IEA Bioenergy Agreement Task 33 Country Report Germany 2021

IEA Bioenergy: Task 33

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Country Report Germany 2021

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Summary

The report offers information on activities in the field of thermal gasification of biomass and waste in Germany for the period 2019-2021.

The focus is on the research institutes and is based on contributions by research associates of the research institutes listed. Each institute is presented with its specific characteristics, facilities and the research projects it has worked on in the past or is currently working on.

In the second part, the activities of German companies are briefly described, concerning their technologies and status of operation for selected plants offered.

Contact persons and contact information for more detailed inquiries are listed.

The map below gives an overview of the players in Germany.

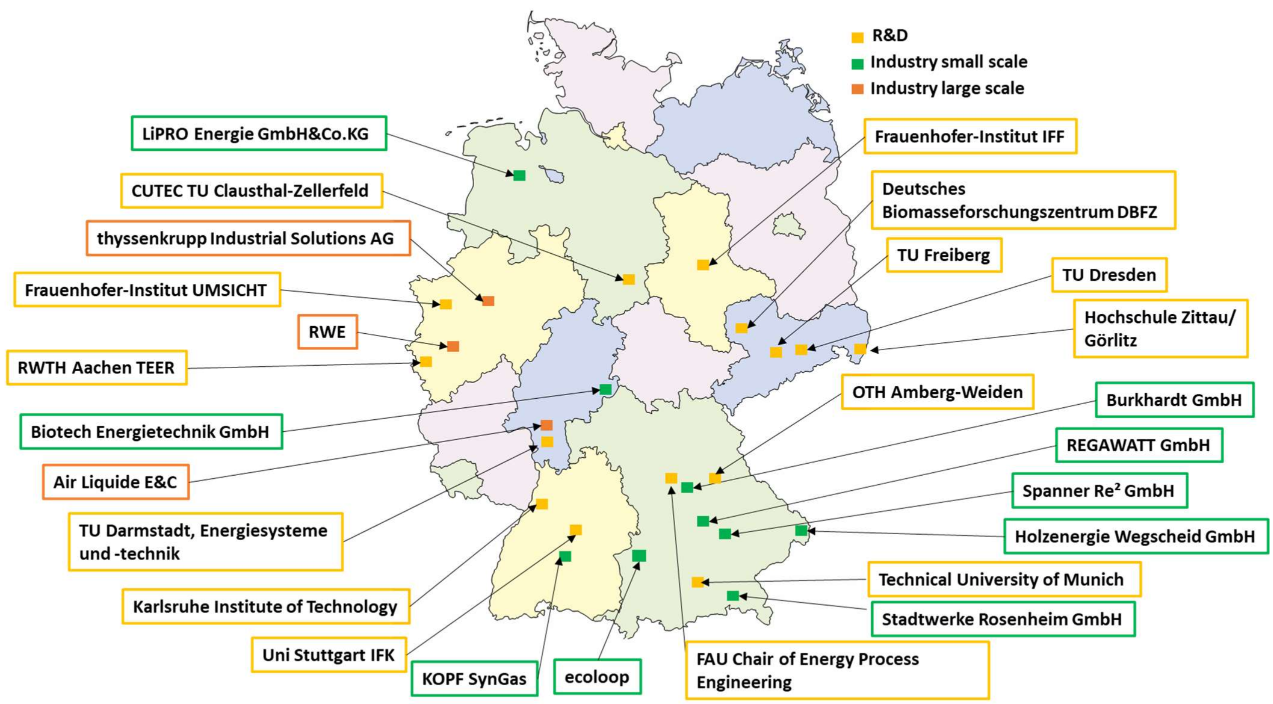

Figure 1: The biomass gasification map of Germany

Research Institutes

THE GERMAN BIOMASS RESEARCH CENTER (DEUTSCHES BIOMASSEFORSCHUNGSZENTRUM – DBFZ)

The German Biomass Research Center, or DBFZ for short, was founded in 2008 with the aim of establishing a central research institution for all relevant fields of bioenergy research and to network the results of the very complex German research landscape in this sector. Its sole shareholder is the Federal Ministry of Food and Agriculture (BMEL).

As a central and independent institution in the field of energy-related and material biomass use, the DBFZ works on the question of how the limited biomass resources available can contribute to the existing and future energy system in a sustainable manner. Within the framework of its research activities, the DBFZ identifies, develops, evaluates and demonstrates the most promising fields of application for bioenergy together with partners from research, industry and the public. The research work of the DBFZ contributes to the overall knowledge on the opportunities and limitations of the energy-related and integrated material use of renewable raw materials in a bio-based economy.

R&D is provided for all conversion pathways and technologies such as biochemical and thermochemical conversion, biorefinery technology and on bioenergy systems. DBFZ operates unique laboratory and pilot scale R&D infrastructure as a special biogas research plant, engine test bed, hydrothermal, gasification and methanization reactors.

The development of new processes, procedures and concepts takes place in close cooperation with partners from industry and commerce as well as with other research institutions. This approach intends the promotion and support of networks in industry and between industry and science. Based on this broad research background, the DBFZ develops scientifically sound decision-making aids for policy-makers.

The target groups of the R&D work, contract research and science-based services are all relevant actors from research, industry and politics within the bio-economy arena. In addition to the BMEL, these include other federal and state ministries. The work is also aimed at other governmental and non-governmental national and international organizations, particularly from the agricultural, forestry and energy sectors. It is also aimed at downstream industries and economic sectors that are directly or indirectly affected by energy production and material use of biomass. In addition, the results of the R&D work and the science-based services are made available to the public, here in particular to the energy industry, agriculture and forestry, the economy in the field of biomass/bioenergy/bioeconomy.

The "Smart Bioenergy" concept developed by the DBFZ comprises the further development of modern biomass utilization systems towards integrated systems. This covers both the optimized interactions among various renewable energy sources and the coupled material-energy use within the framework of the bio-economy. Changed consumption patterns, energy saving aspects and climate protection are important framework conditions of the Smart Bioenergy concept. Thus, it makes an important contribution to a future sustainable energy supply (further info via www.smart-bioenergy.de).

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TECHNICAL UNIVERSITY OF MUNICH CHAIR OF ENERGY SYSTEMS

The Chair of Energy Systems at Technical University of Munich (TUM-CES) conducts research in the field of air- and oxygen-blown entrained flow gasification of raw and pretreated solid fuels, mainly biomass and waste fractions (pretreatment includes torrefaction, hydrothermal carbonization and pyrolysis). TUM-CES focuses mainly on reaction kinetics and particle development during gasification, gas characterization of synthesis gas, flame stability and gas cleaning processes.

Test Facilities

Several test rigs from lab-scale for fundamental research to pilot-scale for industrial-like process conditions are available for experimentation.

PiTER/BabiTER

The pressurized high temperature entrained flow reactor PiTER is used to obtain char samples pyrolyzed in nitrogen or gasified with oxygen, carbon dioxide or steam under industrial conditions. Therefore, a ceramic tube divided by the fuel injection into reaction zone and preheating zone can be electrically heated up to 1800°C. Moreover, the pressure vessel is designed for pressures up to 50 bar. The solid fuel is fed to the reactor by two vibrating dosing units so that defined blending ratios can be investigated. Char samples are obtained at different residence times by a height-adjustable oil-cooled probe. These samples are collected in a filter and further analyzed in the lab or thermogravimetric analyzer, while the major product gas components are directly analyzed by an online gas analyzer. Gas and char not entering the sampler are cooled down in a water quench and leave the reactor as off-gas or waste water. Measured data of the PiTER can be supplemented by data of the atmospheric entrained flow reactor BabiTER. The BabiTER is designed similar to the PiTER except the pressure vessel. Due to its simplicity, the reactor can easily be adjusted in order to develop new experimental methods.

Thermogravimetric Analyzers

The reactivity of chars obtained from PiTER and BabiTER are investigated in various thermogravimetric analyzers. Two pressurized thermobalances are used to determine the gasification kinetics in air, carbon dioxide and steam as well as product gases like hydrogen and carbon monoxide. These balances are designed for pressures up to 50 bar similar to the PiTER. The atmospheric thermobalances are used to investigate the thermal deactivation behavior of the fuel by measuring reactivities of char pyrolyzed at different residence times and temperatures at standard conditions, i.e. at constant temperature and partial pressure of gasification agents.

Wire Mesh Reactor

In order to specify the pyrolysis behavior of fuels investigated in our reactors, their devolatilization is investigated in the Wire Mesh Reactor. In order to achieve heating rates similar to industrial-scale gasifiers, the mesh containing the fuel particles can be heating up to a maximum temperature of 1600°C. Again the reactor can be operated up to 50 bar.

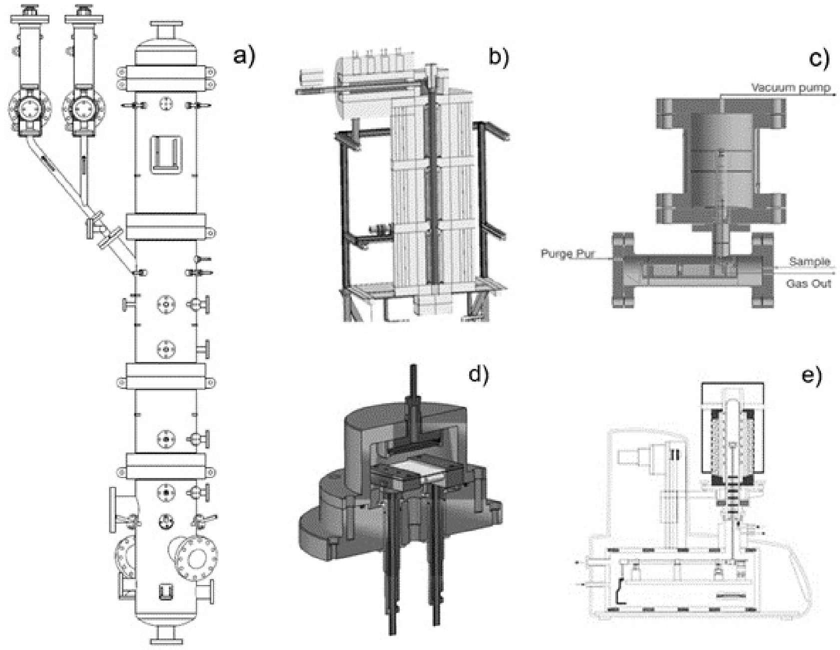

Figure 2: a) PiTER b) BabiTER c) Pressurized TGA d) Wire Mesh Reactor e) TGA

BOOSTER

The biomass pilot-scale entrained flow gasifier is an industrial-like autothermal entrained flow gasifier operating up to 5barg and with a thermal biomass input from 70 – 150 kW. The gasifier has a refractory lining and uses a full water quench for gas cooling. As gasifying agents, oxygen and air can be used. Additionally steam and carbon dioxide can be injected. Particles and gas can be sampled via a central sampling probe adjustable from the bottom to the middle of the reactor. In addition four lateral gas sampling ports are distributed over the reactor height. There are different burners for oxygen and air gasification as well as a flexible burner with adjustable swirl and oxygen outlet area. A flame camera with enables studies regarding flame stability and shape. The BOOSTER is operated with pre-treated (torrefaction and hydrothermal carbonization) and raw biomass and organic residues. The main focus of

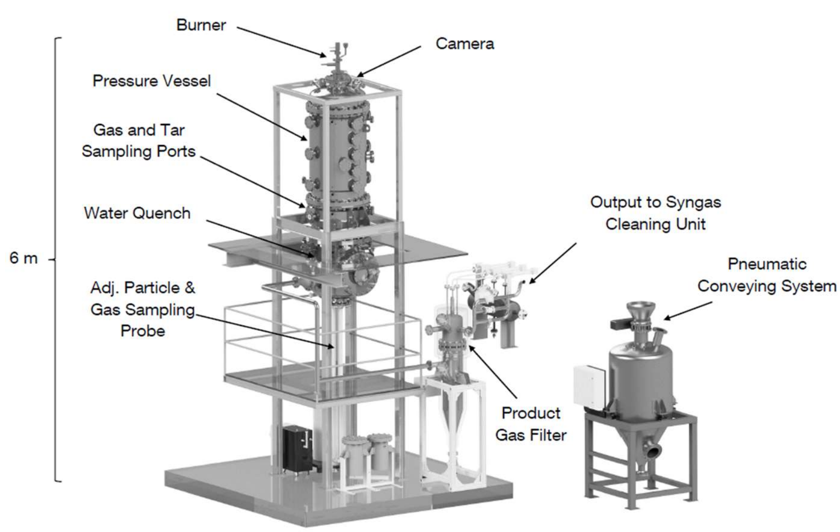

Figure 3: Biomass Pilot-Scale Entrained Flow Gasifier (BOOSTER)

the BOOSTER is the determination of general gasification behaviour and efficiency, particle development, gas composition and concentration of gas impurities as well as flame behaviour and the validation of kinetic models. Measurements include CO, H_2, CO_2, CH_4, N_2, O_2, H_2O as well as HCN, NH_3, H_2S, NO, HCl and Tars. The product gas is attached to a gas cleaning unit and a compressor station, where cleaned synthesis gas can be filled into gas bottles with up to 60 bar.

Gas Cleaning Unit

The pilot-scale gas cleaning unit is in a modular design. During operation a volume flow of 5 Nm^3/h can be purified at a pressure up to 5 barg. The facility consists of a wet scrubber, gas condenser and four fixed-bed adsorbers. The detachable construction of individual cleaning steps allows a flexible application of hot and cold gas cleaning steps. The main focus is on the investigation of different scrubbing solvents, adsorbents and internal material recycling to optimize the gas purity for the downstream processing of synthesis gas. According on requirements, particles, tars and trace gas components such as HCN, NH_3, COS, H_2S, HCl and NO_x can be separated.

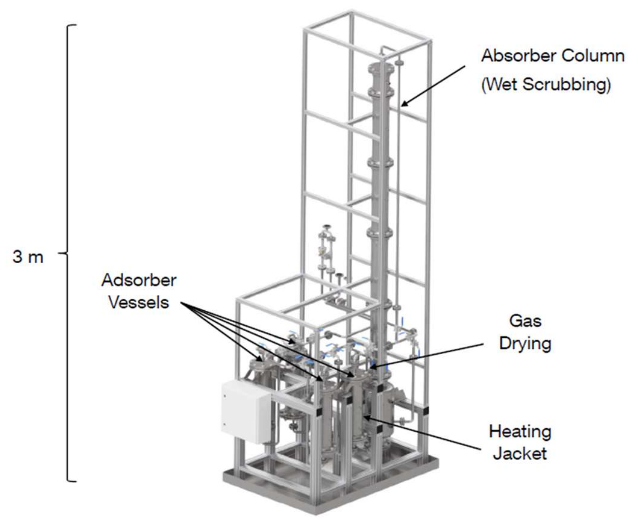

Figure 4: Modular Synthesis Gas Cleaning Unit

Fuel Analysis Lab

The Chair of Energy Systems has wide expertise in the field of investigating solid fuels. Beside standard analysis like moisture, ash content and volatile content, experimental equipment to measure elemental compositions (CHNS including chlorine), ash compositions (RFA, ICP-OES), ash melting behavior, different kind of densities, particle size distributions, heating values, surface areas and porosities are available.

Research Projects

TUM-CES takes part in a couple of research projects nationally funded by BMWi and BMBF.

VERENA

The aim of VERENA is to develop and to evaluate technologies for the polygeneration of electricity and chemicals based on the gasification of residues (waste, biomass, sewage sludge, etc.). The focus of the Chair of Energy Systems is on entrained flow gasification, while other universities and industrial partners investigated the potentials of fixed bed, fluidized bed, two-bed fluidized bed and CORVEED-gasification. Lab-scale reactors like the PiTER, BabiTER, Wire Mesh Rector and the thermogravimetric analyzer are used to determine the pyrolysis and gasification behavior of the residues, while pilot-scale experiments are

performed in the BOOSTER.
The latter will be used in combination with the new gas cleaning system to demonstrate the process chain as well as to characterize and produce syngas for further synthesis. Moreover, the results of the experiments will be used to model, simulate and optimize industrial gasifiers as well as the whole polygeneration process via computational fluid dynamics and AspenPlus. The project VERENA, which started in October 2020, is based on the experience gained by the previous projects HotVeGas I-III, which focused on the gasification of lignites and bituminous coals.

ReGasFerm
In the ReGasFerm project, the technological coupling of a biomass-based entrained flow gasification (TUM Chair of Energy Systems) and a continuous biological conversion of the synthesis gas to alcohols (TUM Chair of Bioprocess Engineering) with an optimized gas purification system is carried out (TUM-CES). Gas composition and purity requirements of the synthesis gas for further use in gas fermentation for four selected bacteria strains are defined, whereby the influence of individual impurities on kinetics and bacterial growth under different reaction conditions and process control is determined. Green cut and foliage from urban areas are used as gasification fuel. From gasification side, the understanding of formation and degradation mechanisms of impurities during entrained flow gasification and the necessary gas analysis and measurement methodology are further developed and expanded down to the trace level. Processes for in-situ reduction e.g. by additives of critical trace components (e.g. HCN) during the gasification process are examined. Additionally a gas cleaning system is built suitable for the process to only clean off critical gas impurities and keep trace components like NH_3, being a nutrient for gas fermentation.

PyroGas
In the PyroGas project, the entrained flow gasification of waste and residual materials pre-treated by pyrolysis with subsequent conversion of the synthesis gas into electricity in a gas engine is investigated. For a future demonstration of the entire plant concept, experience in the entrained-flow gasification of pyrolysis coke (depending on the feedstock and pyrolysis conditions) and the composition of the synthesis gas for further gas cleaning requirements must first be gathered. In addition, it is tested how the synthesis gas behaves during combustion in the gas engine and which critical components are present in the exhaust gas and in what quantities. For this purpose, a 30 kWel gas engine will be connected to the existing 100 kWth entrained flow gasifier (BOOSTER). With the results, the system calculations of the overall concept can be refined and the basis for the technical design of a demonstration plant can be developed. Furthermore, technologies for phosphorus recovery from the ashes are developed and evaluated on a conceptual level. The overall objective is to prove the successful technical operation of the entrained flow gasifier with pyrolysis coke and the subsequent combustion of the product gas in the gas engine.

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FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG, CHAIR OF ENERGY PROCESS ENGINEERING

The Department of Energy Process Engineering works on combustion and gasification of biomass and coal in fluidized bed systems with special focus on allothermal heat pipe based gasification. With unique experimental equipment and CFD simulations. The "Combustion and Gasification of Biomass" research group is studying the ash melting behavior, pyrolysis and gasification kinetics and the integration of innovative storage technologies for electricity and heat generation in decentralized combined heat and power (CHP) systems

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TU DRESDEN, INSTITUTE OF PROCESS ENGINEERING AND ENVIRONMENTAL TECHNOLOGY

Technische Universität Dresden (TUD) is one of the largest technical universities in Germany and one of the leading and most dynamic institutions in the country. With 17 faculties in five Schools, it offers a wide range of 124 degree courses and covers a broad research spectrum. Its focuses Health Sciences, Biomedicine & Bioengineering, Information Technology & Microelectronics, Smart Materials & Structures, Energy, Mobility & Environment as well as Culture & Societal Change are considered exemplary in Germany and throughout Europe. Since 2012, TUD has been one of the “Universities of Excellence”. In July 2019, TU Dresden was once again awarded the University of Excellence title and will thus receive permanent funding within the Excellence Strategy of the Federal and State Governments as of 1 November 2019.

The Chair of Energy Process Engineering (EPE) is part of the Institute of Process Engineering and Environmental Technology, including 6 more chairs and working groups. In particular, EPE is committed to the processes of energy technology and process engineering with regard to mechanical engineering, chemistry, environmental technology and basic industry. The focus is on processes and plants associated with energy conversion and the refinement and recovery of materials. The objectives include the reduction of primary energy consumption, the reduction of emissions, the closing of material cycles and the rational use of energy.

The research activities in the field of thermal gasification of biomass and other alternative fuels are part of various research projects, which are conducted in the Research Group on Fuels and Firing Technology. For experimental investigations with focus on gasification, several laboratory scale facilities are available for fuel characterisation and determination of reaction kinetic data. Furthermore, pilot-scale facilities also exist.

Laboratory scale facilities

Laboratory for power plant chemistry
The starting point for the most different tasks is usually the determination of the fuel properties of the feedstock according to the fuel specific EN and DIN standards. Among others, this includes the contents of the combustible and non-combustible fuel components, the elemental composition, the calorific value, the main and trace elements of fuel and ash, and the ash melting behaviour in oxidising and reducing atmospheres.

Thermogravimetric Analyzers

For the investigation of the conversion behaviour of solid fuels at slow heating rates (0.1 – 100 K/min) two thermogravimetric analyzers (TGA) – a commercial and non-commercial one - can be utilised (Fig. 5). Both TGA can be operated with different reaction gases to simulate oxidizing as well as inert or reducing atmospheres, to determine the devolatilization and char gasification behaviour. Based on the measured time and temperature dependent mass change profiles, reaction kinetic data can be derived for subsequent modelling tasks.

Figure 5: Thermogravimetric Analyzers. Left: Mettler Toledo TGA/ DSC 1 (Star System) Right: Non-commercial high-pressure TGA (up to 100 bar)

The main differences between both devices is the sample amount and the operation pressure. While the commercial device can be used with sample masses in the range of milligrams, sample masses of up to 1 g are possible in the non-commercial device. In order to reduce heat and mass transfer limitation the samples are grinded to a particle size of 200 µm in both cases. In contrast to the commercial device, which is operated at atmospheric pressure, the non-commercial TGA allows pressures of up to 100 bar. In addition, the non-commercial TGA is equipped with sampling points and measuring ports to determine the gas composition and tar concentration depending on the process condition (heating rate, gas atmosphere).

<u>Semibatch-Reactors</u>

With the semi-batch reactors shown in Fig. 6, the conversion behaviour can be investigated depending on the process-specific conditions of a grate and fluidized bed system. Compared to the laboratory, larger quantities of fuel having a large grain size (mostly untreated original grain size) can be investigated, which makes representative examinations, also of heterogeneous fuels (waste, substitute fuels), possible. In both cases the fuel is added discontinuously while the reaction gas is continuously fed into the reactor. For the grate systems, amounts of approx. 30 l are possible instead amounts of approx. 10 g for the fluidized bed.

After fuel addition in the preheated reactor, the individual conversion stages of drying, ignition, volatile oxidation and coke gasification/combustion are carried out subsequently or to some extent in parallel. The fuel conversion process is monitored by means of gas analysers (O_2, CO, CO_2, CH_4, NO_x, SO_2) and thermocouple elements located in the fuel bed or the fluidised bed.

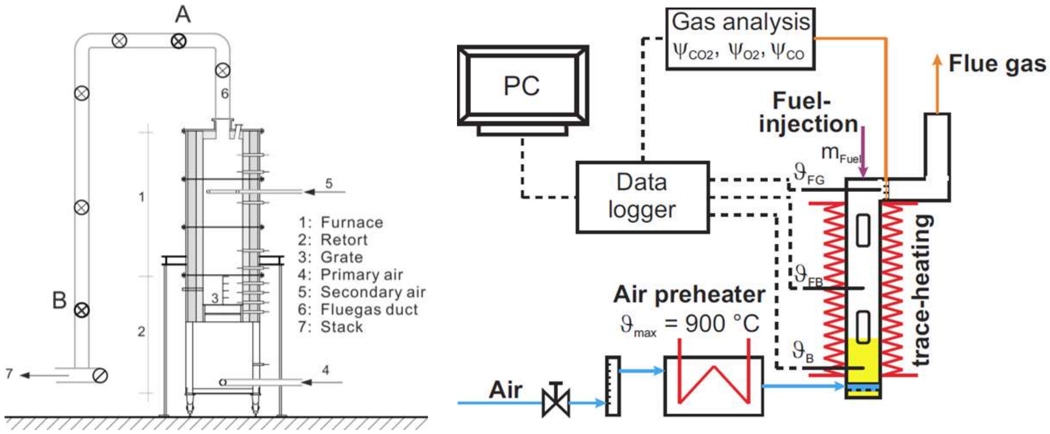

Figure 6: Semibatch reactors. Left: Grate system, Right: Bubbling fluidized bed

Additionally, both semibatch-reactors are equipped with sampling points along the combustion chamber and the flue gas path, which allow further flue gas characterisation by means of additional sampling devices. Here, special reference is made to the wire mesh probe and dust measuring according to VDI 2066, which also allow a qualitative and quantitative characterisation of the fly ash constituents. By the additional use of cooled and uncooled probes it is also possible to derive conclusions regarding the fouling and slagging tendency of the mineral matter.

Pilot-scale facilities

For the experimental investigation of biomass gasification under practical conditions, two fluidised bed pilot plants (bubbling fluidized bed and circulating fluidized bed) with similar thermal capacities are available.

<u>Bubbling fluidized bed gasification</u>
Within the framework of national funded projects of the “Sächsische Aufbaubank (SAB)”, the TC2 process (Fig. 7) was developed and realized for the thermochemical conversion of biogenic feedstock, especially residues like sewage sludge. This process targets a decentralized application, i.e. a power range of 100 – 1.000 kW thermal input, and the provision of electrical power.

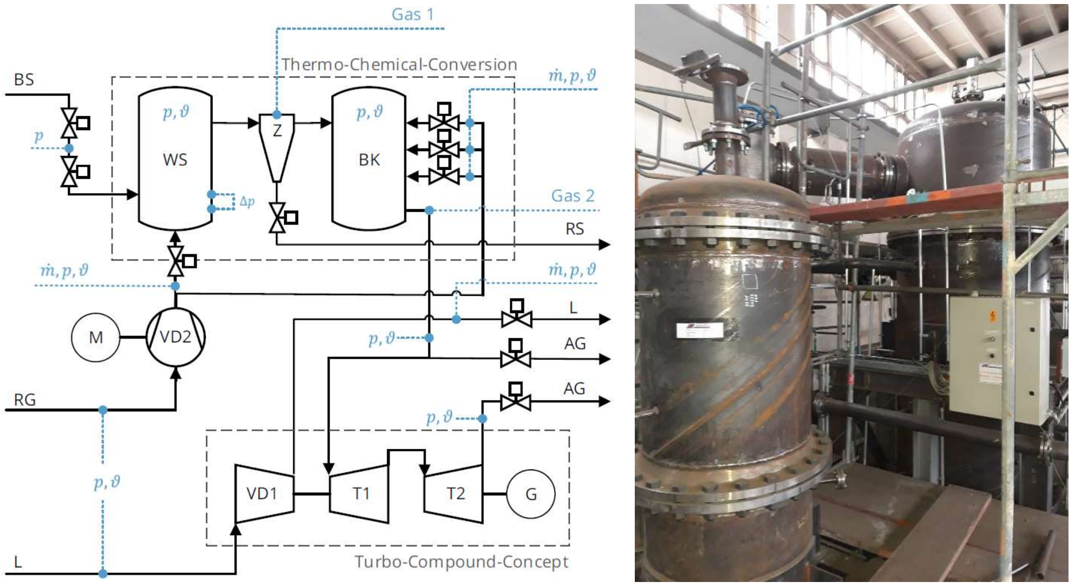

Figure 7: Fluidized bed gasification as part of the TC²-process - Thermo-Chemical-Conversion & Turbo-Compound-Concept (AG-Flue gas; BK-combustion chamber; BS-Fuel; G-Gear box and Generator; RG-Reaction gas; L-Air; M-Motor; RS-Residue; WS-Fluidized bed reactor; VD-Compressor; T-Turbine stages; Cyclone)

The process mainly consists of two stages – first, a fuel conversion (Thermo-Chemical Conversion) at 3 bar pressure abs. and, second, a power process (Turbo-Compound-Concept). The first stage of the process is composed of a pressurized fluidized bed gasification to convert the combustibles, a cyclone for dust separation and a downstream pressurized combustion chamber for the combustion of the gasification gas. For the provision of electrical energy, the second stage contains a turbo-compound-concept as power process which is thermodynamically identical to the gas turbine process. Compared to the state of the art the process is characterized by its suitability for a broad range of combustibles, especially for „difficult“ input materials (e.g. low ash melting temperature). This is achieved by the staged design of the process, the utilized devices and the durability of the chosen engine.

<u>Circulating fluidized bed gasification</u>

The 300 kWth circulating fluidized bed combustion test facility, schematically shown in Fig. 8, consists of a 13 m high reactor. Due to its modular design, the plant can be operated under both gasification and combustion conditions. For gasification operation, the reactor inside diameter is 200 mm and for combustion operation 320 mm.

Fuel and possible additives can be supplied into the return leg of the fluidized bed cooler or directly into the riser at different positions along the reactor. For staged process operation, three secondary air streams are available that, can be electrically preheated. The heat extraction takes place in a fluidized bed cooler, which simultaneously influences the bed inventory and the fluidisation state.

For the characterisation of fluidisation state, burnout and pollutant emissions, several axially and radially arranged measuring ports are available, that are equipped with pressure sensors, thermocouples and gas analysers. For additional characterisation of the bed material particles can be extracted at the bottom of the fluidized bed cooler and the downcomer.

At the outlet of cyclone 1 the flue gas is analysed with commercial analysers for the measurement of e. g. CO, CO2, O2, and NO.

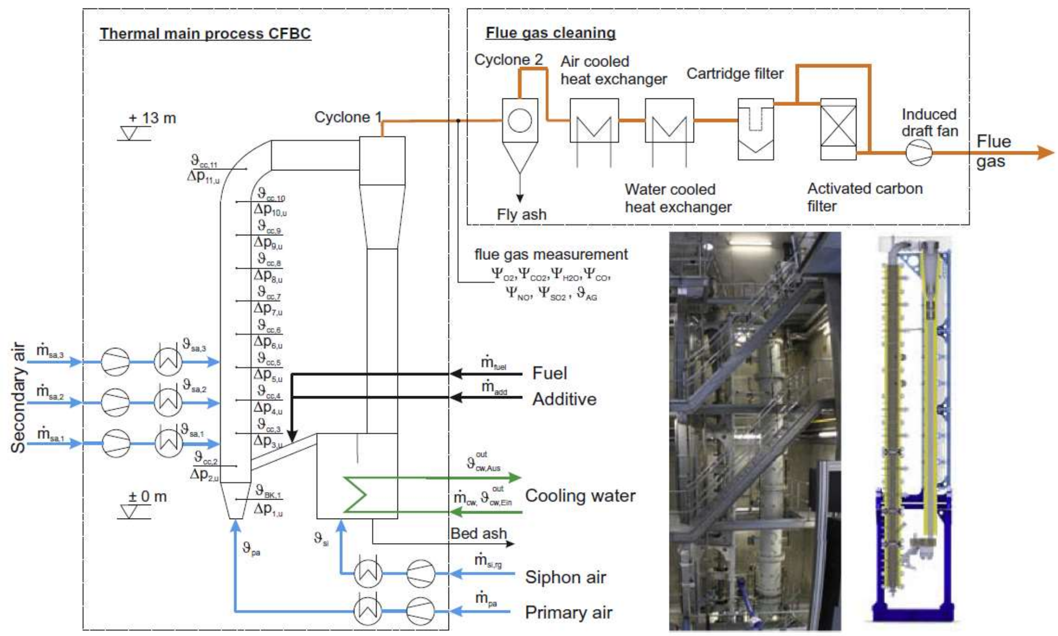

Figure 8: Process diagram of circulating fluidized bed rector and flue gas treatment

In the gasification mode, the gasification gas is fed through a combustion chamber followed by the flue gas cleaning section shown in Fig. 8.

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CLAUSTHALER UMWELTTECHNIK FORSCHUNGSZENTRUM (CUTEC)/TU CLAUSTHAL-ZELLERFELD

CUTEC was founded in 1990 as a non-university research institution of the federal state of Lower Saxony. The aim was strongly application-oriented research. That is why the institute was equipped with an extensive range of equipment on a technical scale, which could be continuously expanded over years. In 2017, CUTEC was transferred to Technical University of Clausthal.

The department Thermal Processes deals with topics in the field of pyrolysis, gasification and combustion. Research and development topics are the biomass conversion, treatment of household, commercial and production waste with the thermal processes mentioned. The team is also working on improving processes and new products by developing initial ideas from the laboratory scale and improving yields. In the field of gas cleaning, topics relating to dry sorption, scrubbing processes and thermal post-combustion are dealt with. Finally, the area of emission measurement and the preparation of proposals for emissions should be mentioned. Mobile measurement devices are available for this purpose, with which measurements can be carried out on industrial plants, power plants and waste incineration plants.

The department manages an extensive number of thermal plants such as two different sized pyrolysis rotary kilns, a reverse-acting grate for testing household refuse incineration, a smaller stationary fluidized bed and a circulating fluidized bed biomass gasifier. There are also smaller ovens for various tasks.

Since 2004 the CUTEC Research Center operates the circulating fluidized bed gasifier ArtFuel for biomass conversion. The research plant has a thermal fuel capacity of 400 kWth, which is an equivalent fuel mass flow of about 60 – 80 kg/h, depending on the calorific value of the fuel used. The gas cleaning system with ceramic filter, water-gas-shift reactor, Water- and RME-scrubber delivers the gas to a synthesis plant that produces FT-Liquids. The dimensions of the gasifier are 30 cm in diameter and 8 m in height. Typical gasification temperatures are between 750 and 850 °C. Both air and steam with oxygen can be used as gasifying agents. To influence the softening of the ash or formation of tars, additives such as lime, quicklime or dolomite can be added via additional bunkers and feeding options. Previous input materials were various biomasses, such as wood (pelletized or as wood chips), straw, miscanthus, switch grass, algae and digestates but also waste material such as refuse derived fuel or sewage sludge. Various feed systems are available for the above-mentioned different input materials from loose and stalk-like straw to compact material such as pelletized fuels or sewage sludge. The gasification plant is operated in three-shifts. Approximately 8 to 10 hours are estimated for each test point, so that up to about 10 trials can be approached in a test campaign within a working week.

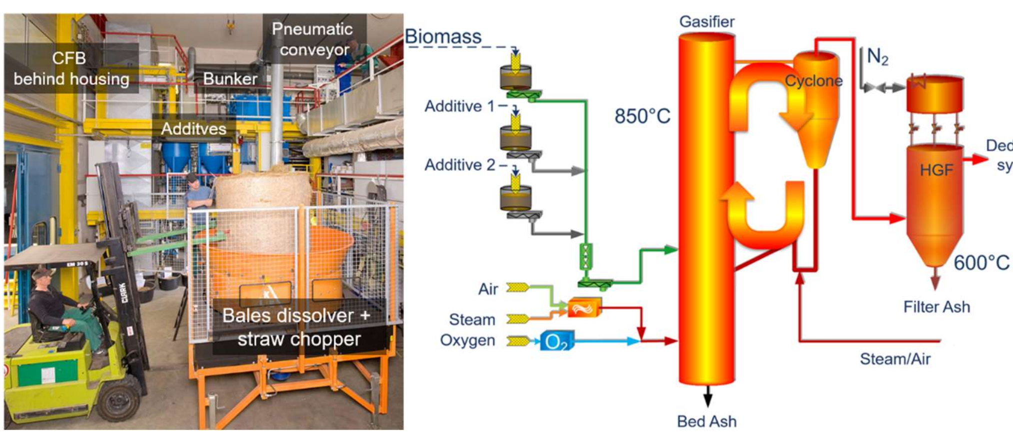

Figure 9: CUTEC-Gasifier

The plant is equipped with an extensive measuring and analysis equipment. This includes online gas analysis in duplicate for both raw gas and pure gas. There are also pressure, temperature and flow meters. Thus, quite precise mass and energy balances can be created.

Between 2008 and 2010, the plant was expanded to include fine cleaning for the synthesis gas generated in the ArtFuel-Gasifier. The synthesis gas fine cleaning system now also consists of a COS hydrolysis, a Sulferox scrubbing for separating hydrogen sulphide and a following Selexol stage for washing out carbon dioxide. At the same time, the facility was equipped with a feeding system which is able to convey straw-like biomass. In addition, a bale breaker and a straw mill with a subsequent pneumatic conveying system were purchased, which conveys straw into the actual storage bunker.

Latest project on the gasifier was the international project called "ASHES" with the German partners Fraunhofer UMSICHT/Sulzbach-Rosenberg, KIT (ITC), FZJ (IBG-2 Plant Science), Fraunhofer IGB, TECNARO, BAM, OUTOTEC and different Brazilian partners like Universidade Federal de Goiás (UFG) and Federal Institute of Goiás (IFG). Aim of the project was to extract nutrients from ashes from the thermal recycling of sugarcane bagasse. The challenge was that bagasse ashes are inherently low in nutrients and, for example, only have a fraction of the phosphorus content typical of sewage sludge. Thus, nutrient-rich additives typical of Brazil had to be found in order to increase the nutrient content in the ashes. The project partners KIT and UMSICHT produced incineration ashes. As a comparison, ashes from gasification were produced at the CUTEC research centre. In sum 26 test runs were carried out as part of this project with a temperature range between very low 710°C and higher 860°C. As additional nutritious material sewage sludge, chicken dry dung, soya straw and sugarcane straw were used. The produced ashes were then used for planting trials at Forschungszentrum Jülich, either directly as ash or as material performed at Bundesanstalt für Materialprüfung (BAM) using the OUTOTEC process.

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FRAUNHOFER INSTITUTE FOR FACTORY OPERATION AND AUTOMATION IFF MAGDEBURG

Demand for energy in the form of electricity and heat has grown steadily in recent years with no turnaround in sight in the near future. Energy costs are a crucial factor with a direct economic impact on businesses and manufacturers in particular. Efficient use and handling of energy carriers are most imperative, not only economically but also ecologically.

The objective is to create closed and efficient energy and material cycles for manufacturing processes. The waste streams produced should be harnessed to lower energy and waste disposal costs sustainably.

The challenge is to adjust manufacturing processes and material and energy streams, which are different in virtually every company, to the specific circumstances and to develop individual system solutions to integrate heat and power recovered from material optimally in the manufacturing process. We develop custom system solutions and process solutions that do this for your company.

The Fraunhofer IFF not only has expertise in the implementation of distributed energy conversion systems in energy systems and the simulation and modeling of their processes but also in the development of process and plant systems that recover heat and material from renewable solid fuels in efficient conversion systems. Biomass, agricultural waste and industrial waste can be put in this category, for instance.

What is more, the Fraunhofer IFF also optimizes industrial manufacturing processes that require process heat in terms of waste recycling. Environmentally compatible conversion of waste on site to generate heat and power combines cost cutting with a capability to reduce CO2 by conserving fossil energy carriers.

Test Equipment

In our projects, we conduct pilot studies of the recovery of heat from renewable solid fuels, such as biomass, agricultural waste and industrial waste, among others.

Our process development laboratory is equipped with numerous instruments that analyze gas composition of the fuel and flue gases produced during the gasification and combustion of biomass, fuels and waste. Even the fuels themselves as well as the gasification and combustion processes can be evaluated and simulated.

The laboratory additionally has advanced instrumentation and control systems for implementing and testing control processes for thermal systems. The instrumentation includes systems for exhaust and fuel gas analysis too.

Laboratory fluidized bed gasifier with a gas purification test bench

A stationary laboratory fluidized bed gasifier with a gas purification test bench can be operated at the Fraunhofer IFF Magdeburg's Virtual Development and Training Center to test the efficiency of gasification processes with different gasification agents (air, steam and oxygen) and variable catalyst materials. A gas mixing system and extensive gas instrumentation are also on hand.

Stationary laboratory fluidized bed combustor

A stationary laboratory fluidized bed combustor with gas instrumentation is on hand to test combustion processes and analyze the flue gases they produce.

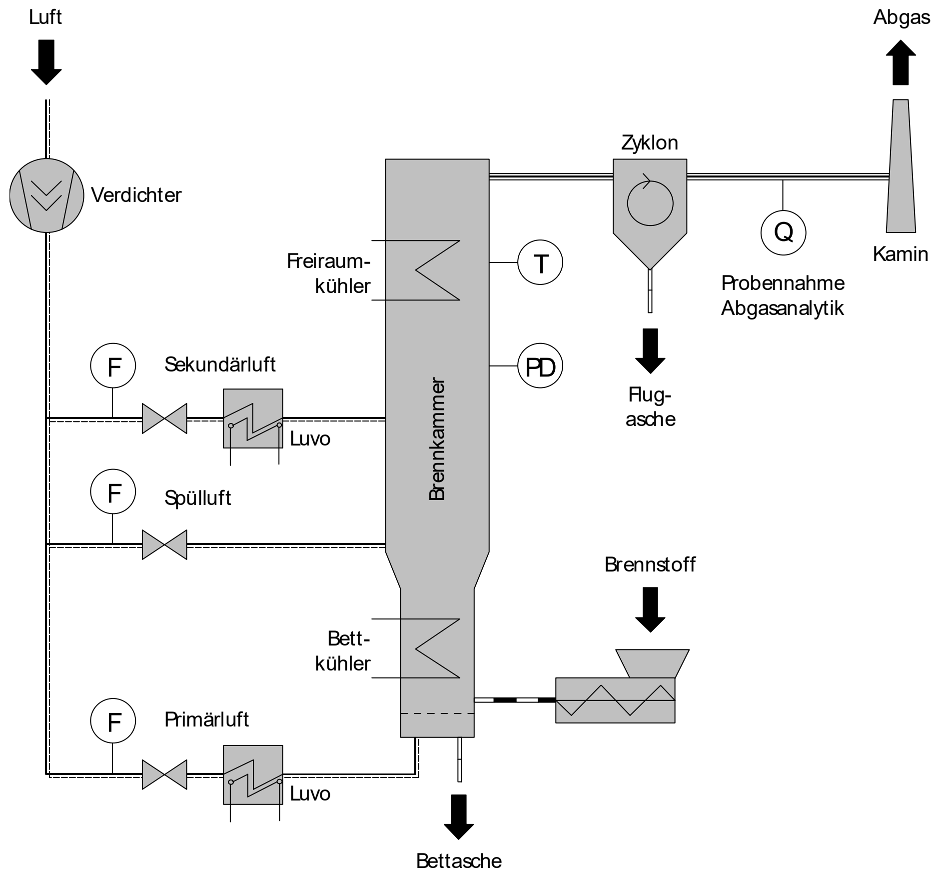

Figure 10: Simplified process flow diagram of the laboratory fluidized bed combustor SWSF 100

Projects

Technical Study of the Testing of the Combustion of Recyclable Materials in Stationary Pilot Fluidized Beds and Analysis of the Results

The company recovers solvents from residual coating materials, e.g. paint sludge or overspray, from coating systems at one of its facilities. Stripped and distilled solvents can be reused to manufacture products but solid residual materials accumulate during the process. The recovery process requires process heat, currently provided by the fossil energy carrier heating oil. A resource-efficient process solution utilizing the residual material from which heat can be recovered to supply heat would be expedient.

The feasibility in principle of incinerating the residual materials from solvent recovery in a stationary fluidized bed is therefore being tested in this project. To this end, the samples are initially characterized by preliminary testing in the laboratory to be able to draw conclusions about their combustion and theoretically potential emissions.

This is the basis for testing the residual materials' real combustion in a technical pilot study. The data obtained from this are intended to provide information on compliance with emissions standards and on the extent to which action must be taken for compliance (options to reduce primary pollutants, i.e. mitigation actions during combustion itself and the amount of flue gas purification required if necessary). Moreover, a worst case will be identified based on the tests, which is intended to serve as the foundation for designing a plant.

Technical Testing and Evaluation of a Method of Pyrolyzing Sewage Sludge

The company contracted the Fraunhofer Institute for Factory Operation and Automation IFF to test technically and evaluate the C-Cracker pyrolysis plant, which it developed, for the recovery of heat from organic, phosphorus-rich residual materials.

Distributed plant designs are entering the focus of research and engineering to enable sewage treatment plant operators to ensure more reliable waste management under new regulatory standards and concomitant increased demand for capability to recover heat, to make costs calculable, and to cut hauling costs.

Along with incineration, pyrolysis has proven to be an innovative method for harnessing the material and thermal properties of residual materials. The solid products (carbon) produced by pyrolysis can be used in agriculture as soil improvers because of their phosphorus content.

Other plans for use are emerging as well, e.g. use as activated carbon in the sewage treatment process to capture pharmaceuticals and other micropollutants. The high-heating-value gas produced during pyrolysis can additionally be used as an energy source to produce heat and power.

A survey of pyrolysis as a method of heat recovery will be compiled, factors for regulatory approval will be recorded, the C-Cracker will be specified in detail, and "full power" operation factoring in the sewage sludge used will be analyzed in the project to better classify the C-Cracker pyrolysis plant. A comparison of pyrolysis plants will additionally spotlight the plant's key features.

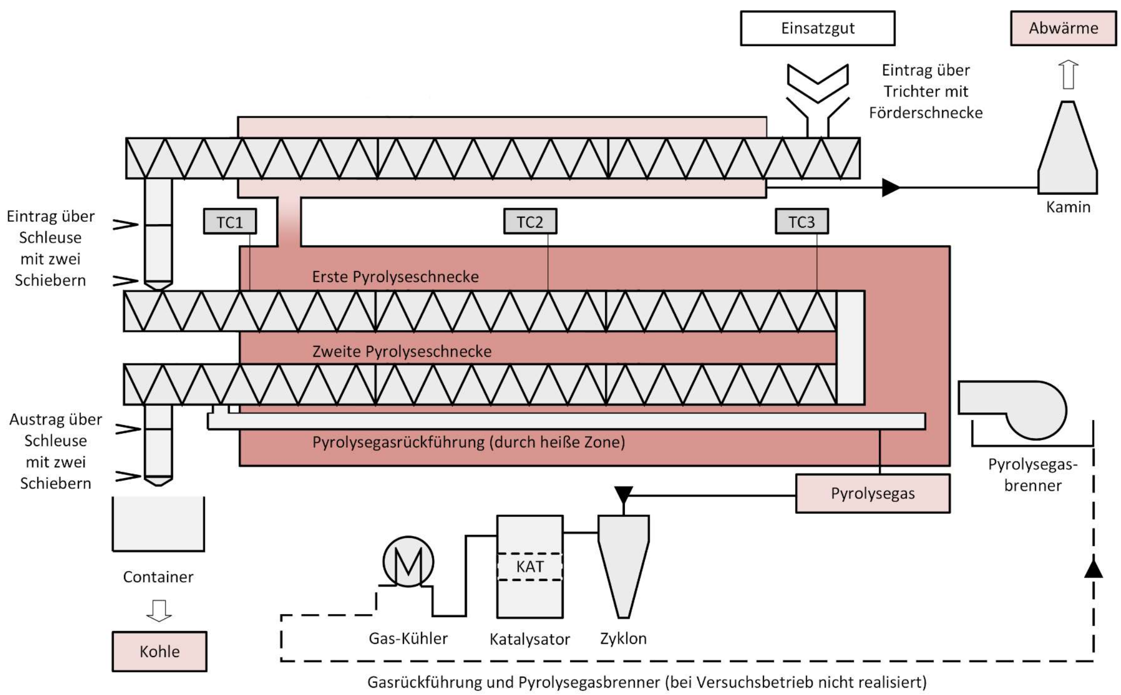

Figure 11: C-Cracker process flow diagram

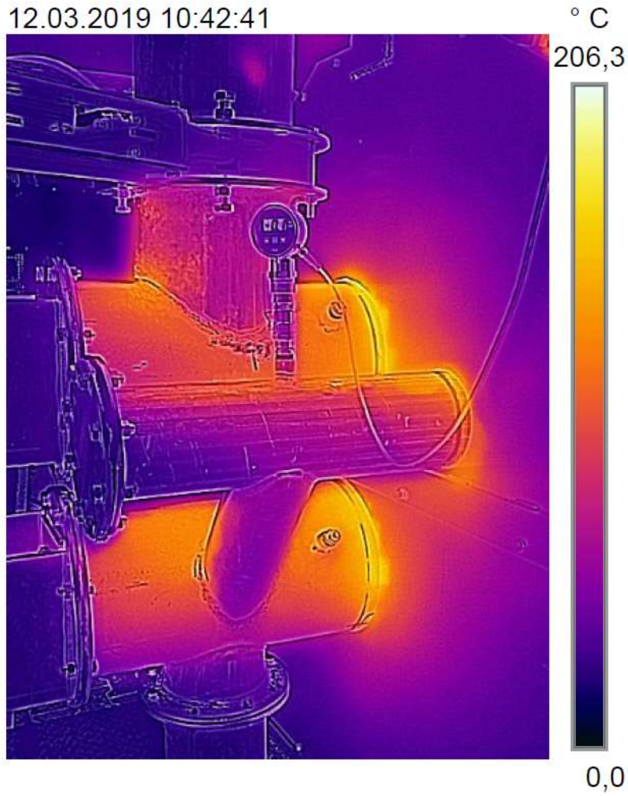

Figure 12: Thermogram of the pyrolysis plant's connected screw conveyor and insulated reactor chamber

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FRAUNHOFER-INSTITUT FÜR UMWELT-, SICHERHEITS- UND ENERGIETECHNIK UMSICHT

Research area:

Fraunhofer UMSICHT developed since 1994 a power plant concept for CHP on the basis of an atmospheric, air-blown stationary fluidized bed gasifier for 1-20 MW thermal fuel input and spark-ignition engines. The core development was the catalytic reforming of tars in a high dust containing producer gas directly downstream of the gasifier using Ni-based catalysts supported on honeycomb monolithic ceramic carriers. Recent research focuses on the further development of reforming catalysts in a bench scale test rig with simulated synthesis gas from steam and oxygen/air blown biomass gasification (mixed from bottles) on one hand and on synthesis gas chemistry for the production of methane, methanol and higher alcohols under fluctuating conditions regarding flow rate and synthesis gas composition on the other hand in experimental facilities ranging from 100 mg to 4.5 kg catalyst.

Additionally, Fraunhofer UMSICHT offers consulting and concept development for the application of biomass gasification as source for gaseous fuels in high temperature processes, the production of substitute natural gas and the combination of biomass gasification with power-to-gas/liquids/chemicals concepts.

Experimental work on the characterization of different fuels in combustion and gasification mode can be performed in a 100 kW bench scale stationary fluidized bed reactor under atmospheric pressure fluidized with (preheated) air. The versatile feeding system can handle solid feedstock in a large bandwidth of densities from pellets with approx. 850 kg/m^3 down to straw or fluff with about 120 kg/m^3 bulk density. Also, high amounts of fines can be tolerated, as the fuel is introduced into the lower part of the fluidized bed.

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TU DARMSTADT, ENERGIESYSTEME UND ENERGIETECHNIK

EST – The research of the Institute for Energy Systems and Technology focusses on innovative methods and concepts for energy supply based on thermal conversion processes. In particular, processes based on fluidized bed technology are being investigated. In addition to experience in In addition to experience in the experimental field, the institute has expertise in the modelling and simulation of multiphase flows. In 2009 a plant in pilot scale (1 MWth) consisting of a dust-fired combustion chamber and two fluidized bed reactors was built and has been in operation since then. Especially experiments on CO2 separation processes (Carbonate-looping and chemical-looping process) have been investigated in the reactors so far. In addition, pilot tests for fluidized bed combustion of various fuels such as straw and substitute fuels have been carried out. In 2015, one of the reactors was extended by the functionality of a High Temperature Winkler (HTW) gasifier. Several gasification test campaigns in 0.5 MWth scale have already been done. Currently the pilot plant is extended by a gas treatment plant to produce a high quality synthesis gas.

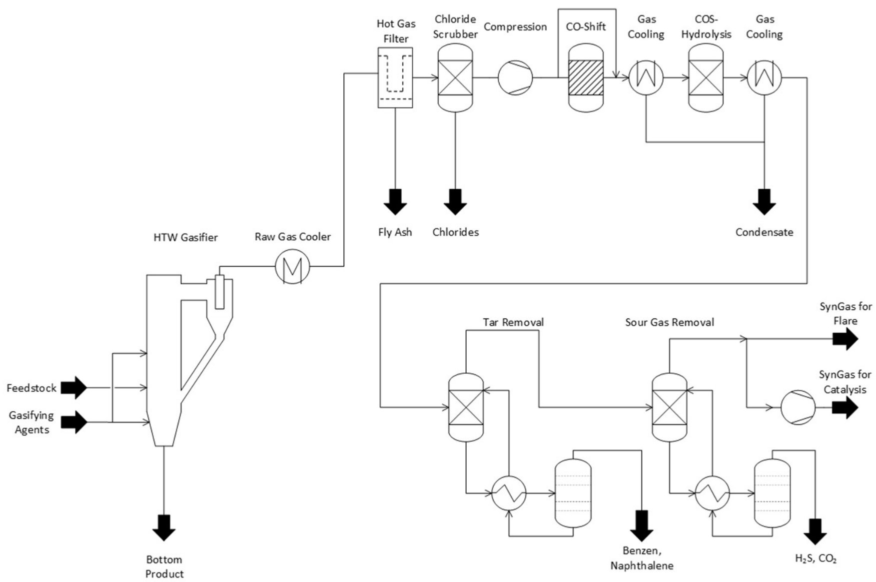

Figure 13: Process diagram of gasifier and gas treatment unit at EST

The process chain is shown in Figure . It includes the gasification of the fuel, the raw gas treatment and the possibility to test different polygeneration concepts (Technologies for flexible production of electricity and synthetic fuels). It contains the HTW gasifier followed by a raw gas cooler, a hot gas filter and a chloride scrubber. These steps take place under atmospheric pressure. Afterwards the gas is compressed and further processing steps take place: The gas undergoes a CO-shift, COS hydrolysis, gas cooling steps, benzene and tar removal and the sour gas removal. The synthesis gas can be further compressed to use it for the catalytic production of synthetic fuels. Various research projects are currently running on this plant.

Lig2Liq is a research project co-funded by the European Commission managed Research Fund for Coal and Steel (RFCS). The project consortium consists of seven partners from research and industry. Aim of the project is the development of an economically efficient concept for production of liquid fuels, such as Fischer-Tropsch fuels or methanol from lignite and solid recovered fuel from municipal waste. Therefore, in a first step a concept for HTW gasification is developed and tested for the production of syngas, which is optimized with respect to cold gas efficiency, carbon conversion efficiency and operability. The full process chain is tested using the process chain shown in Figure .

Clara is a Horizon 2020 project funded by the EU, involving 13 partners investigating a novel biomass-to-biofuel process chain. Aim of the project is the development of an efficient technology to produce liquid fuels based on chemical looping gasification. Innovative concepts for the biomass pre-treatment, the chemical-looping gasification (CLG) and syngas cleaning are developed, tested and optimized. A suggested process chain of the process is shown in

Figure 10 on the left side. It includes biomass pre-treatment, chemical-looping gasification, syngas treatment and fuel synthesis. The main targets are 33% of carbon utilization, an energetic fuel efficiency of 55% and fuel production costs of 0.7 €/l. Unlike the process shown in Figure , chemical-looping gasification is used instead of HTW gasifier in the first step. This process is shown in

Figure 10 on the right side. In this process, oxygen for the gasification process is provided through cyclic reduction and oxidation of a circulating oxygen carrier material. A costly air separation unit is not necessary.

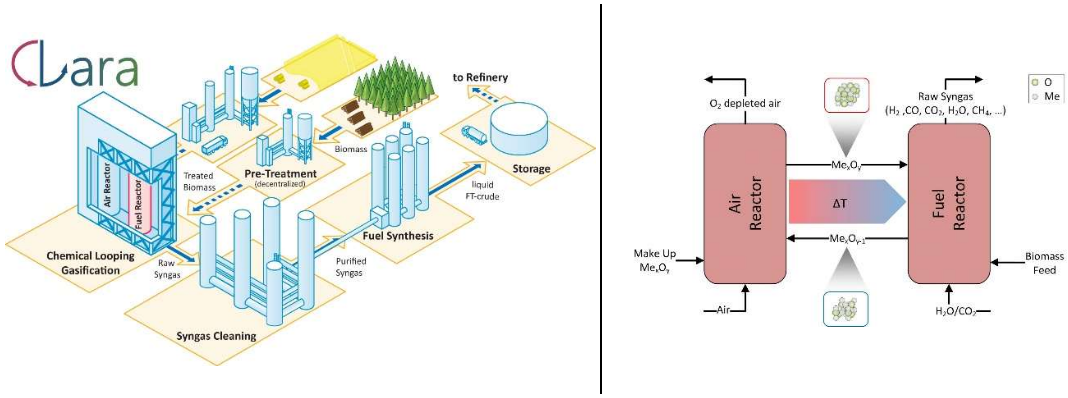

Figure 10: Left: Biomass-to-biofuel process chain of the Clara process;
Right: Chemical-looping gasification process

VERENA is a BMWi (Federal Ministry for Economic Affairs and Energy) funded project, involving thirteen partners from research and industry. The main objective of the project is the development of polygeneration plants for flexible production of electricity or fuels using different residues and investigating different gasification processes. The focus is on further development and testing of gasification technologies, as there is only little experience with the gasification of residues so far. At EST HTW and chemical-looping gasification process are investigated using the process chain shown in Figure . In addition fixed bed, entrained flow and COORVED gasifier experiments are performed at project partners.

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UNI STUTTGART, INSTITUT FÜR FEUERUNG- UND KRAFTWERKSTECHNIK (IFK)

The University of Stuttgart (USTUTT) is one of the leading nine technical universities in Germany (TU9), with highly ranked programs in civil, mechanical, industrial and electrical engineering. Around 25.700 students are enrolled in the courses offered by 160 degree programs. The University of Stuttgart has over 5.330 employees among them 283 full professors who work in over 150 institutes, 10 faculties and in central institutions. Research at the University of Stuttgart is strengthened through interdisciplinary networks of cooperation with other research institutions and industry in order to continue to expand the cutting-edge position in these fields.

The Institute of Combustion and Power Plant Technology (IFK) at the University of Stuttgart has gained expertise in energy research for more than 50 years and thus holds considerable experience concerning the thermal utilisation of gaseous, liquid and solid fuels such as coals, biomasses and solid recovered fuels.

For all commercially available combustion and gasification systems (i.e.: fixed bed, pulverized fuel, fluidized bed systems and gaseous and liquid fuel boilers), experimental facilities are available with capacities ranging from 5 kW up to 500 kW. In the field of gasification, in these facilities mainly the following technologies are investigated: sorption enhanced gasification/reforming (SEG), air gasification, oxygen/steam gasification, and multi stage gasification.

A well-equipped laboratory for fuel, ash and sorbent characterization as well as liquid and gas sample analysis is available at USTUTT. Apart from different mills, crushers and other equipment for fuel and sample preparation, a range of online gas analysers is at disposal (

Table 1). Particularly interesting for the SEG tests in RECORDS will be an online tar analyser that is available at USTUTT for tests at small and pilot scale. In addition, tars and other pollutants can be scrubbed from the synthesis gas and can be subsequently analysed in the laboratory which will also allow an analysis of tar species.

Table 1: online gas analytics available at USTUTT.

Measurement principle	**Gas species**
NDIR	CO, CO_2, CH_4, SO_2
FTIR	Non-standard IR-active gases in flue gas (e.g. HCl)
Paramagnetic	O_2
Chemiluminescence	Nitrogen oxides
Micro GC	Non-condensable hydrocarbons, H_2S, COS
Thermal conductivity	H_2
Impact jet	Moisture (e.g. steam content in wet syngas)
IFK in-house developed online FID TTA300	Total tars
hot gas online GC (currently under trial)	Light tars, hydrocarbons, HCl, NH_3, H_2S, H_2O

Hydrogen or syngas production from biomass with optional BECCS

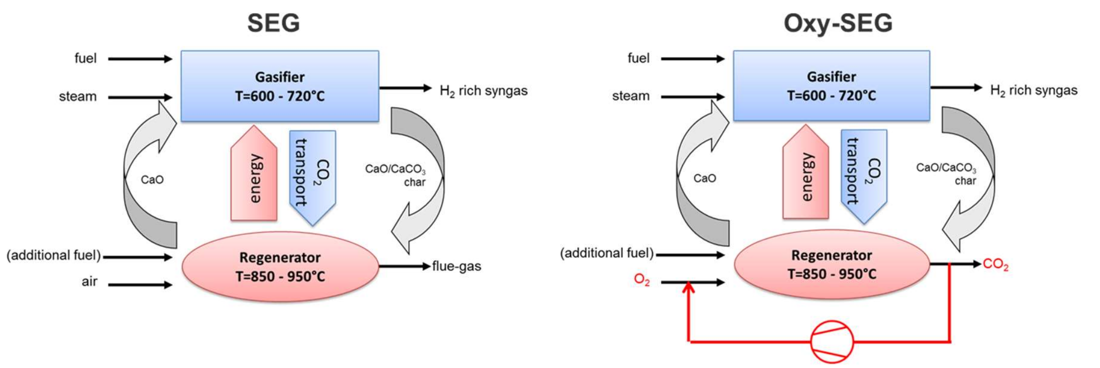

Figure 115: Principle of Sorption Enhanced Gasification without (SEG) and with oxyfuel regeneration (Oxy-SEG)

Indirect (or allothermal) gasification in a dual fluidised bed (DFB) system using steam as gasifying agent has been proven a promising biomass gasification concept for syngas or hydrogen production. In this indirect gasification concept, energy required for steam gasification is delivered by the circulating material that has been heated up in a separated fluidised bed combustor using residual char and additional fuel (if needed) as fuels. Due to the fact that air is only fed into the combustion/regeneration reactor, syngas obtained in this indirect gasification concept is almost N_2-free without using pure oxygen as gasifying agent, and so avoiding the energy-demanding and capital cost intensive air separation unit that is used in the conventional O_2-steam gasification process.

When using a CaO-based CO_2 sorbent as circulating material in an indirect gasification process (i.e. limestone) instead of inert solids (i.e. sand or olivine), a sorption-enhanced gasification (SEG) process (also known in the literature as absorption enhanced reforming – AER), results as shown in Figure 11. CO_2 absorption by the CaO introduced into the biomass gasifier removes CO_2 as soon as it is formed, shifting gasification and water gas shift reactions towards hydrogen production. Gasification temperatures in this case are in the range of 600-700°C, well below those used in a standard indirect gasification process, to allow the carbonation of CaO. In the SEG process, energy needed for biomass gasification with steam is largely supplied by the highly exothermic carbonation reaction. In addition, some sensible heat is provided by the hot solids circulated from the combustor ($CaCO_3$ regeneration) reactor that is operated at a higher temperature (i.e. approx. 900°C), as in the classic indirect gasification process. Similarly to the classic indirect gasification process, unconverted biomass char leaves the gasifier with circulating solids to be sent to the combustor reactor, where it is combusted with air supplying the heat required for solids heating and $CaCO_3$ calcination (i.e. CO_2 removal). Additional fuel may be needed in the combustor, to maintain suitable calcination temperatures. Further advantages associated to the use of CaO as bed material in this process rely on the fact that CaO-based materials are catalytically active towards tar cracking. Therefore, despite the lower temperatures used in the SEG process, it has been experimentally demonstrated that tar production is up to five times lower than in conventional fluidized bed gasification processes. Another inherent benefit of the SEG process that uses limestone as a sorbent material is that the high CaO content within the bed material of the process reduces problems caused by low ash melting temperatures that can cause bed agglomeration and fouling issues. In this way, the SEG process allows to use also critical fuels that are problematic in other fluidized bed gasification processes.

The process can also be used for carbon capture and storage (CCS) or when biomass is used as fuel bio energy carbon capture and storage (BECCS). For this the regenerator is fired with pure oxygen from an air separation unit. By this measure, highly concentrated CO2 is obtained as flue gas, which can be stored or utilized.

200 kW SEG demonstration facility

In Figure 12, the main characteristics and operating conditions of the MAGNUS facility as presented. The facility is constructed for process validation in industrially relevant conditions. It is designed with flexibility to be is for operation in a wide range of different conditions that are of economic and scientific interest. Its special design allows for switching between different configurations of interconnection of the gas and solid flows, hence giving the possibility to investigate a number of processes on one single facility (e.g. combustion, gasification, solid looping processes). For sorption enhanced gasification processes the facility will be operated in BFB-CFB mode. The sorbent regeneration reactor and steam gasifier can be operated in either air or oxygen combustion mode. The facility is equipped with a gravimetrically controlled dosing system with two units each for fuels and sorbents. As the reactors are refractory lined, they need to be heated up with a natural gas burner over the course of approx. 24 hours and consequently require shift work during test campaigns. The test facility offers numerous sampling ports to access the process with online gas analysers and solids sampling probes.

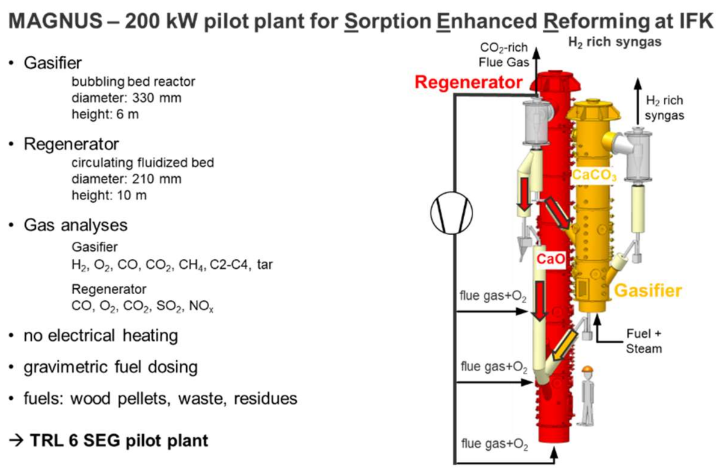

Figure 126: MAGNUS Oxy-SEG demonstration plant at IFK

Development of the SEG and Oxy-SEG process

The SEG process has now been studied in different scale during the last decade by several groups. Most research was done by TU Vienna and IFK University of Stuttgart. At IFK the development started from bench scale and has reached now a demonstration at TRL 6 in the MAGNUS facility (Figure 13). For most demonstration trials, wood pellets were used as fuel, however in two recent projects FLEDGED (H2020, 2016-2020) and NuCA (BMWI, 2018-201) also waste derived fuel pellets and shredded municipal solid waste were used successfully. The characterization and optimization of Oxy-SEG for waste fuels is now ongoing. Oxy-SEG is seen as a great opportunity for deploying chemical recycling of waste while additionally separating and storing CO2. Since waste contains high shares of biogenic carbon, this CO2-capture qualifies as BECCS and effectively removes CO2 from the atmosphere.

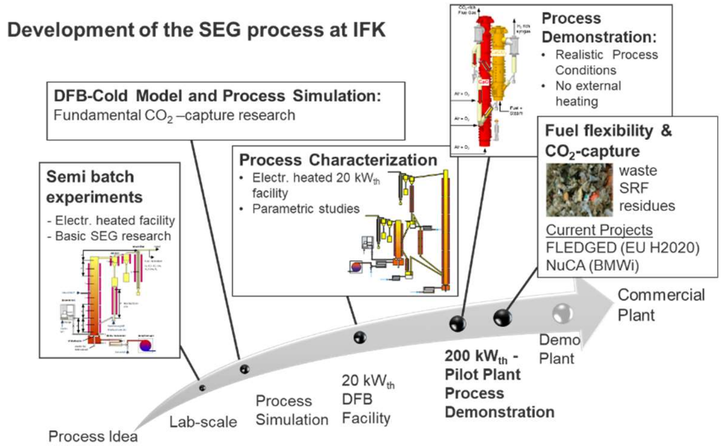

Figure 137: Development of Oxy-SEG at IFK

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TU BERGAKADEMIE FREIBERG, INSTITUTE OF ENERGY PROCESS ENGINEERING AND CHEMICAL ENGINEERING (IEC).

Research area:
The education and R&D profile of the Chair of Energy Process Engineering and Thermal Waste Treatment (EVT) at the Institute of Energy Process Engineering and Chemical Engineering (IEC), TU Bergakademie Freiberg, focuses on innovative processes, technologies and systems associated with closing the carbon cycle and the transformation from a linear to circular carbon economy for sectors ranging from energy, chemical, waste, metallurgy to processing industries. This profile is strengthened by the integration of the Fraunhofer Institute IMWS Branch Lab “Circular Carbon Technologies” at the institute. Key objective is the minimization of CO2 emissions associated with the thermo-chemical conversion of primary and secondary carbon resources. These include fossil as well as renewable energy resources such as crude oil, natural gas, coal, biomass, carbon-containing waste and CO2. Through a coupling with renewable energy (“green” electricity, “green” hydrogen) and the chemical recycling of secondary carbon resources, CO2 emissions-free chemical production can be achieved and technically realized.

To achieve our objectives, modern energy process engineering methods ranging from experimental process evaluation, CFD simulation, flow-sheet simulation, mineral phase simulation, reactive fluid dynamics to thermodynamic process chains analysis are utilized. The interdisciplinary integration with chemistry (organic, inorganic, physical and analytical), numerical mathematics, material engineering, non-ferrous and ferrous metallurgy as well as with business administration/economics/social sciences support a holistic evaluation of energy and raw material systems which is a unique strength of the chair.

To support the national transition towards a low carbon economy, IEC engages in the R&D of processes for the production of green hydrogen and carbon-neutral synthetic fuels from biogenic waste. IEC is currently developing a first-of-its kind project based on proprietary gasification technology for large-scale green hydrogen production from waste wood to support the National Hydrogen Strategy. Furthermore, IEC supports the low carbon transition in the mobility sector with synthetic fuels. To complement the developments in electricity-based liquid fuels (“E-Fuels”) IEC is developing biogenic waste-based fuels (“W-Fuels”) and biogenic waste-based fuels with integration of electricity-based renewable hydrogen (“WE-Fuels”).

Plants in Operation

FlexiSlag Pilot Plant at Institute of Energy Process Engineering and Chemical Engineering (IEC), TU Bergakademie Freiberg

The FlexiSlag gasification pilot plant at the Institute of Energy Process Engineering and Chemical Engineering (IEC), TU Bergakademie Freiberg, is a next generation slagging fixed-bed gasifier (further development of the BGL-technology) designed for flexible feedstock e.g. biomass waste, coal, petcoke, municipal waste, plastic waste etc. The technology offers:

1. adjustable gas application
    a. gas qualities for syngas application: low dust, tar and phenols-free, low C_xH_y,
    b. gas qualities for SNG and liquid products application: low dust, rich in light oil and C_xH_y,
2. highest C-recovery in syntheses products and strong reduction of water consumption for syngas application.

IEC has designed, constructed and tested a research facility with a BGL reactor in cooperation with Envirotherm GmbH. This facility consists of a scaled BGL-reactor with a diameter of 0.6 m and a height of 5 m. It is the smallest reactor of its kind in the history so far. This plant has a capacity of 10 MW (fuel heat) and is designed to operate at 40 bar in a 24/7-shift system.

The facility is constructed with the aim to investigate the basic processes taking place in the BGL reactor. It is equipped with state-of-the-art systems, such as control systems and measurement techniques, e.g. measurement of temperatures at different locations along the height of the reactor and along the radius of the insulating wall and the fuel bed. Among the special measuring techniques are also those for image acquisition of the slag tapping process and sampling systems for slag, gas-liqueur and gas-water. The fixed-bed gasification facility enables the study of processes including but not limited to slag production, gasification reactions and the heat transfer, the effect of varying fuel composition, operation load, gasification agent composition ratio (Steam/Oxygen) and tuyere velocities, etc.

Besides conventional fuels, alternative feedstock such as biomass has been tested in the gasifier. Extensive preliminary investigations have been carried out to detect and balance corn straw pellets, wood pellets, torrefied wood pellets and their mixtures. Based on the experiments, operating parameters are defined to enable mono gasification in the FlexiSlag gasifier. One focus of the experiments is the variation of additives to achieve an appropriate ash melting behavior.

Web: https://tu-freiberg.de/fakult4/iec/evt/downloadspublikationen

Figure 148: FlexiSlag gasification pilot plant at IEC, TU Bergakademie Freiberg

FlexiEntrained (GSP) Pilot Plant in Freiberg

The FlexiEntrained gasification pilot plant – operated by the DBI-Virtuhcon GmbH in cooperation with the Institute of Energy Process Engineering (IEC), TU Bergakademie Freiberg – is an entrained-flow gasifier equipped with a water-cooled cooling screen, a spray full quench for gas cooling and a Sulfurox Plant for desulfurisation as well as a waste water treatment plant.

Moreover, the complex features a pneumatic feeding test rig of commercial size. The FlexiEntrained gasification system is able to convert a board variety of feedstock into a high-quality tar-free syngas and vitrified slag. The tested feedstock varies from hard coal, lignite, biomass, coke or char and coal-waste mixtures to municipal waste, sewage sludge and RDF.

The FlexiEntrained gasification Pilot Plant with 5 MWth (built by Pressag Noell) was originally designed as a demonstration facility for the Noell Conversion Process (NKV) combining pyrolysis of residues or municipal solid waste (MSW) with subsequent entrained flow gasification, operating in a range of pressure between 0.6 and 2.6 MPa.

The entrained-flow gasifier operates with pulverized or liquid (slurry) feed in co-current flow with short residence time in the gasifier (a few seconds). The feed is ground to a size of 500 µm or even less to promote mass transfer and allow transport in a dense flow feeding. Dry feedstock preparation is essential for this type of gasifier. Given the short residence time, high temperatures are required to ensure a good fuel conversion, and therefore all entrained-flow gasifiers operate in the slagging temperature range (above 1200 °C), which leads to a high oxygen demand. The ash slagging at high temperatures is used to build a protection layer on the cooled inner wall of the reactor chamber and for the vitrifying of the ash and its leachable components.

The FlexiEntrained gasifier operated by DBI-Virtuhcon GmbH does not have any specific technical limitations on the type of fuel used, although feedstocks with a high ash melting temperature or high ash content (> 40%) will drive the oxygen consumption to levels where alternative processes may have an economic advantage. By using the cooling screen wall designed for the reaction chamber, temperatures up to 1900°C are manageable in the FlexiEntrained gasifier. The generated gas is free of hydrocarbons, has a very low amount of methane and needs less efforts for gas cleaning.

The plant has been used for different industrial organizations to investigate their feedstock including feedstock preparation and the evaluation of gasification conditions and validation of products and byproducts. The plant is equipped with a wide variety of measurements and sampling components in combination with its own laboratory capacity and expertise.

Latest research projects have focused on the optimization of sewage sludge gasification and testing of suitability for gasification of thermally-prepared RDF pellets.

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Figure 159: FlexiEntrained gasification pilot plant in Freiberg

FlexiCOORVED Pilot Plant at the Institute of Energy Process Engineering and Chemical Engineering (IEC), TU Bergakademie Freiberg

The FlexiCOORVED gasification pilot plant is a fluidized-bed gasifier specially designed and developed by the Institute of Energy Process Engineering and Chemical Engineering (IEC), TU Bergakademie Freiberg.

The FlexiCOORVED gasifier (CO2-reduction by innovative gasifier design) combines an internal circulated fluidized bed with a moving bed gasification zone to achieve high carbon conversion rates for fine as well as coarse particles. It is originally designed to be applied for feedstocks with a high ash content.

The FlexiCOORVED gasifier combines different flow patterns in one reactor. The main reaction zone where the feed and the primary gasification agent are inserted is located in the middle section of the reactor. The injected primary gasification agent forms a jet and therefore a circulation cell in the fluidized bed. Depending on the oxygen content and the subsequent exothermic combustion reactions, the temperatures in this flame-like zone could exceed 2000 °C. Because of the high temperatures, particle agglomeration takes place at temperatures above the sinter temperature. When the agglomerates are big enough in size, they drop out of the jetting bed and reach the bottom section of the gasifier.

Below and above of the main reaction zone, two post gasification zones are located. In the upper part of the reactor, a fast-fluidized or entrained regime occurs. Here fine particles which are carried out of the spouted bed will be post-gasified. In the bottom section of the reactor, a moving bed can be found where post-gasification of carbon-containing agglomerates falling out of the spouted bed takes place. Therefore, an oxygen-containing secondary gasification agent is injected into the bottom of the reactor. Between the moving bed and the main reaction zone, a bubbling fluidized bed is present. A mixture of the raw gas and unreacted secondary gasification agent rising from the moving bed are used as fluidization agent.

The FlexiCOORVED gasifier is operated at ambient pressure with a thermal capacity between 40 and 60 kW in continuous mode. The temperatures in the main reaction zone are in a range from 850 °C to 1200 °C under the use of $CO2$ or steam as gasification agents.

With its unique design, the FlexiCOORVED gasifier overcomes the disadvantages of classic fluidized bed gasification. It has an almost complete carbon conversion (up to 99 %) and can easily handle ash-rich feedstocks. The FlexiCOORVED gasifier has been used in several research projects with sewage sludge as well as biomass-containing waste with high ash content. During the test runs, stable operation has been achieved with almost complete carbon conversion. In addition, the gasifier has been used to separate phosphorus from sewage sludge. It has been demonstrated that it is possible to extract the phosphorus in the gaseous phase via the use of the FlexiCOORVED gasifier.

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Figure 16: FlexiCOORVED gasification pilot plant at IEC, TU Bergakademie Freiberg

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RWTH AACHEN, TECHNOLOGIE DER ENERGIEROHSTOFFE (TEER)

RWTH Aachen University is a public research university located in Aachen, Germany. With more than 45,000 students admitted in 144 study programs, it represents the largest technical university in Germany. The Unit of Technology of Fuels (TEER) at RWTH has started its work under the direction of Prof. Dr.-Ing. Peter Georg Quicker in August of 2009. TEER teaches and researches in the areas of thermal, physical and chemical conversion of renewable, secondary and fossil energy carriers. Special focus lies on thermal conversion of waste and the reduction of harmful environmental effects, especially the reduction of airborne pollutants. TEER's research activities range from conceptual studies to process assessment and development on a laboratory scale as well as on an industrial scale. In this context, the development and optimization of measurement methods, especially for tars, (poly-) aromatic hydrocarbons (PAH, BTX) and particles as well as fibers play an elementary role in TEER's research. TEER's analytical competence ranges from the continuous measurement of syngas and flue gas composition to various discontinuous gas sampling setups. The Unit disposes over a fuel laboratory where basic properties (e.g. water, ash, volatiles, heating value and elementary analysis) as well as special parameters (e.g. ash softening behavior, BET surface) can be determined. TEER's technical center is equipped for the operation of pyrolysis, gasification and combustion tests on a semi-industrial scale.
In the following, two examples for research projects in the field of gasification are described that are conducted currently at TEER:

One main challenge of biomass gasification plants is the limited storability of the produced syngas due to its limited stability. Operating plants in the field compose almost exclusively of a direct syngas usage, e. g. in gas motors for cogeneration of heat and power (CHP). A current research project at TEER (IntenseMethane, public funding in context of the 7th Energy Research Program of the German Federal Government under the funding code 03EI5405D) addresses this problem by coupling a staged biomass gasifier (ca. 230 kWth fuel input) to a biogas fermenter. This innovative concept aims at the development of a biological methanation stage in order to allow storing the produced methane gas or feeding it into the existing public gas infrastructure. TEER's part in the project mainly focuses the nitrogen-depleted operation of the gasifier, the characterization and minimization of tars as well as volatile hydrocarbons (VOC) in the syngas in order to protect the biological methanation stage from those partly toxic substances. The project started in 2020 and is funded for three years. Partners in the project consortium are the Chair of Energy Process Engineering at Friedrich-Alexander-University Erlangen-Nürnberg (FAU), LiPRO Energy GmbH & Co KG and BEKON GmbH.

Another current contract research project at TEER addresses the development and assessment of a gasification process for problematic polymer waste, in particular expanded polystyrene (EPS) originating from construction/demolition sites. Due to fire safety regulations, EPS in the construction sector contains significant levels of brominated flame retardants, which can form toxic polybrominated dioxins and furans (PBDD/F) in thermochemical processes under certain conditions. The project approach is based on an operational wood gasification system, which was optimized and upgraded for the co-gasification of expanded polystyrene in a bed of wood chips. TEER's works in the project consist of the scientific support during the process development and the permit procedures for the pilot plant and the characterization of the thermochemical behavior of the input materials on a laboratory scale. Furthermore, experimental campaigns on a prototype with 270 kWth fuel input were conducted in cooperation with the project partner Ecoloop GmbH in July/August 2020. During the experimental campaigns, the plant was successfully operated with a fuel mixture of up to 50/50 wood/EPS (energetically). The syngas was utilized in a gas motor for CHP cogeneration with very low gas emissions. An extensive measurement and sampling program was conducted in order to characterize different operation stages and to assess possible emission levels. The project started in 2018 and runs until end of 2020.

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OTH AMBERG-WEIDEN, INSTITUT FÜR ENERGIETECHNIK

The Ostbayerische Technische Hochschule Amberg-Weiden (OTH AW) is a young, up-and-coming and innovative University of Applied Sciences at the heart of Eastern Bavaria. With its campuses in Amberg and Weiden, about 40 kilometres apart, it provides the region with first-class higher education. It supports the regional industry through knowledge and technology transfer, and its highly trained graduates strengthen the businesses in the region.

a) Center of Excellence for Cogeneration Technologies (CoECogen)

The Center of Excellence for Cogeneration Technologies was founded in 2012 and is part of the faculty for mechanical and environmental engineering at the OTH AW. It focuses on the applied research of cogeneration technologies, such as engine powered CHP units, fuel cells, steam processes and more. The relevance of the research for practical applications is ensured by implementing results from research in demonstration and pilot projects with their partners in the region.

In 2016 the new laboratory building for CHP systems opened in Amberg. The laboratory is equipped with 6 test benches for CHP systems in total, 4 of which are designed for small CHP systems with an electrical nominal power of up to 25 kWel and 2 for medium sized CHP systems up to 600 kWel. The laboratory is outfitted with a large range of measurement equipment, including exhaust measurement systems, power analysers and indicating systems for combustion analysis.

Figure 17: The CoECogen laboratory building in Amberg (top) with one of the test benches (bottom)

One area of the CoECogen's research over the years has focused on the utilization of products form biomass pyrolysis and similar processes, such as syngas, as fuel for CHP systems. Furthermore, current research is focusing on hydrogen, which can be produced from biomass and biowaste. Currently the infrastructure of the CoECogen laboratory is being updated to include a state-of-the-art hydrogen supply. The test benches will be able to run on either natural gas or hydrogen. Moreover, the admixing of hydrogen to natural gas will possible. The effect of injecting hydrogen into the natural gas grid on the operation of different CHP technologies, such as gas engines and fuel cells, will be investigated.

b) Institute of Energy Technology (IfE)

The Institute of Energy Technology (IfE) is a spin-off institute of the OTH Amberg-Weiden –Technical University of Applied Sciences. Their team of approx. 40 scientists and engineers work on a range of energy topics. These include the development of strategic energy plans of municipalities and industrial sites, the scientific monitoring and support of demonstration and pilot projects and working on applied research and development projects with an emphasis on renewable energy and combined heat and power technologies.

Since 2017 the Institute of Energy Technology (IfE) has been working on the utilization of sewage sludge as an energy source in cooperation with Fraunhofer UMSICHT. Dried sewage sludge can be processed into a gaseous and a liquid fuel by means of thermal catalytic reduction (TCR), a process developed by the Fraunhofer UMSICHT branch Sulzbach-Rosenberg. The role of the Institute of Energy Technology (IfE) is to utilize the produced fuels in a CHP unit providing power generation and heat production simultaneously.

A further current topic is the use of hydrogen from renewable energy sources, such as biomass and biowaste or excess electricity from renewable power production, such as wind or PV, by means of electrolysis. In recent years the public utility company Stadtwerk Haßfurt launched several research projects that the Institute of Energy Technology (IfE) supports as scientific partner. In 2016 a power-to-gas plant was commissioned as a power storage solution. In order to store surplus electric power from local wind and PV systems a 1.25 MW electrolyser was installed. The hydrogen produced by the electrolyser is stored in a high pressure tank and can then fed into the natural gas grid. In 2017 a further research project started in order to enhance the capabilities of the power-to-gas system and enable the conversion of the hydrogen back into electricity during times of high demand (project partners: 2G Energy AG, IfE). A prototype CHP-unit running on 100 % hydrogen was commissioned in June 2019. The aim of the research project is to optimize the engine operation while running on hydrogen and natural gas, respectively. Moreover, a fluent transition between the two different fuels is to be implemented for the CHP-plant to run continuously and non-dependent on the hydrogen supply. Further projects will include the utilisation of the produced oxygen from the power-to-gas plant in the local wastewater treatment facility in Haßfurt. In addition, a small scale thermal sewage sludge treatment unit is to be implemented as part of a research project. The waste heat of the process will be used for drying the sludge together with heat from an already existing CHP unit. Within the project consortium IfE will be responsible for the design of the energy system and the integration of the components on-site. Since 2020 the city of Haßfurt is an official EnergyLab of the OTH Amberg-Weiden Technical University of Applied Sciences. This will enable a greater cooperation and transfer of knowledge between the municipal utility company Stadtwerk Haßfurt and OTH.

Figure 18 The hydrogen powered CHP unit in Haßfurt

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THE KARLSRUHE INSTITUTE OF TECHNOLOGY (KIT)

KIT – The Research University in the Helmholtz-Association – was established by the merger of the University of Karlsruhe and Karlsruhe Research Center in 2009, both well-respected institutions with a long tradition. Today, the KIT is a leading German and European research institution with about 9.300 employees and 25.000 students. From fundamental research through to application, it excels in a broad range of disciplines, i.e. natural and engineering sciences, economics, humanities and social sciences worldwide unique large-scale research infrastructures.

The research work at KIT on gasification is focused on a detailed understanding of the different process steps taking place in such a multi-phase reacting system (solid / liquid / gas), which is mandatory for the design and optimization of a technical gasifier.

A multi-scale research approach will be followed, i.e. a wide range of technical and model fuels will be investigated using a wide range of experimental facilities from generic laboratory scale to globally unique pilot plants, supported by the development of process adapted measurement techniques and numerical simulation based on and validated by experimental results.

Fuel characterization: Experimental data on droplet evaporation, gas yield, solid particle structure evolution during pyrolysis, mass transfer in pores, intrinsic gasification kinetics and catalytic effects of ash are generated under well-defined conditions using a wide spectrum of atmospheric and pressurized experimental tools.

Atomization: The atomization of highly viscous, non-Newtonian suspension fuels using twin-fluid atomizers at high reactor pressure are investigated. Based on a detailed mapping of the spray from experiments at the Pressurized Atomization Test rig PAT using different model fuels, a mathematical model are derived to describe the influence of fuel specification and process parameters on spray quality. Research on atomization results in a “Virtual Spray Test Rig” that will enable the prediction of spray quality at high process pressure based on numerical simulation with a minimum amount of experimental data as the basis for burner design and optimization of gasifier operation.

Atmospheric gasification: The gasification of suspension fuels from model substances, as well as technical fuels from the bioliq® are investigated in detail at the atmospheric Research Entrained flow GAsifier REGA. This experiments give detailed information about the evaporation and pyrolysis behavior of the liquid and solid fuel phase in the burner near-field, the structure and reactivity of the char produced in this zone as a function of local stoichiometry and turbulent mixing, as well as temperature and stoichiometry requirements in the down-stream gasifier zone required for complete fuel conversion.

The mathematical models derived from these data are implemented in flow sheet simulations and in the numerical simulation tools.

The knowledge transfer from small-scale experiments and modelling to the technical process are accomplished using the data from the pilot scale high-pressure entrained flow research gasifier. Experimental data concerning global and local mass and energy balances, local energy flux, syngas quality and slagging behavior derived for a wide spectrum of fuel specifications and process parameters

bioliq®-Pilot plant

The bioliq® process, developed at the KIT aims at the production of synthetic fuels and chemicals from biomass. The bioliq® technology is based on a two-step process with decentral pyrolysis for the production of a transportable slurry from residual biomass (e.g. straw) and central slurry gasification with fuel production.

The pilot plant with 2 MW_{th} fast pyrolysis for biosyncrude production and 5 MW_{th} high pressure entrained flow gasifier operated at pressures up to 8 MPa (both designed and built in cooperation with AirLiquide E&C, Frankfurt), as well as the hot gas cleaning (MUT Advanced Heating GmbH, Jena), dimethylether and final gasoline synthesis (Chemieanlagenbau Chemnitz GmbH) are in operation.

The aim of the pilot plant is to demonstrate the bioliq®-technology at a TRL level of 6.

The facility is operated in several measurement campaigns in a 24/7 continuous mode in order to collect operating data for a wide range of feed and to gain practical experience in the operation and the equipment used.

The construction and installation of the bioliq® pilot plant was enabled by substantial funding. The investment of 64 m € was funded by the German Ministry for Food and Agriculture together with the Agency for Renewable Resources (FNR) with 30 m €, by the state of Baden-Württemberg with 2 m € partly using EU EFRE funds. The Helmholtz Association of large research institutions in Germany, KIT is belonging to, supported the plant with about 5.4 m €. The partners from industry contributed one quarter of the investment costs.

Web: www.bioliq.de

Figure 19: The bioliq® - pilot plant

Test facilities include the bench-scale Research Entrained flow Gasifier REGA (60 kW) for basic research on the gasification behavior of biogenic and fossil liquid and suspension fuels and the VERENA pilot plant for hydrothermal gasification.

The **REGA** is a head-fired entrained-flow gasifier (60kW$_{th}$) for the gasification of carbon-based liquid fuels or fuel suspensions under atmospheric pressure. Oxygen-enriched air is used as gasification and atomization medium, whereby stoichiometry, process temperature and atomization quality can be varied independently. The heat loss of the system is minimized by electric heating of the reactor walls. The reactor is equipped with flanges on 4 levels for sampling probes and thermocouple access. For laser-based measurements the flanges can be equipped with sight glasses, which are purged with nitrogen. By means of a vertically movable burner construction, radial profile measurements can be taken at any distance from the atomizer. The research work focuses on the influence of the fuel specification and the atomization quality on the yield and quality of the synthesis gas produced and the efficiency of the gasification process. Using the measured gas phase composition at the reactor outlet and elemental balancing, characteristic parameters like carbon conversion and yield of H2 and CO are derived.

Experiments are supported by flow sheet and CFD simulations of the gasification systems.

Figure 20: Research Entrained flow GAsifier REGA

The pilot plant **VERENA** (German acronym for „experimental facility for the energetic use of biomass") is designed for a total throughput of 100 kg/h of biomass with up to 20 % dry matter.

In the feed system, if necessary, biomass is mixed with water, crushed and conditioned. The educts in form of a solution, a dispersion or a suspension is then compressed up to 300 bar with a high-pressure pump and delivered into the reaction system. In the reaction system, the feed is heated up in a heat-exchanger and a first pre-heater. Thereby, inorganic salts precipitate and are separated. Then, the biomass is heated up to 670 °C in a second pre-heater and is subsequently gasified in the reactor. The reaction products are hydrogen, carbon dioxide, methane, ethane and traces of carbon monoxide. These product gases form a homogeneous phase with the excess process water. The required reaction energy is brought up in the pre-heaters and the reactor by heating via flue gas or hot nitrogen. The discharging products are conducted in reverse flow through the heat-exchanger and transfer their heat-content to the biomass feed. This step is enabled by the high process pressure and is essential for the energy efficiency of the process. By cooling down the product gas, the remaining heat is dissipated via cooling water. This can be used as source of low pressure steam or hot water. In the separation system, the formed reaction gases are separated from the process water by one or two step pressure relief. The second separator is equipped with an integrated CO2 scrubber. The product gas is used for energy production. After appropriate conditioning (reforming or methanation), the product gas can also be used for chemical applications. The process water can be discharged in a preflooder of a sewage treatment plant.

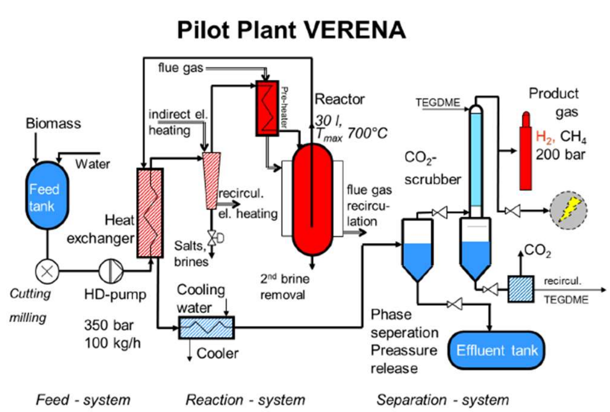

Figure 215: VERENA Flow sheet

The Energy Lab 2.0 is a large-scale research infrastructure for the research on the interaction of components for future energy systems and the testing of new approaches to stabilizing energy grids. Electrical, thermal and chemical energy flows are linked by new information and communication technologies. The aim of the research is to improve transport, distribution, storage and usage of electricity in order to create the foundations for the transition to renewable energy generation. As a development environment for the control of local intelligent energy systems, SEnSSiCC provides an experimental platform with all relevant components on a small scale to study even critical operating conditions as well as to train. Further, SEnSSiCC provides a power hardware in-the-loop test facility with real-time monitoring and control. SEnSSiCC also enables the detailed investigation and simulation of multi-scale energy systems with different energy carriers. Energy Lab 2.0 connects the following plants and facilities:

- solar power storage park with 1 MWel peak output
- bioliq® pilot plant for the production of synthetic fuels from residual biomass
- micro gas turbine with a rated power output of 100 kWel, used for the dynamic generation of electrical energy from synthesis gas or natural gas
- a new lithium-ion battery system with a capacity of 1,5 MWh
- two plants to convert electrical energy and carbon dioxide into synthetic methane (power-to-gas) and into synthetic fuels (power-to-liquid), respectively, with an output of about 100 kWth each
- high-temperature thermal energy storage facility in Stuttgart at the German Research Centre for aeronautics and space (DLR)
- a new facility to be established at the Forschungszentrum Jülich (FZJ) for dynamic testing of large electrolyzers

Research Projects:

Program-Oriented Funding (POF) of Helmholtz Association - Research Field Energy

At the Helmholtz Association, research is organized into programs. The Association designs these programs in accordance with the strategic guidelines formulated by the funding partners in dialog with the Helmholtz Association. The work is organized into six research fields, one of which is the research field energy. The Helmholtz Association brings together 19 scientific-technical and biological-medical research centers and is Germany's largest scientific organization.

Within the framework of the program "**Energy Efficiency, Materials and Resources**" 2015-2020, KIT research work is carried out with respect to biomass gasification. Fundamental work on the atomization of biomass suspensions in entrained flow gasifiers, reaction kinetic studies and experimental work at the REGA and bioliq® research plants have been and are being linked by means of numerical modeling.

The program "**Renewable Energies**" 2015-2020 investigates and further develops innovative technologies that complement an energy system based on the consumption of renewables. The Helmholtz Association enables the operation of unique and extensive research infrastructures that are used as part of the program to achieve breakthroughs in the development of energy technologies. Examples include the BESSY II synchrotron, the solar tower in Jülich, the bioliq® pilot plant and the Gross Schönebeck geothermal research platform.

The **Materials and Technologies for the Energy Transition (MTET)** 2021-2027 research program aims to provide essential scientific knowledge and viable technologies for the energy transition in Germany and for the sustainable transformation of the energy supply and use worldwide.
The work on gasification processes is located in Topic 5, Resource and Energy Efficiency. The overarching goal of this topic is the development and implementation of energy- and resource-efficient processes, technologies and system solutions that are the key enablers of a sustainable circular economy. In this program, gasification is a central process within this chemical recycling loop of carbon containing residues, e.g. mixed (industrial) plastic waste.

While the novel technologies are addressed in the Materials und Technologies for the Energy Transition (MTET) program, within the scope of the **Energy System Design program (ESD)** 2021-2027 program, the energy system transformation is classified as a complex sociotechnical process that comprises not only a variety of novel technologies, but also a multitude of actors and societal groups. The corresponding R&D challenges addressed by the ESD program are i) systemic analyses and develops sustainable transformation pathways and ii) digitalization and system technology to design and operate integrated energy systems.

https://www.helmholtz.de/

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reFuels – Rethinking Fuels

Renewable hydrocarbon fuels can be produced from various carbon sources from agriculture and forestry (Biomass-to-Liquid - BtL) as well as from CO2 and hydrogen produced by electrical energy from renewable sources (Power-to-Liquid - PtL). Also, the combination of both is possible to make full use of the biogenic carbon.

In the application oriented initiative “reFuels – Rethinking Fuels”, seven KIT institutes are working on the efficient production, use, and evaluation of regenerative fuels in cooperation with the federal State of Baden-Württemberg and 22 partners from the automotive, automotive supply, and mineral oil industries. The aim is to enable vehicles – including the existing fleet – to run with regenerative fuels already on short term.

The project is based on a synthesis gas platform available at KIT: The bioliq® pilot plant and the Energy Lab 2.0. For the refuels project, 2 tons each of renewable gasoline and diesel are produced, which are blended to a fuel mix with conventional fuels to achieve a significant share of avoided fossil CO2 emissions on short term. On a longer term, these fuels should also meet the existing standards as stand-alone fuels. First application in a small vehicle fleet and test engines showed that the emissions of the fuel blends mostly meet the regulations; differences need to be understood and are investigated in more detail.

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	http://www.refuels.de/english/index.php

Industry Activities

The following chapter gives examples of German companies, their technologies and their main activities in the biomass and waste gasification area. Detailed information is available at the websites of the companies. A lot of information in this chapter we obtained from the industry guide[1] that was produce by the Fördergesellschaft Erneuerbare Energien FEE e.v.

Entrained Flow gasifiers

AIRLIQUIDE EC

AirLiquide Engineering & Construction is a plant manufacturer that offers a process portfolio for large scale syngas plants. They took over the MPG™ gasification technologies from Lurgi GmbH. Within the bioliq®-project in Karlsruhe AirLiquide Engineering & Construction built the high pressure entrained flow gasifier for the conversion of suspension fuels (slurry) produced via pyrolysis from biogenic residues. AL E&C is an ongoing research partner for KIT in the bioliq®-project.

Web: https://www.engineering-airliquide.com/de/synthesegas

THYSSENKRUPP INDUSTRIAL SOLUTION (TKIS)

ThyssenKrupp Industrial Solutions is a plant manufacturer that offers a process portfolio for large scale syngas and chemical plants. TKIS took over the PRENFLO® and HTW® gasification technologies from former Uhde GmbH. With the BioTfuel®-Project in northern France ThyssenKrupp Industrial Solutions and their French partners develop and demonstrate a process for synthetic fuels (Jetfuel and Diesel) from biomass residues like waste wood using the PRENFLO PDQ gasification technology. The feedstock for the gasifier is produced via a torrefaction process.

Web:https://www.thyssenkrupp-industrial-solutions.com/en/products-and-services/chemical-plants-and-processes/gasification/

BioTfuel:https://www.thyssenkrupp.com/en/company/innovation/processes-that-conserve-resources/biotfuel.html

RWE

RWE is an energy company that has built an experimental plant for the recovery of phosphorus in their innovation center Niederaußem. In the so-called multi-fuel conversion (MFC) plant, a mixture of sewage sludge, sewage sludge ash and lignite is converted into synthesis gas under gasification conditions at 1500°C and phosphorus is separated for fertilizer production. The plant was commissioned at the beginning of July 2021.

Web: https://www.rwe.com/en/our-portfolio/innovation-and-technology/technology-research-development/coal-innovation-centre/multi-fuel-conversion

1 https://fee-ev.de/images/FEE__Holzgas_Branchenguide_2020.pdf

Fluidized bed gasifiers

SÜLZLE KOPF SYNGAS

Since 2000 SÜLZLE KOPF SynGas is a developer and producer of bubbling fluidized bed gasification systems for sewage sludge for heat, or combined heat and power (CHP) applications. They have built a pilot plant with 250 kWth for sludge drying, a commercial Gasification-CHP plant with 390 kWel and 460 kWth, as well as a plant delivering synthesis gas to a burner providing heat (1,5 MWth) for sludge drying. All gasifier systems are fed with dried sewage sludge.

Address: Derendinger Straße 40, 72072 Tübingen

Email: b.v.deest@kopf-syngas.de

Web: www.kopf-syngas.de

Referenzes:

- Waste water treatment plant Mannheim
- Waste water treatment plant Balingen
- Waste water treatment plant Koblenz

BURKHARDT GMBH

Since 2010 Burkhardt GmbH is a producer for co-current stationary fluidized bed wood gasifiers for combined heat and power (CHP) applications. T. Burkhardt offers 3 sizes of gasifier systems, 50 kWel, 165 kWel and 180 kWel that are fed with wood pellets. All systems produce heat and power from gas engines.

The company has delivered more than 240 plants.

Address: Kreutweg 2, 92360 Mühlhausen
Email: energy@burkhardt-gmbh.de
Web: www.burkhardt-gruppe.de

References:

- Ladbergen, 32 Plants, Airport / District Heating
- Hinterschmiding, 2 Plants, Wood dryer / Pellet production
- Hohenburg, 7 Plants , Sewage Sludge drying
- St. Peter, 1 Plant, District Heating
- Grafenau, 1 Plant, District Heating
- Wunsiedel, 2 Plants , District Heating
- Garrel, 7 Plants, Turkey Breeding
- Lupburg, 1 Plants District Heating
- Horb, 2 Plants, District Heating
- Plößberg, 4 Plants, Sawmill
- Achental, 2 Plants , District Heating
- Winden im Elztal, 1 Plant, Hotel

STADTWERKE ROSENHEIM GMBH

Since 2015 Stadtwerke Rosenheim is a producer for wood gasifiers with staged pyrolysis and co-current fluidized bed reactor. The system is used for combined heat and power (CHP) applications, wood gas is used in gas engines. Stadtwerke Rosenheim offers its gasifier with a capacity of 110 kWth and 50 kWel , it is fed with untreated wood chips.

The company operates 1 pilot plant and delivered a second one.

Address: Bayerstraße 5, 83022 Rosenheim
Email: yves.noel@swro.de
Web: http://www.swro.de/kraftwerke/holzvergaser.html

LIPRO ENERGY GMBH&CO.KG

Since 2016 LiPRO Energy GmbH&CO.KG is a producer for a multi-stage gasification system with a pyrolysis step, a gas cracking step and a coke gasification with rotating grid. The system is used for combined heat and power (CHP) applications. LiPRO Energy offers their gasifiers from 60 – 100 kWth and 30 – 50 kWel that are fed with wood chips. All systems produce heat and power from gas engines.

The company has delivered 9 plants.

Address: Ostkamp 22, 26203 Wardenburg
Email: info@lipro-energy.de
Web: www.lipro-energy.de

References:

- Hude, 1x LiPRO Contracting-Plant
- Deggenhausertal, 2x LiPRO Contracting- Plant
- Hilders-Brandt, 1x LiPRO Customer - Plant
- Wüstenrot, 3x LiPRO Operating Company - Plant

Fixed bed gasifiers

SPANNER RE² GMBH

Since 2006 Spanner is a producer for co-current fixed bed gasifiers for wood. The system is used for combined heat and power (CHP) applications. The modular design of the wood gasifier makes it possible to combine several plants. Spanner offers units for 22 kWth – 3 MWth and 9 kWel – 2 MWel. They are fed with wood chips, pellets and briquettes. The systems produce heat and power from gas engines.

The company has delivered more than 700 plants worldwide.

Address: Niederfeldstraße 38, 84088 Neufahrn
Email: info@holz-kraft.de
Web: http://www.holz-kraft.com

References:

- Bio-energy village Engelsberg, LK Neumarkt
- Organic Farm Braun, LK Freising
- Wellnessresort Stemp, Passau
- District Heating Steinhausen, LK Ebersberg
- Parquet floor Factory Hofer, LK Landshut
- Carpentry Heckel, LK Unterallgäu

ECOLOOP

A new supplier on the market is Ecoloop. With a fixed-bed gasifier based on the technology of Spanner Re2s HKA 70, Ecoloop converts a fuel into synthesis gas consisting of a mixture of EPS agglomerates, lime and wood chips. With a demonstration plant in Dillingen, Bavaria, the company shows the feasibility of the technology in the 123 kwth range.

Address: Bahnhofstraße 30, 83278 Traunstein
Email: info@ecoloop.eu
Web: www.ecoloop.eu

REGAWATT GMBH

Since 2010 REGAWATT is a producer for a counter current fixed bed wood gasifier. The system is used for combined heat and power (CHP) applications. REGAWATT offers their gasifier from 600 – 4300 kW_{th} and 300 – 2000 kWel. The gasifiers are fed with wood chips and lumpy biomass. All systems produce heat and power from gas engines or gas turbines.

The company has delivered 6 plants.

Address: An den Sandwellen 114, 93326 Abensberg
Email: info@regawatt.de
Web: http://www.regawatt.de

References:

- Naturenergie Hersbruck, District Heating
- Moos Kombi Power System® Arco Clean Energy
- Sengenthal CHP Max Bögl
- Bad Füssing Bio-Energie Holmernhof

BIOTECH ENERGIETECHNIK GMBH

Biotech Energietechnik GmbH is a producer for a multi-stage gasification system. The system is used for combined heat and power (CHP) applications. Biotech Energietechnik GmbH offers its gasifiers with 75kWth and 25 kWel that are fed with natural wood chips. All CHP systems are combined with gas engines.

The company has delivered 3 plants.

Address: Biotech Energietechnik GmbH, Plainfelder Straße 3, A-5303 Thalgau
Deutschland Mitte: Roter Weg, D-36163 Poppenhausen
Deutschland Süd: Nessensohn GmbH, Steigäckerweg 6, Hochdorf, D-88454 Hochdorf
Email: m.kurz@biotech-heizung.com
Web: https://www.biotech-heizung.com

Referenzes:

- District Heating, Ebersburg, 36157 Weyhers
- Medical Centre Neue Rhön, 36151 Burghaun

IEA Bioenergy
Technology Collaboration Programme