VIENNA
UNIVERSITY OF
TECHNOLOGY
Institute of Chemical Engineering

FUTURE
ENERGY
TECHNOLOGY
Dual Fluidized Bed Systems

. . . join the research platform

FUTURE ENERGY TECHNOLOGY

to bring visions to life . . .

Preface

Prof. Dr. Hermann Hofbauer
Head

After nearly 35 years of research at the Institute of Chemical Engineering at Vienna University of Technology, we are proud to say that we have reached a highly respected position among institutions, for carrying out research and development into future energy technologies in general and particularly in the field of fluidized bed systems.

I am grateful that I have had the privilege to contribute to this process in a leading role for the last three decades, as a researcher and later on as Head of the Institute. It has been a privilege to see plants based on our innovative technologies built, both in Austria and abroad.

It has been an honor to chaperon young students and scientists on their sometimes rough path, through the academic landscape and on their first steps into a bright, innovative "universe of knowledge" without borders, driving themselves and society ahead. To teach them and moreover, to enlighten them about our topics of study and research fields, and to see and feel their enthusiasm in working within our FUTURE ENERGY TECHNOLOGY platform, helping to solve problems on our way to a sustainable energy supply.

We are working to provide answers to the demanding questions in our modern world. Questions raised by rising energy consumption and the undeniable necessity of more environmentally friendly and therefore, sustainable energy generation.

Based on our core competence, dual fluidized bed technologies, we have worked for years on the optimization of energy generation from biomass and subsequently energy carriers, such as

Prof. Hofbauer is Head of the Chemical Engineering Department at the Vienna University of Technology and is leading the FUTURE ENERGY TECHNOLOGY platform. He has been honored with several national and international awards for his scientific contributions and his precursory work in renewables. In addition to this, he was the initiator of the renewable energy network in Austria – RENET - which made the Güssing model possible. Currently he is key researcher in the BIOENERGY 2020+ center of excellence in addition to his academic engagements.

biofuels, as well as various possibilities for more efficient energy generation.

Currently, united under the synonym DUAL FLUID technology, we are pursuing various research fields under the FUTURE ENERGY TECHNOLOGY platform, from plant and process simulation to synthetic biofuels, and from advanced gasification technology to chemical looping combustion.

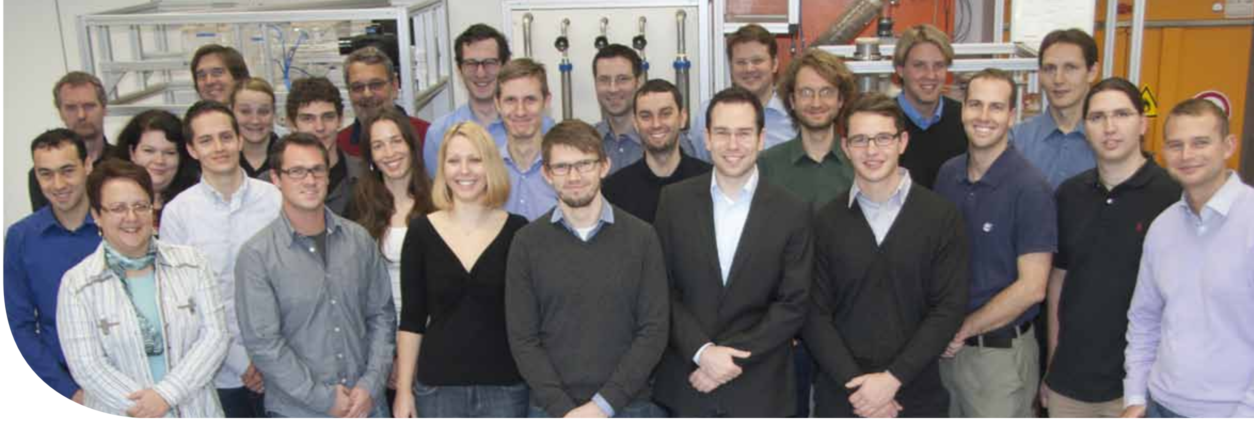
We are working along a broad but focused path towards solutions for the challenging energy future. The activities, research projects and technology developments within the FUTURE ENERGY TECHNOLOGY platform will continue to deliver fundamental contributions to emerging technologies and sustainable solutions ...

... to turn visions into reality.

Hermann Hofbauer

Vienna University of Technology

The Vienna University of Technology is located in the heart of Europe, in a cosmopolitan city of great cultural diversity. For nearly 200 years, Vienna University of Technology has been a place of research, teaching and learning in the service of progress and prosperity in Austria. One of the biggest institutes within Vienna University of Technology is the Institute of Chemical Engineering providing a place to work for more than 150 scientific employees. Chemical Engineering is a science of technology, dealing with the research, development and technology of material conversion. It is an interdisciplinary subject and unifies aspects of: mechanical engineering, chemistry, physics, biology, and electrical engineering. The basics are the scientific disciplines of applied chemistry, technical physics, and biotechnology. Chemical engineering concentrates on conversion and modification processes and develops and optimizes industrial processes with particular consideration for conservation of resources and environmental protection. The FUTURE ENERGY TECHNOLOGY platform represents almost one third of the employees at the institute whose work is focused on the subject of Future Energy Solutions.



Future Energy Technology

Background & Key competences

In the history of industrial development, Europe has always faced large challenges because of the limited local availability of resources and raw materials. For this reason, research and technology development has consistently focused on an efficient utilization of resources.

This has enabled the development of several technologies in Europe, which represent outstanding solutions with respect to energy efficiency. Also, the future energy strategy within the European Union targets further improvements; by reducing energy consumption, reducing greenhouse gas emissions, and stimulating a rising share of regenerative energy sources.

Therefore, current research and development surrounding energy technologies is under pressure to find new innovative solutions for our future energy supply.

The research platform FUTURE ENERGY TECHNOLOGY at the Institute of Chemical Engineering at Vienna University of Technology unifies essential competences for research and development in the field of energy technology and fluidized bed technologies. Energy technologies today are confronted with a technological change targeting:

- Increased energy efficiency,
- Reduced resource consumption,
- Substitution of fossil fuels with alternative biogenic fuels,
- and reduced greenhouse gas emissions.

Research Groups

The mission of the research platform FUTURE ENERGY TECHNOLOGY strives for these goals through the application of fluidized bed technologies. The platform consists of four independent research groups and the unit for Management and Strategic Development:

- **Future Energy Technology** – Hermann Hofbauer, **Head**
  - **Test Laboratory for Combustion Systems** – Emmanuel Padouvas, **Head**; Harald Kohl, **Vice Head**
  - **Synthetic Biofuels** – Reinhard Rauch, **Head**
  - **Zero Emissions Technologies** – Tobias Pröll, **Head**
  - **Gasification and Gas Cleaning** – Christoph Pfeifer, **Head**
  - **Management & Strategic Development** – Michael Fuchs, **Head**

Within these fields the research platform, together with major industrial partners, has already accomplished several successful national as well as international research projects.

Research activities undertaken have focused on: experimental investigations, design of experimental pilot plants, preparation for on-field demonstrations, process simulation, cold flow modeling of fluidized bed systems, fuel testing, testing of combustion systems, and optimization of existing industrial plants.

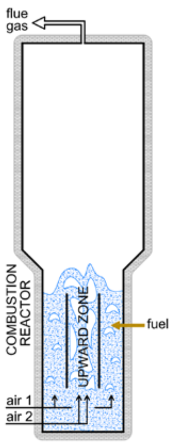
The methods used have been based on the vast "know-how" and rich experience of Prof. Hofbauer and his senior team, gained from over 30 years of R&D work in the field of energy technology.

The findings and results achieved are now part of many existing experimental facilities, pilot and demonstration plants, as well as large-scale commercial plants.

Development of the DUAL FLUID system

Fluidized bed technologies are key for several applications in energy conversion technologies. Fluidized bed systems have been investigated at the Institute of Chemical Engineering in Vienna since the 1970s, and are an integral part of all activities within the FUTURE ENERGY TECHNOLOGY research platform.
Prof. Hofbauer has been involved in the development of fluidized bed systems at the Institute since the early 1980s, and his work has made lasting impacts, especially the development of different DUAL FLUID bed concepts, from stationary fluidized beds to fast internally circulating beds.

The improvements made over time have always aimed to improve the quality of achieved products by enhancing the gas-solid interaction in the fluidized bed, and by preventing bed material agglomeration, or segregation effects of fuel particles. Additional improvements have been in the conditions where high residence times for the solid fuel particles, the gas phase, and bed



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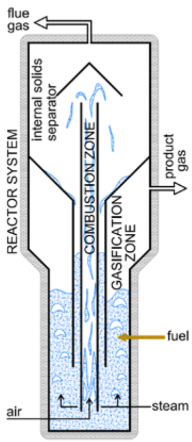

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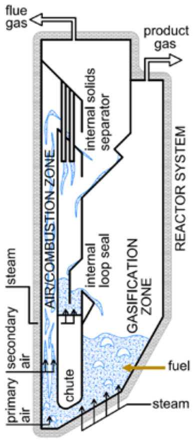
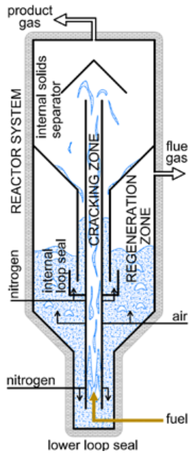


1995



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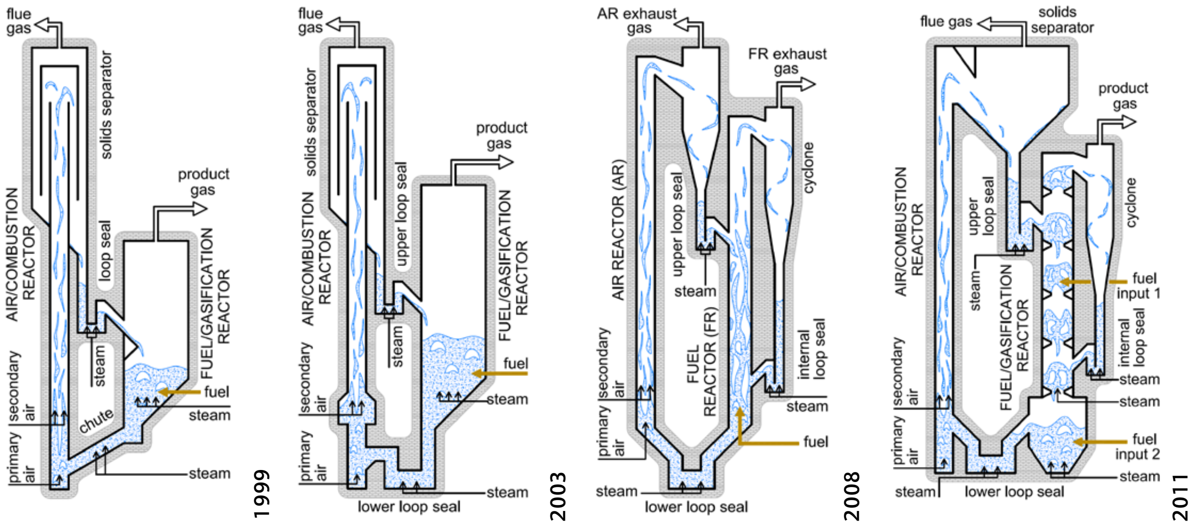


material particles are guaranteed. DUAL FLUID bed systems have enabled significant improvements by addressing the key issues previously mentioned.

Typical applications are: the gasification of solid fuels as an initial process for syntheses, sorption enhanced reforming, and different chemical looping processes. Therefore, the system is divided into a primary and a secondary fluidized bed reactor.

Two gas streams are obtained separately; the gas output of one reactor is typically nitrogen free. The two reactors are interconnected via loop seals to assure the global circulation of bed material, and to avoid gas leakages from one reactor to the other. This way, two different processes can be carried out in two reactors connected to each other by circulating bed material.

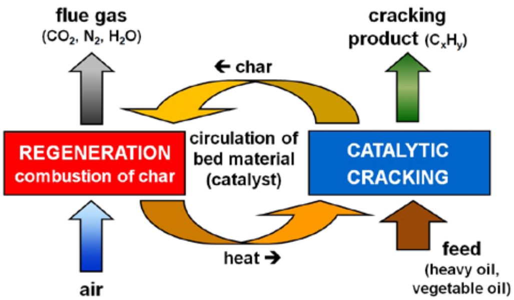
The latest developed reactor system is based on two circulating fluidized beds with a counter current effect enhancing the gas-solid contact.

Operational Systems

The development steps made have enabled excellent preconditions for the application for many different chemical processes.

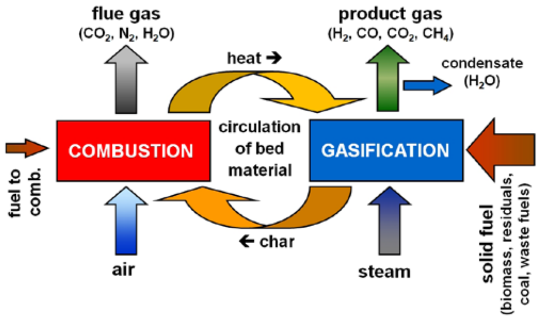
DUAL FLUID systems are mainly known for their application to gasification and looping cycles as:

- Fluid catalytic cracking (production of valuable hydrocarbons)
- Fluid bed gasification (production of synthesis gas)
- Sorption enhanced reforming (production of H_2 enriched synthesis gas)
- Calcium/carbonate looping processes (CO_2 separation from flue gas)
- Chemical looping combustion (production of pure CO_2)
- Chemical looping reforming (production of synthesis gas)

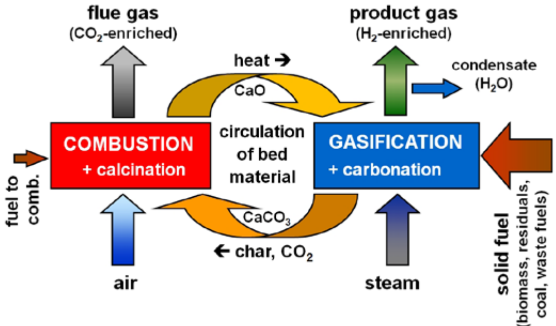


Fluid catalytic cracking

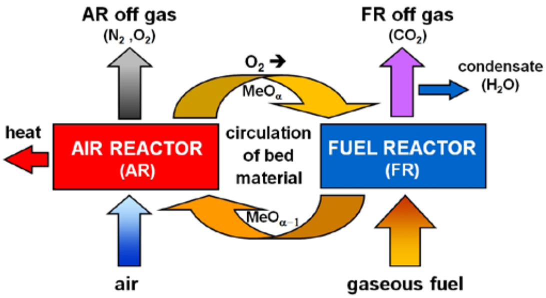
These processes are acknowledged as potentially key processes for future energy technologies and several pilot, demonstration, and commercial plants have already demonstrated the capabilities of such DUAL FLUID bed reactor systems.



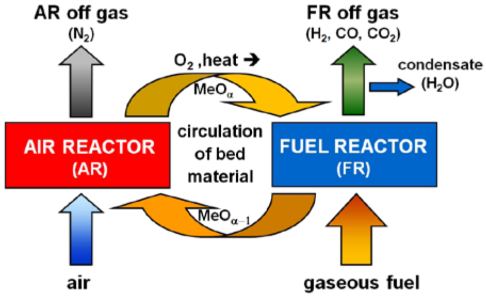
DUAL FLUID bed steam gasification



Sorption Enhanced Reforming



Chemical looping combustion



Chemical looping reforming

References

Pilot plants and experimental test facilities: (design, production and operation)

- DUAL FLUID gasification pilot plant, 100 – 140 kW_{th}, Vienna University of Technology
- CLC/CLR pilot plant, 120 – 200 kW_{th}, Vienna University of Technology
- Oxy-fuel pilot plant, 100 kW_{th}, Gumpoldskirchen, Austria
- Fischer-Tropsch pilot plant, Güssing, Austria
- Synthesis for hydrogen production, Oberwart, Austria
- Cold flow model – Advanced DUAL FLUID Gasifier, Vienna University of Technology
- TSA pilot unit, Vienna University of Technology

Demonstration plants and industrial sized units: (design, start-up and optimization)

- DUAL FLUID gasification demo-plant, 8 MW_{th}, Güssing, Austria
- DUAL FLUID gasification plant, 8 MW_{th}, Oberwart, Austria
- DUAL FLUID gasification plant, 15 MW_{th}, Villach, Austria
- DUAL FLUID gasification plant, 14 MW_{th}, Senden/Neu-Ulm, Germany
- DUAL FLUID gasification plant, 32 MW_{th}, Gothenburg, Sweden
- DUAL FLUID gasification plant in Klagenfurt, Austria (planned)
- BioSNG pilot plant, 1 MW_{SNG}, Güssing, Austria
- CLC/CLR Demonstration (planned)

Supporting the operation of industrial facilities: (trouble-shooting, process optimization)

- Troubleshooting and design recalculation for a 40 MW_{th} fluidized bed waste and sludge incinerator, Fernwärme Wien GmbH, Vienna, Austria, 2004.
- Troubleshooting and design recalculation for a 40 MW_{th} fluidized bed biomass combustor (wood chips), BEGAS AG, Heiligenkreuz, Austria, 2006.
- Scientific supervision 3 MW_{th} rotary kiln pyrolysis of agricultural residues, EVN AG, Dürnrohr, Austria, 2007-2009.
- Analysis of operating data for 16 MW_{th} rotary kiln hazardous waste incinerator, Fernwärme Wien GmbH, Vienna, Austria, 2008.
- Analysis of operating data and proposal for design modification for 16 MW_{th} fluidized bed sewage sludge incinerator, Fernwärme Wien GmbH, Vienna, Austria, 2009.
- Troubleshooting and design recalculation for a 55 MW_{th} fluidized bed waste and sludge incinerator, Kent Enviropower 'Allington', U.K., 2010.
- Troubleshooting and design recalculation for a 3 MW_{th} hospital and slaughterhouse waste incinerator, Valor Ambiente, Madeira, Portugal, 2011.
- Flow sheet modelling, balancing and optimization of steam utilization including district heating system, Fernwärme Wien GmbH, Vienna, Austria, 2011.

Outlook

The research and development activities of the FUTURE ENERGY TECHNOLOGY platform at the Institute of Chemical Engineering at the Vienna University of Technology, will lead to further improvements in DUAL FLUID systems for different applications in the field of energy technologies. The realized achievements will ensure a valuable contribution to the creation of a sustainable energy system. A large number of experimental results show that a very good scale-up of the different pilot plants to industrial-scale plants is possible. In addition to electricity and heat production, the nitrogen free gas produced from the DUAL FLUID steam gasifier, or from the CLR plant is well suited to chemical syntheses. Various research activities at the Vienna University of Technology focus on the production of: hydrogen, Fischer-Tropsch diesel and petrol, synthetic natural gas, and other chemicals, such as methyl alcohol. Thus, DUAL FLUID technology also presents the possibility of increasing the share of renewable materials in the chemical industry.

Synthetic Biofuels

The Research Group for Synthetic Biofuels focuses on the subsequent synthesis of fuels from biomass product gas. This technology was made possible by the development of the biomass gasification technology at the Institute of Chemical Engineering, and the successful implementation at the biomass CHP, Güssing.

Following the building of Güssing, other R&D topics considering a more efficient usage, than an immediate incineration of the valuable product gas in a gas engine for CHP, have been developed.

The major recent R&D work within this group has focused on production of the following synthetic biofuels:

- BioSNG – “Biomass to Synthetic Natural Gas”
- Fischer Tropsch Diesel – BioFiT “Biomass to Fischer Tropsch”
- Mixed Alcohols
- Hydrogen

As the basic synthesis gas for all projects, real syngas generated in the biomass CHP Güssing or CHP Oberwart is used for the experiments.

Due to the success in developing these technologies, the working group has grown over the past years and now has several employed researchers. The research group is fully financed from applied research project sources. The main funding sources for projects linked to these activities have been European projects (Renew, BioSNG), and national projects (Programme Energy Systems

of Tomorrow, Climate and Energy Fund). Also, directly funded projects by industry have become increasingly important. There is also a close cooperation with the center of competence Bioenergy 2020+, where several PhD theses are shared.

Research Topic Synthetic Natural Gas

The first synthesis investigated by the research group was the methanation reaction to produce synthetic natural gas from biomass (BioSNG). The first experiments were performed in 1997 at the 100 kW gasifier at the Institute. In 2003, the EC-project BioSNG started, where a 1MW (100Nm³/h BioSNG) demonstration plant was erected and operated. Within this project the whole chain from wood chips to the use of the BioSNG in a gas propelled car was successfully demonstrated.

The actual challenge and main topic of work is to test different sulfur resistant catalysts, to simplify the gas treatment.

biomass CHP Güssing (left), BioSNG demonstration plant (middle) and Technikum (right)

Synthetic Biofuels

Research Topic Fischer Tropsch Diesel

The second synthesis that gained interest was the Fischer Tropsch synthesis (FT) to produce Diesel from wood. This work started with the EC-project RENEW in the early years of 2000. In the course of the project, a pilot plant with a capacity of 5kg/day FT products was designed, erected and optimized.

A slurry reactor was used as the FT reactor in this project. This reactor type is the standard research reactor for FT technology, as from our perspective, it has several advantages compared with other technologies, such as scalability, and catalyst efficiency. The main R&D work is currently: the optimization of the gas treatment focused on FT, tailor-made technologies for an easy scalability by the integration of hydroprocessing, and the testing of different FT catalysts.

The research facilities and pilot plants for the BioSNG and FT research activities are situated in Güssing. There is also an innovative gas treatment unit with the capacity of 1bpd available, which was erected in an industrial project in 2011.

Research Topic Mixed Alcohols

As described, the synthesis for SNG and FT are extremely sensitive to sulfur poisoning. To widen the portfolio and to be able to install synthesis technologies at sites where high sulfur concentrations are present in the gas, or where a gas treatment unit is applicable in the future, a robust synthesis has been investigated.

The synthesis of mixed alcohols can be performed using a MoS catalyst, which is resistant to sulfur poisoning. Using this technology, a pilot plant designed to convert about 5 Nm^3/h of product gas from the biomass CHP, Güssing is

currently in operation. The main aim of this work is to obtain insight into this synthesis and to get enough measured data to establish the mass and energy balances for a commercial plant.

Research Topic Hydrogen

Hydrogen has been discussed for a long time as a clean energy carrier. To be counted as CO_2 neutral, hydrogen has to be produced from renewable sources. Actually, the cheapest option to produce renewable hydrogen is through using biomass gasification.

A techno-economic study was done with an industrial partner and based on these results a 50MW demonstration plant near the biggest refinery in Austria is planned. To verify the design of the demonstration plant, a pilot plant has been designed as a slip stream of the biomass CHP, Güssing and this pilot plant should be in operation by the end of 2012.

The main aim of this work is to obtain more data for the design of the demonstration plant, and also to test the different steps for the long-term.

The biomass CHP, Güssing was developed over recent years as a synthesis gas platform, where different pathways from wood chips to transportation fuels and chemicals are investigated. This joint potential is named Polygeneration. Also, at the second biomass CHP in Oberwart, the first projects on producing valuable gases from wood are in their final phases. At both plants the Institute of Chemical Engineering and Bioenergy 2020+ are doing the main R&D to develop these technologies further and to introduce them, together with their industrial partners, into the market.

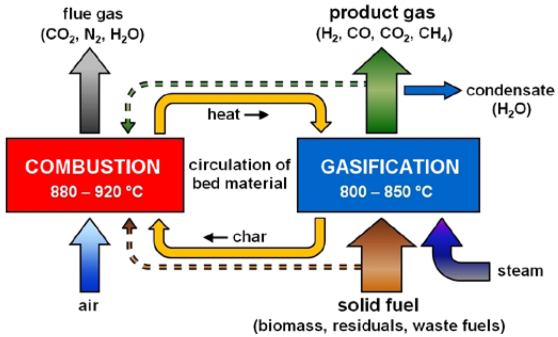
Gasification and Gas Cleaning

The Gasification and Gas Cleaning Research Group focuses on projects in the energy technology sector, specifically:

- Gasification technologies, gasification in fluidized beds,
- Gas cleaning,
- Catalytic active materials for tar removal in fluidized beds,
- Catalytic tar reforming in downstream process units,
- Looping processes in dual fluidized beds for Sorption Enhanced Reforming (SER),

The principal motivation of the research group is to contribute as an innovator towards the demonstration of future technologies for energy supply, in close cooperation with plant operators, manufacturers and utility companies.

The mission of the research group is to encourage the development of fuel flexible and efficient gasification technologies for the production of



Concept of dual fluidized bed steam gasification

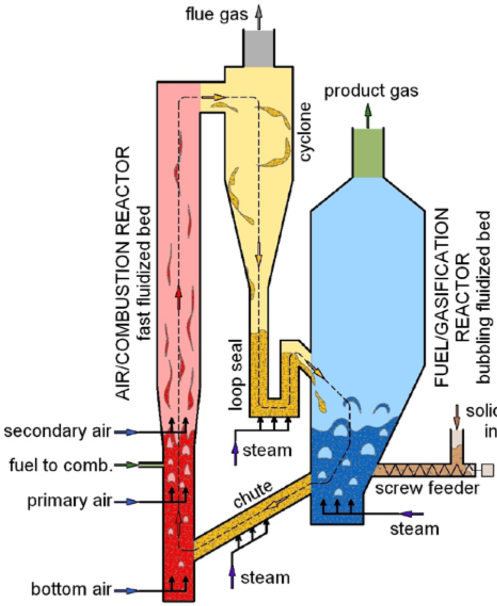
high quality syngas. The group's expertise comprises design and operation of cold flow models of fluidized beds, and the design and operation of test facilities for fluidized bed gasification and catalytic gas cleaning.
These key issues are complemented by experience in computational modeling and simulation of energy processes. Recent topics of investigation are:

- Dual fluidized bed steam gasification of various feedstock: biomass, coal, waste materials (biomass as well as plastic wastes)

- Product gas adaptation and cleaning by catalytically active bed materials
- Catalytic reforming of hydrocarbons in secondary fixed bed units
- Development of a new gasification process based on the dual fluidized bed system
- Sorption Enhanced Reforming in dual fluidised bed systems for hydrogen production
- Pressurized gasification

The concept and design of the dual fluidized bed system for steam gasification for the production of high quality synthesis gas, was developed in the 1990s at the Institute of Chemical Engineering. The technology was initially investigated as a cold flow model and subsequently at a pilot plant with 100 kW fuel input.

Industrial feasibility and the operation of the dual fluidized bed system were first demonstrated with the CHP Güssing, Austria. Over the last years, several power plants with biomass steam gasification were put into operation, or are currently under construction all over Europe. However, the major driver for further development is the need for increased fuel flexibility, further increased reliability, and improved conversion towards gaseous components.



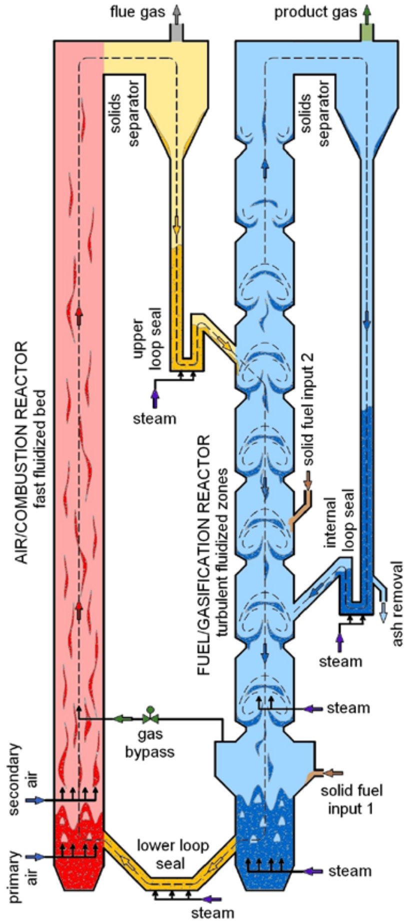
Scheme of the DFB reactor of CHP Güssing

Gasification and Gas Cleaning

The classical dual fluidized bed (DFB) is based on a reactor design where two different gas streams are exposed to a circulating stream of solids, transporting heat and chemical compounds in a selective way. This classical design of DFB systems integrates a bubbling fluidized bed (BFB) reactor into the solids return loop of a circulating fluidized bed (CFB) system.

A 100 kW_{th} pilot plant has been in operation since 2004 to test different bed materials, feedstocks and optimize process parameters. Moreover, fundamental research on sorption enhanced reforming has been performed during the last decade.

Based on this experience, a DFB system consisting of two interconnected CFB reactors was proposed in which solids are entrained from one CFB and directed via a fluidized upper loop seal to the second CFB reactor. The second CFB features circulation of solids in itself through an internal loop seal, and then the solids move back to the first CFB through a fluidized lower loop seal



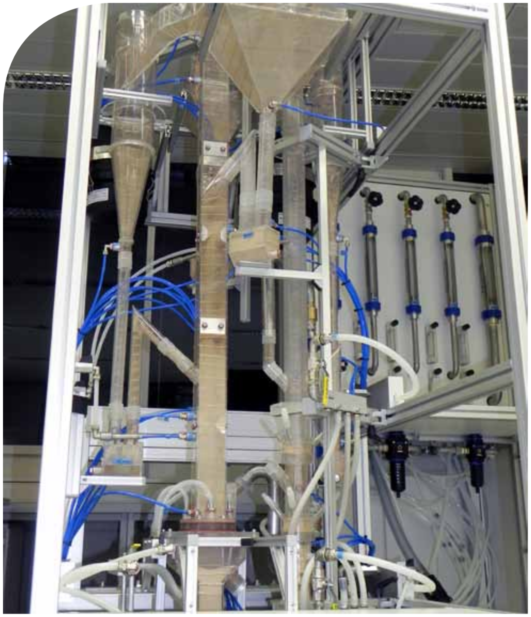
Improved reactor concept with counter-current flow

connecting the bottoms of both reactors. This novel system with increased gas-solid contact and counter-current effect is expected to be a key component in making gasification feasible and easy for up-scaling, even to large-scale gasifiers with fuel inputs larger than 100 MW.

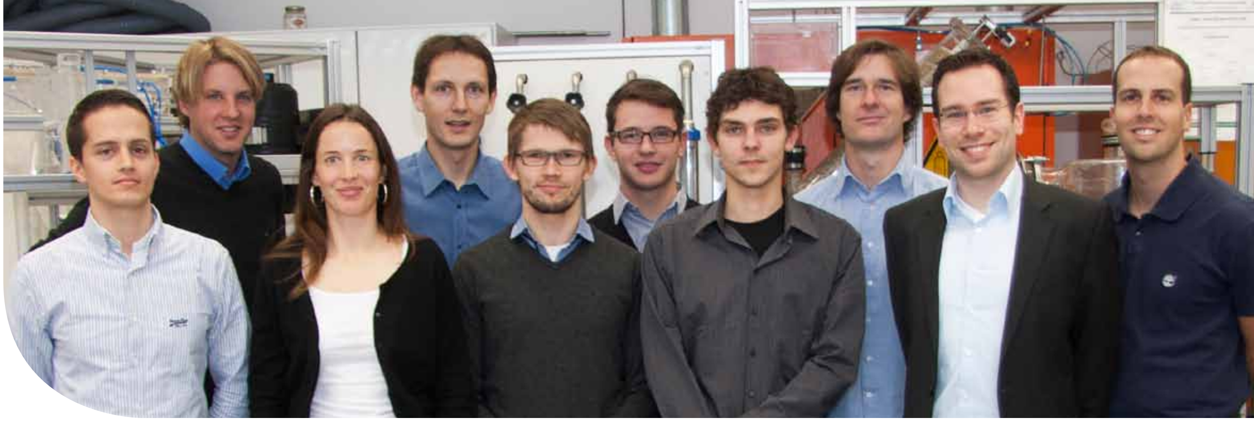
A cold flow model has been designed and was built in 2011 to provide the basis for a 100 - 200 kW_{th} pilot plant to be built in 2013. Another research focus is catalytic hot gas cleaning, which is considered as a very promising cleaning method due to the complete destruction of the tars instead of creating a waste stream, which is difficult to dispose of.

Based on experiments on a laboratory-scale, a 100 scm/h slip stream reactor has been installed at the biomass combined heat and power plant in Güssing, Austria.

The gas contaminated with tar is sucked off from the freeboard of the gasifier, fed into the catalytic reactor, and then the cleaned gas is discharged back to the product gas line between the gasifier and the gas cooler.



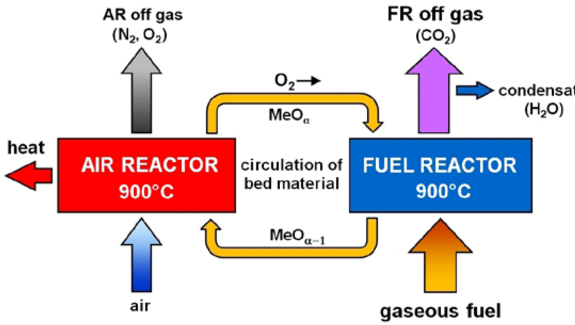
Cold flow model of new reactor concept with counter-current flow



Zero Emission Technologies

The Research Group for Zero Emission Technologies focuses on projects in the energy technology sector with goal, in order to substantially reduce greenhouse gas emissions. Here, three general approaches are put forward:

- Energy efficiency increase in industrial processes
- Renewable fuels substituting fossil energy
- Capture of CO_2 from energy conversion processes

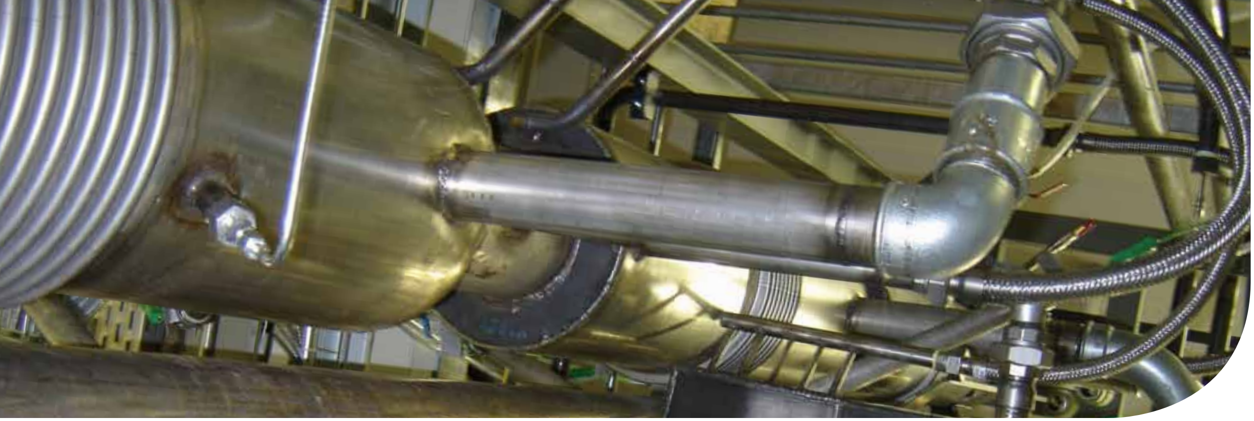


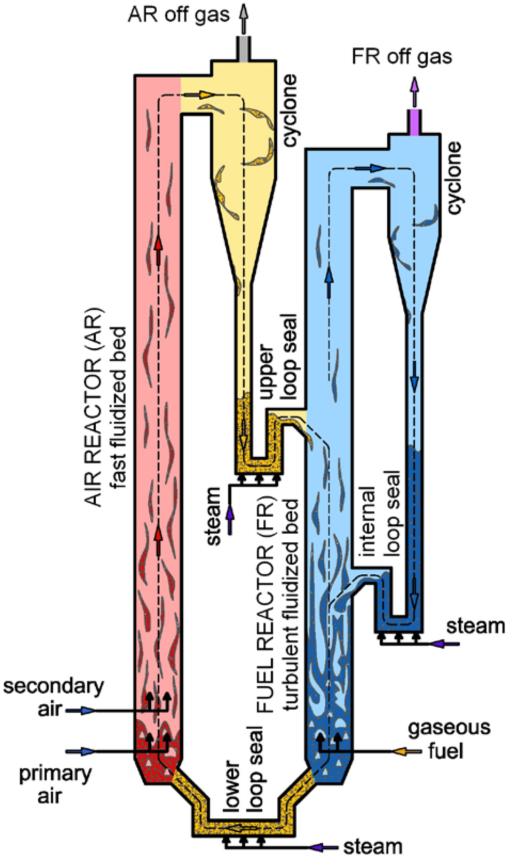
Chemical looping combustion

The mission of the group is to develop sustainable technology solutions ready for on-field demonstration.

The group is experienced in design and operation of fluidized bed pilot units and in modeling and simulation of energy technology processes. Recent topics of investigation are:

- Fluidized bed systems for inherent CO_2 capture (Chemical Looping Combustion)
- Catalytic reforming in fluidized beds (Chemical Looping Reforming)
- Oxyfuel combustion in circulating fluidized bed regime
- Analysis and optimization of industrial fluidized bed combustors
- Techno-economic evaluation of fossil energy substitution in industry





Chemical looping combustion

The Zero Emission Technologies Research Group is subdivided into three topical project groups:

Project Group
Chemical Looping Technologies

www.chemical-looping.at

The research focus of the Chemical Looping Technologies Project Group lies in chemical looping combustion (CLC), and chemical looping reforming (CLR). In both technologies, oxygen is selectively transported from one fluidized bed reaction zone to another by circulating metal oxides. CLC is discussed as a very efficient technology to capture CO_2 from combustion. CLR is a robust method of hydrocarbon reforming. The main research contributions are in the fields of: reactor hydrodynamics, detailed reactor modeling, process modeling, and process demonstration in a 120 kW_{th} pilot plant for gaseous fuels, which is currently the largest pilot plant with published successful operating.

Zero Emission Technologies

Project Group Oxyfuel Combustion

In oxyfuel technology, fuels are oxidized by artificial mixtures of recycled flue gas and oxygen. The output of the combustion is virtually N_2-free and thus, is a CO_2-rich flue gas, which is suitable for subsequent separation of pure CO_2 for storage. A circulating fluidized bed oxyfuel pilot plant with a riser diameter of 150 mm is operated at an air separation plant site in Messer, Austria close to Vienna.

CFB oxyfuel pilot plant

The plant is designed for hard coal, but with additional feeding devices for alternative solid fuels, such as sewage sludge and wood chips.

The main research focus has been on oxyfuel combustion of low calorific fuels, taking advantage of the possibility to work with increased oxygen concentrations in the artificial combustion air.

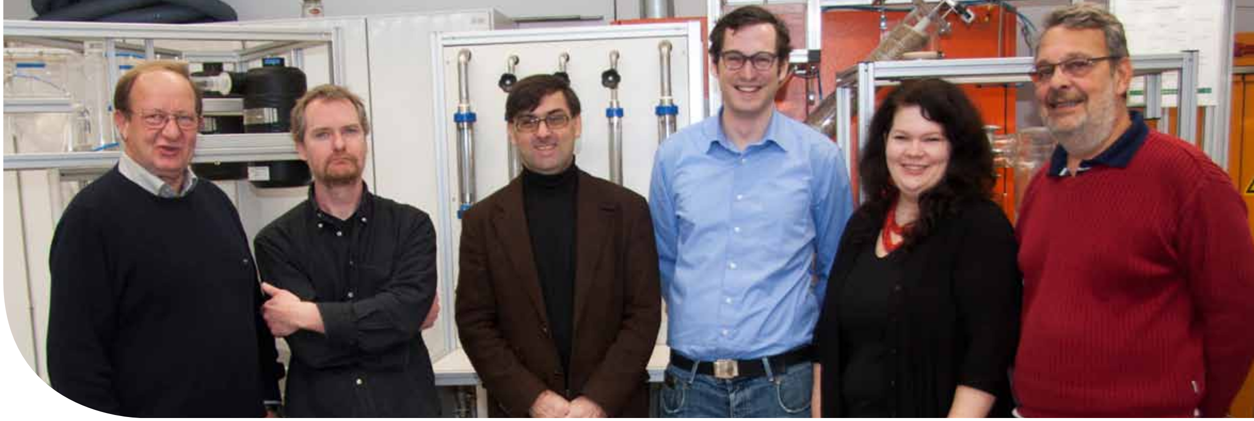
Project Group Process Simulation

Process modeling and simulation can make an essential, indispensable contribution to the successful development of new, highly efficient production processes in energy technology and chemical engineering. Process modeling and simulation were important right-from-the-start in the realization of the commercial DUAL FLUID biomass gasification plants in Güssing and Oberwart.

DCFB pilot plant for CLC and CLR

Apart from biomass gasification, the modeling activities also cover pyrolysis and combustion plants for biomass and waste.

The tasks performed include mass and energy balances for new process configurations, accompanying modeling and simulation of operation startup of pilot plants and industrial-scale units, as well as troubleshooting for industrial-scale units.



Test Laboratory for Combustion Systems

The history of the Test Laboratory for Combustion Systems at the Vienna University of Technology can be traced back to the days of imperial Austria in the 19th century.

Since then, the guidelines for the development of the laboratory to its current standard have been focused on customer needs, based on the fulfillment of high quality standards and principles of scientific work.
This long tradition is based on tremendous experience and "know-how", which helps to face the daily challenges in modern analytical work.

Currently, the Test Laboratory for Combustion Systems is one of the leading laboratories for fuel characterization, and the testing of small as well as large-scale combustion systems, and measurements of gaseous emissions in Austria.

This high standard is represented by the accreditation for its main activities and the established quality management system according to EN ISO 17025. Further activities:

- Furnishing of expertise
- Development of new measurement methods
- Conducting of research topics
- Cooperation in development of relevant standards
- Participation in international research projects
- Organization of measurement campaigns (national and international)

All measurements and analyzes are conducted according to the needs of a high standard quality management system.

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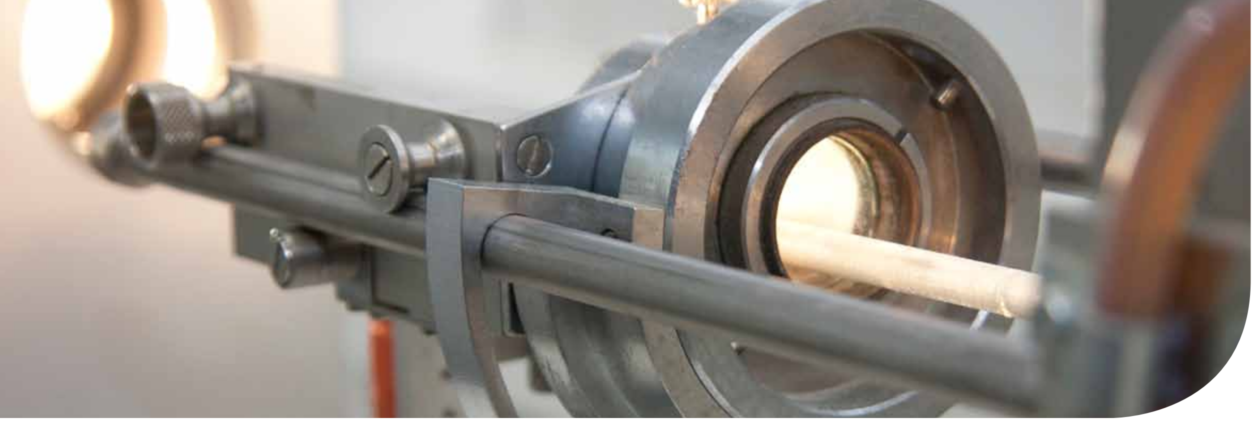

Service Portfolio

TESTING OF COMBUSTION SYSTEMS

- Wood log stoves
- Wood pellets stoves
- Wood log boilers
- Wood pellet boilers

EMISSION MEASUREMENTS

- Oxygen (O_2)
- Hydrogen (H_2)
- Carbon dioxide (CO_2)
- Methane (CH_4)
- Carbon monoxide (CO)
- Nitrogen oxides (NO_x)
- Total organic carbon (C_xH_y)
- Sulphur dioxide (SO_2)
- Nitrogen (N_2)
- Hydrocarbons

FUEL ANALYSIS

- Lower and higher heating value
- Water content
- Ash content
- Volatile matter
- Ash melting
- C, H, N, S, Cl

SAMPLING AND ANALYSIS

- Sulphur hydroxide (H_2S)
- Ammonia (NH_3)
- Hydrogenchloride (HCl)
- Sulphur dioxide (SO_2)
- Tar GC/MS
- Tar gravimetric
- Char (organic)
- Dust (inorganic)
- Water (H_2O)

Notes

Notes

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