suitable storage technologies can be selected. In addition, we are creating a process concept for the storage unit and fit the plant and material components. For both the integration of the storage unit and the consecutive use, we are offering scientific support as for instance with data analysis of the charging and discharging behavior. Thus, further optimization potentials can be identified and customer-specific adjustments are possible.

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SUSTEEN® TECHNOLOGIES GMBH

Susteen Technologies is a clean technology development and marketing company based in Sulzbach-Rosenberg, Germany. The company focuses on thermo-chemical conversion technology for biomass.

The Board of the Fraunhofer-Gesellschaft decided to establish TCR® technology actively on the market in the form of a spin-off. The unique selling point of the procedure and the high expected market potential of the technology on an international level were crucial to this decision. For this reason, the Fraunhofer-Gesellschaft founded this spin-off as “Susteen® Technologies GmbH” in April 2014, together with a founding team. Susteen will organize the distribution of TCR® plants together with regional project development partners and concentrate on the development and sale of the core components of TCR® plants.

FRAUNHOFER UMSICHT

Fraunhofer UMSICHT in Sulzbach-Rosenberg has been developing business-related concepts and processes to produce and use energy, raw substances and materials since 1990. The focuses include thermal and chemical energy storage, energy conversion from biomass and waste, raw substances, materials and interfaces for energy technology and resource management. Fraunhofer UMSICHT supports its customers from the first idea of the process, through to the pilot plant, product development, and pilot production. Integrated process evaluations for efficient, economical and sustainable solutions are the focal point here. As part of the Center for Energy Storage, which was founded on-site in 2012, the focus is on integrated, local energy conversion and energy storage systems. The Sulzbach-Rosenberg branch in the metropolitan region of Nuremberg employs about 120 employees. The institute branch has been part of the Fraunhofer-Gesellschaft since 1st July 2012. Fraunhofer UMSICHT in Oberhausen was also founded in 1990 and develops technical innovations in the field of environment, material, process and energy technology. The objective of the institute is to promote sustainable economies, environmentally-friendly technology and innovative behavior in order to improve the quality of life for people and encourage the economy’s innovative capacity. Fraunhofer UMSICHT generated an operating budget of about €38.1 million in 2014 with 559 employees. As one of 66 institutes and independent facilities of the Fraunhofer-Gesellschaft, Fraunhofer UMSICHT has a global network and promotes international cooperation. Fraunhofer is the largest organization of applied research in Europe.

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