



IEA Bioenergy

Technology Collaboration Programme

Status report on thermal gasification of biomass and waste 2021

Research special report

IEA Bioenergy: Task 33

February 2022





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Research special report

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IEA Bioenergy: Task 33

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Abstract

One of the aims of the IEA Bioenergy Task 33 is monitoring of gasification status, thus each triennium a Status report is published on the Task webpage (Status Report 2016, Status Report 2019). Nevertheless, in no Status report the research institutions and their activities are mentioned, furthermore no comprehensive overview regarding the research activities was found at all.

This Status report focuses on research on gasification of biomass and waste in Austria, France, Germany, India, Italy, the Netherlands, Spain, Sweden, UK and USA.

Research activities can show the future directions of gasification technology, furthermore, this report can be used to establish the contacts, since by each institution not only research activities but also contact information is displayed.

A part of this report is also an actual list with gasification facilities, which is based on the data from the IEA Bioenergy Task 33 database.

The report is a common effort of the Task 33 member countries representatives, as well as experts from France and Spain, which are actually not a part of the Task.

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Introduction

One of the aims of IEA Bioenergy Task 33 is monitoring of actual status of thermal gasification, thus the online database, which is a part of Task 33 website was created. Here the references of pilot, demonstration and commercial could be found.

In the last two reports (Status report 2016 and 2019), the focus was mostly given to commercial thermal gasification projects in IEA Bioenergy Task 33 member countries. Anyway, to be able also to predict the progress in the field of gasification it is necessary to take into account several further conditions and parameters. Beside the policy and socio-economic frames, it is also research, which gives direction of projects implementation. It should be pointed out that without research no progress could be achieved and thus also research should be mentioned talking about status of gasification of biomass and waste.

The author's motivation to focus on research activities on gasification in this Status report was the fact that till now, no comprehensive overview was published regarding the research at institutions and companies including research topics and actual projects on thermochemical gasification.

Additionally, the contact information of each institution is included to offer the possibility of research cooperation or getting further detailed information. In this way, the partners for e.g. research programmes and projects could be found easily.

In the last years, a shift regarding the feedstock could be observed. Nowadays, the focus is given to waste streams, which are coupled with more demanding feedstock preparation (upstreams) or gas cleaning (downstreams). The forest-, agricultural-, industrial- and municipal waste streams are taken into account by feedstock employment. On the other hand, also the research on gas utilization goes in direction of gaseous or liquid biofuels and biochemicals.

The importance of by-products is growing as well, first of all the importance of bio-char. There are several ways for biochar utilization; it could be used for soil improvement and long-time carbon storage, for animal feeding, as a filter medium or it could be even added into the building materials (e.g. green road, green concrete). The potential of the biochar utilization is not exploited yet.

Gasification is a versatile technology also regarding circular economy; waste streams could be used for production of value added products. Furthermore, a synergy with other technologies could be provided to boost the amount of products and/or to increase the process efficiency. And last, but not least, the gasification could be very beneficial for the environment, e.g. as technology converting biomass into biofuels and biochemicals as well as a carbon storage decreasing in this way a footprint.

Country reports on bioenergy

With the end of 2021 the IEA Bioenergy published Country reports on bioenergy¹, included are 25 countries worldwide and the EU28.

This summary report together with the separate country reports, was prepared from IEA statistical data, combined with data and information provided by the IEA Bioenergy Executive Committee and its Tasks. All individual country reports were reviewed by the national delegates to the IEA Bioenergy Executive Committee, who have approved the content.

The highlights regarding renewables and bioenergy in different sectors are summarized below:

- Bioenergy plays a role in the three main energy sectors: electricity, fuel/heat consumption and transport energy consumption. Particularly for heat and transport bioenergy/biofuels are the dominant renewable energy types.
- The main growth of renewable electricity in the past decade has been in wind power, followed by solar power and biomass-based power. In Denmark, Finland and Estonia, bioenergy represents more than 15% of electricity production (predominantly through combined heat and power - CHP), followed by the UK, Sweden, Germany and Brazil. In other countries, typical levels of biomass-based electricity are 2-5%.
- For most countries solid biomass is the dominant fuel to produce bioelectricity. However, in Germany, Italy and Croatia bioelectricity is mainly produced from biogas. In Switzerland renewable MSW is the dominant fuel for bioelectricity.
- The main support systems for renewable power have been feed-in tariff systems and obligations connected with tradable green certificates. Recently there is a trend to work with tender systems on a competitive basis. A point of attention is that, apart from the production cost per MWh, policy actions also need to reflect the multiple benefits of using bioenergy for electricity, including rural development, waste management and dispatchability.
- In most of the analysed countries fossil fuels still dominate in fuel/heat provision, typically exceeding 75% of total fuel/heat provision. Biomass is the dominant type of renewable heat. The most important progress in renewable heat has been made in countries with important shares of district heating (Denmark, Estonia, Sweden, Finland), particularly through the replacement of fossil fuels by biomass for centralised heat production.
- The main support systems for renewable heat have been subsidies for renewable heat projects and financial support for domestic renewable heat instalment. Several countries (particularly in Scandinavia) have implemented a CO2 tax on fossil fuels which was an important driver for industries (and heat producers) to move from fossil fuels to bioenergy.
- Fossil fuels still represent over 95% of transport energy in most countries. This reflects the challenge to displace fossil fuels in the transport sector. Brazil and Sweden have achieved a renewable energy share in transport of 25% and 21%, respectively, with Norway and Finland also reaching more than 10%. Most other countries have renewable shares of 4 to 6% or lower.
- Biodiesel (including an increasing share of HVO) and bioethanol are the dominant biofuel types. Bioethanol is mainly important in countries with high shares of gasoline cars (Brazil, USA, Canada).

¹ <https://www.ieabioenergy.com/blog/publications/2021-country-reports/>

Biodiesel gains attention with the increased focus on heavy duty transport, which relies on diesel fuel. There is an increasing trend to advanced (residue based) biofuels and drop-in biofuels to avoid blend walls (ethanol limits in gasoline and FAME limits in diesel).

- The main support systems for biofuels are tax incentives for biofuels and blending obligation systems. More systems start to be based on the carbon intensity of the fuels, e.g., the Californian Low Carbon Fuel Standard, or RenovaBio in Brazil. There is also support for (advanced) biofuel production facilities to move from pilot to commercial production.
- Renewable electricity is considered as an important option in transport, particularly towards the coming decades and mainly in the light duty segment. As of today, electricity use only represents between 0.1 and 4% of transport energy (currently mostly in rail), with the renewable share depending on the national electricity mix. Sales of electric cars are substantially increasing in recent years and several regions put high targets on EV sales. Nevertheless, with different EV introduction speeds in different regions and considering typical vehicle lifetimes of over 10 years, the replacement of the car fleet will take time so fuels will still be needed for the car sector in the next few decades; moreover, the heavy-duty sector will still remain dependent on (predominantly diesel type) fuels for quite some time. So renewable fuels will remain an important option to displace fossil fuels in transport.

Research activities on thermochemical gasification of biomass and waste

In this chapter the research activities in Austria, France, Germany, India, Italy, the Netherlands, Spain, Sweden, UK and USA will be described. It should be noted, that only research at academic institutions is included in this report. The data is based on information from IEA Bioenergy Task 33 representatives and recognized experts in area of thermochemical gasification.

AUSTRIA

Since last three or even four decades a research on gasification of biomass takes place at Austrian research institutions. At the beginning only clean woody biomass was in focus as a feedstock for the conversion process, anyway, during the last twenty years a shift to waste materials can be observed. Regarding the application of the producer gas from gasification, also here a change can be seen. Heat or combined heat and power production was the application at the beginning, now the production of biofuels and biochemicals is in the focus with increasing concern to by-products such as biochar.

In Austria, several institutions are active in research on gasification of biomass and waste.

Vienna University of Technology

Institute of Chemical, Environmental and Bioscience Engineering

Research groups:

- Research Unit of Fuel and Energy System Engineering
- Research Group for Industrial Plant Engineering and Application of Digital Methods
- Accredited and Notified Testing Laboratory for Combustion Systems

The Research Area “Fuel and Energy Systems Engineering” provides the ideal professional framework for research-led education and for the development of innovative technologies and processes for the energy system of the future. This includes testing, analysis, modelling, experimental investigation and validation, and transformation to commercial scale using modern digital methods. This research area supports the profiling of the institute, the faculty and the Vienna University of Technology by exploring a sustainable fuel-based ecologically sound “energy supply”.

The research group “Industrial Plant Design and Application of Digital Methods” acts as an international research partner for a sustainable utilization of biogenic raw materials and residual resources for the reduction of fossil carbon utilization. The group provides competence for technology development by the use of experimental infrastructure as well as advanced digital methods.

Nowadays the Test Laboratory for Combustion Systems is one of the leading laboratories for fuel characterization, testing of small as well as large scale combusting systems and measurements of gaseous emissions in Austria. The high standard is represented by the accreditation for its main activities and the established quality management system according to EN ISO 17025. Currently the main focus is renewable energy especially biomass and biofuels.

Research topics and projects from the last 3-5 years and ongoing:

- Testing of the advanced dual fluidized bed (DFB) gasification (G-volution) technology in 100 kW pilot plant scale²
 - fuel flexibility and impact on product gas quality (agricultural, municipal and industrial waste)³

² <https://doi.org/10.1007/s13399-019-00486-2>

³ <https://doi.org/10.1016/j.energy.2018.08.146>

- influence of different bed materials on the product gas quality⁴ and change of product gas along the reactor height⁵
- investigation of selective carbon dioxide removal with the sorption enhanced reforming/gasification process (SER/SEG)⁶
- (partial) replacement of steam by CO₂ as gasification agent⁷
- assessment of correlations between product gas composition and tar concentration⁸
- Gas cleaning and gas upgrading for production of hydrogen and SNG in 10 kW scale:
 - scrubber with biodiesel/water
 - fixed bed activated carbon and ZnO
 - pressure swing adsorption (PSA)
 - water gas shift (WGS) unit
- Fluidized bed methane synthesis
 - thermodynamic calculations of different gas sources⁹
 - experimental investigations in 10 kW scale from gas cylinders or live-gas from 100 kW DFB gasification pilot plant
- Support of industrial gasification processes during commissioning and operation by
 - calculation of mass and energy balance
 - measurement of gas composition and impurities.

More information:

<https://www.vt.tuwien.ac.at/home/EN/>

Address:

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University of Natural Resources and Life Sciences Vienna (BOKU)

Institute of Chemical and Energy Engineering

Research groups:

- Research Group Process Engineering of Renewable Resources (Head: Univ.Prof. Christoph Pfeifer)
- Research Group Energy Technology and Energy Management (Head: Univ.Prof. Tobias Pröll)

The Research Group “Process Engineering of Renewable Resources” deals with the development of thermo-chemical conversion technologies (pyrolysis, hydrothermal carbonization and gasification). The main focus lies on the implementation of these technologies into biorefineries and therefore mainly handling residues and waste streams.

Different cold flow models (bubbling fluidized bed, dual fluidized bed) as well as hot units (20kW bubbling fluidized bed, 10kW screw reactor, batch reactors) are available. Moreover, the group operates a fuel analysis laboratory (full set of proximate and ultimate analyses) and has competence in calculation of mass- and energy balances using the simulation software IPSEpro with support from the research group “Energy Technology and Energy Management”.

Moreover, team members are involved in several scientific committees of the main international scientific conferences

⁴ <https://doi.org/10.1016/j.energy.2018.05.158>

⁵ <https://doi.org/10.1016/j.energy.2019.02.025>

⁶ <https://doi.org/10.1016/j.rser.2019.03.013>

⁷ <https://doi.org/10.1016/j.fuel.2019.04.168>

⁸ <https://doi.org/10.1016/j.apenergy.2019.01.181>

⁹ <https://doi.org/10.1007/s13399-020-00910-y>

dealing with gasification, representing Austria (industry as well as academia). Finally, editorial board memberships are important: Carbon Resources Conversion Journal, Energies Journal, Biomass Conversion and Biorefinery Journal.

Research topics and infrastructure

- Fuel analysis (proximate and ultimate analysis, bomb calorimeter, ash fusion microscope, CHN analysis, ...)
- Sampling and analysis of gaseous, liquid and solid products from gasification and pyrolysis
- Thermo-gravimetric analysis (TGA-MS)
- Mass- and energy balances for processes development as well as verification of experiments
- Development of gasification processes with a special focus on fluidized bed applications
- Cold flow modelling and CFD simulation of fluidized bed processes with a main focus on gasification and pyrolysis
- Biochar production and utilization with a special focus on negative CO₂ emissions
- Evaluation and optimization of industrial gasification applications

More information:

<https://boku.ac.at/en/map/ivet>

Address:

University of Natural Resources and Life Sciences, Vienna
Institute of Chemical and Energy Engineering
Muthgasse 107
1190 Vienna
Austria

Contact:

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Graz University of Technology

Institute of Thermal Engineering, Division Thermal Energy Systems and Biomass

The working group "Thermal Energy Systems" and Biomass develops and evaluates innovative technologies for energy conversion and efficient methods for heat generation.

Another research focus includes the experimental development of technologies based on combined heat and power generation of gasification processes with fuel cells. Furthermore, experimental research and development in the field of solid oxide fuel cells (SOFC) as well as solid oxide electrolysis cells (SOEC) is increasingly being conducted. One research focus in this field includes the development of degradation mitigation.

A selection of current research projects of the working group Thermal Energy Systems and Biomass are listed below:

- CFD based burner and process optimization
- Numerical Simulation of Gas/Solid Interaction in High Temperature Processes using coupled CFD/FEM Simulation
- Development of the reliability- and durability diagnosis tools for solid oxide fuel and electrolysis cells
- Reversible solid oxide cells for electrochemical energy conversion and energy storage
- Experimental characterization and evaluation of special fuels (such as: ammonia, wood synthesis gas, biogas, diesel, ethanol, ...) for application in solid oxide fuel cells
- Electrochemical characterization and performance assessment of SOC stacks in reversible operation

More information:

<https://www.tugraz.at/home/>

Address:

Graz University of Technology, Institut of Thermal Engineering, Inffeldgasse 25/B, A-8010 Graz

Contact:

Univ.-Prof. Dipl.-Ing. Dr.techn Christoph Hochenauer: christoph.hochenauer@tugraz.at

BEST

BioEnergy and Sustainable Technologies GmbH is a K1 Competence Centre in the Austrian COMET programme and closes the gap between academic research and industrial technology development by undertaking industry-driven applied research and development in the fields of bioenergy, the sustainable bio-based economy, and future-proof energy systems.

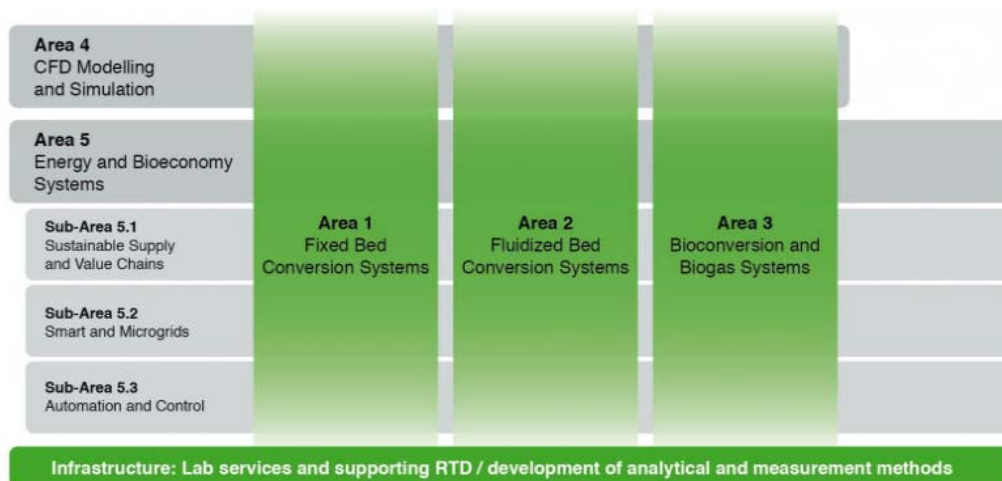


Figure 1: Organisational structure of BEST¹⁰

Actually, the project Waste-2-Value¹¹ should be mentioned here.

The Waste-2-Value project is driving the use of waste residues to produce hydrogen-rich syngas. The project focuses on waste fuels such as sewage sludge, residues from the pulp and paper industry, and mixtures with waste wood. In a second process step, the syngas is synthesized into liquid fuel (high quality diesel and kerosene). The current stage of the project runs to 2023 and covers construction and start-up of the pilot facility to gain the relevant operational experience. The Waste2Value research programme examines the entire process chain, starting with the waste fuel, and including syngas production, purification, treatment and synthesis through to the final refining and use of the FT fuel in fleet trials for public transport. The plant is the first of its kind in the world designed to demonstrate the use of this technology in a single, end-to-end process in an industrial environment. The project results will allow the process to be evaluated in economic and technical terms, providing the basis for the planned industrial-scale implementation of the process.

The COMET project is funded by the Austrian Research Promotion Agency (FFG) and managed by the K1 Competence Centre BEST. In addition to Wien Energie and SMS Group, the company partners also include Heinzl Paper, Wiener Linien GmbH, Wiener Netze GmbH and the Österreichische Bundesforste (Austrian Forest Authority), while Vienna University of Technology and the Luleå University of Technology are the scientific partners.

More information:

<https://best-research.eu/>

Address:

BEST - Bioenergy and Sustainable Technologies GmbH, Inffeldgasse 21b, 8010 Graz, Austria

¹⁰ <https://best-research.eu/en/company/overview>

¹¹ https://www.best-research.eu/en/competence_areas/all_projects/view/611

Contact:

Markus Luisser: markus.luisser@best-research.eu

MCI Innsbruck

The research focus lies in the intersection of energy and process engineering and deals with the multifaceted issues of these fields. Focal points are, for example, in the areas of energy supply from biogenic and renewable raw materials, the topic of water with its characteristics of waste water, process water and drinking water as well as an energy-efficient and resource-efficient use of snow-making systems.

The aim of the research projects in this field is to develop innovative solutions and concepts for current and future challenges, which are often developed together with partners from industry and research.

More information:

<https://www.mci.edu/en/>

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Contact:

Dr. Martin Spruck, MSc.: martin.spruck@mci.edu

MCI Innsbruck - Josef Ressel Centre

The Josef Ressel Centre for production of activated charcoal out of municipal residues was established in 2020 for the duration of five years at the Management Centre Innsbruck, Department for Environmental-, Process and Energy Engineering.

Coal from wood gas power plants can play an important role in wastewater treatment. How to equip the powdered coal with the desired properties in the gasification process is the subject of research at this JR Centre.

Wood gas power plants are primarily used to provide renewable energy. When gasifying wood, including residual wood from the communal environment, powdered coal is also a by-product. This coal is currently used as an additive for liquid manure treatment (odour reduction), as a soil improver, but also for the stabilization of biological processes (biogas and digester gas processes) without the underlying mechanisms being known in detail.

Contact:

Prof. Dr. techn. Angela Hofmann: angela.hofmann@mci.edu

Further information regarding industries and implementations in Austria can be found in Country Report Austria 2021.¹²

¹² http://www.task33.ieabioenergy.com/app/webroot/files/file/country_reports/2021/CR%20Austria%202022.pdf

Association Technique Energie Environnement - Club Pyrogazéification

The “Pyrogasification Club” (French Club Pyrogazéification) is a professional association, part of the French Technical Association for Energy and Environment (ATEE), gathering the main stakeholders in the sector (pyrolysis/gasification of biomass and waste) across its entire value chain: biomass and waste managers, manufacturers, “end customers” (industries), equipment manufacturers, engineering offices, laboratories and researchers, gas network managers, major energy companies, etc.

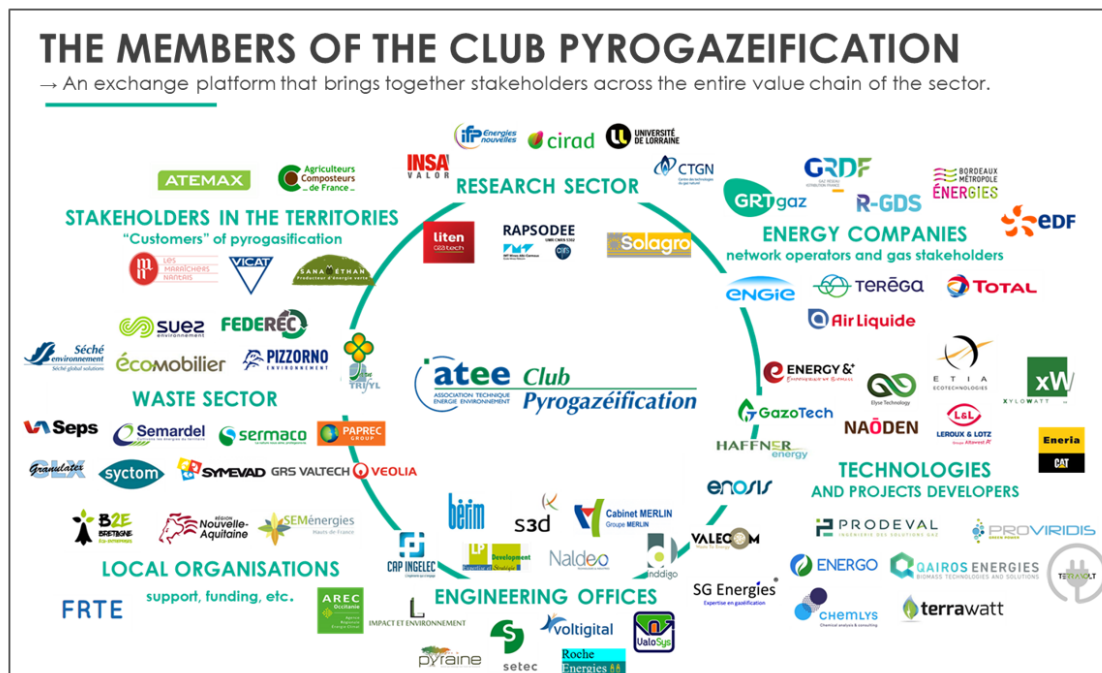


Figure 2: The members of the Club of pyrogasification

More information:

<https://atee.fr/energies-renouvelables/club-pyrogazéification>

Address:

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Atomic energy and Alternative Energies Commission (CEA) - LITEN

The French Atomic Energy and Alternative Energies Commission (CEA) is a public scientific, technical and industrial research body (EPIC). As a major actor in research, development and innovation, the CEA operates in four areas: defence and security, low-carbon energies (nuclear and renewable), technological research for industry and fundamental research. Relying on a recognized expertise capacity, the CEA participates in the establishment of collaborative projects with numerous academic and industrial partners.

Having initially developed skills in the recovery of cellulosic biomass by gasification, LITEN, a CEA Tech institute, then turned to alternative waste treatment processes with a high calorific value: household waste, food residues and sewage sludge, for

example.

CEA Liten's expertise in gasification processes (thermochemical route) covers all stages of resource treatment.

More information:

<https://www.cea.fr/cea-tech/liten>

Interprofessional Committee for Wood-Energy (CIBE)

The Interprofessional Committee for Wood-Energy (CIBE) was created in 2006. It coordinates and supports the players in collective and industrial wood heating to professionalize practices, establish the rules of the art, train professionals and promote high and medium-power boiler rooms to public and private decision-makers.

It brings together 150 companies, owners (public and private), professionals in the wood industry and the world of energy. In 2019, CIBE carried out a status study on wood gasification in France at the request of ADEME, the French ecological transition agency.

More information:

<https://cibe.fr/>

Center for International Cooperation in Agronomic Research for Development (CIRAD)

The Center for International Cooperation in Agronomic Research for Development is the French organization for agricultural research and international cooperation for the sustainable development of tropical and Mediterranean regions.

BioWoodEB: Technical diagnosis of biomass pyrolysis and gasification processes

Along with its knowledge of the processes, CIRAD has developed expertise in the collection, sampling and analysis of products from pyrolysis and gasification. This skill is essential for evaluating the operation of a reactor, for diagnosing faults and for optimizing processes. It also makes it possible to measure the potential environmental impacts of the processes. A portable sampling line has been specially designed in Montpellier to analyze permanent gases in situ and sample condensable products. This skill has been implemented with private companies in France, Europe, Brazil and China.

More information:

<https://www.cirad.fr/>

<https://ur-biowoeb.cirad.fr/expertises-produits/expertises-biomasse-energie/diagnostic-procedes-de-pyrolyse-gazeification-de-biomasse>

IFP Energies Nouvelles

IFP Energies Nouvelles (IFPEN) is a major player in research and training in the fields of energy, transport and environment. From research to industry, technological innovation is at the heart of its action. IFPEN operates in four main areas: Sustainable mobility, Renewable energies, Responsible fuels, Climate, environment and circular economy.

IFPEN research teams work on one or more of three complementary objectives :

- Developing economical transport with low environmental impact,
- Producing fuels, chemical intermediates and energy from renewable sources,
- Producing fuels and chemical intermediates with low environmental impact from fossil resources.

IFP School (formerly the National Higher School of Petroleum and Engines or ENSPM), part of IFPEN, trains young engineers according to these objectives. The teams can join forces with other academic establishments on certain themes.

More information:

<https://www.ifpenergiesnouvelles.fr/>

IMT Mines Albi - RAPSODEE

The RAPSODEE laboratory (Albi Research in Process Engineering for Divided Solids, Energy and the Environment) been associated with CNRS¹³ since 2001 as a UMR (joint research unit). The laboratory's activities are structured into two research groups that conduct research in the fields of energy (renewable energies: solar and biomass), the environment and particulate engineering with particular emphasis on sustainable processes: more intense, more energy efficient, more environmentally friendly and safer.

THE VALTHERA PLATFORM

Located near the city of Albi, VALTHERA is a technological platform specializing in the development of high energy efficiency thermal processes for the recovery of residues and by-products of biomass transformation. These abundantly available resources can be valued in the form of energy or value-added materials.

VALTHERA offers a technological offer including thermal processes (drying, combustion, gasification, etc.) using, in certain cases, a renewable energy source (solar). It also offers high-performance equipment for the treatment of emissions and various pollutants.

The platform has a role of disseminating to companies, and in particular SMEs wishing to complete research and development programs, to demonstrate the feasibility of the project or to extrapolate a process.

More information:

<https://www.imt-mines-albi.fr/fr/rapsodee>

<https://www.imt-mines-albi.fr/fr/plateforme-valthera>

INSA VALOR - PROVADEMSE platform

INSAVALOR is the Research & Development, Valuation and Continuing Education subsidiary of INSA (national institute of applied sciences) Lyon. INSAVALOR promotes relations between laboratories and companies looking for technological solutions, skills and training for their innovative projects.

Its role: to identify the needs of companies in terms of knowledge and technology, training and mobilize scientific teams in order to bring out innovative responses.

The platform PROVADEMSE

PROVADEMSE is the technological innovations platform of INSAVALOR, the subsidiary of valorisation of the INSA (Applied Sciences National Institute) of Lyon. Their experts help and support the development of ecotechnologies in being a linking unit between research and industry. They develop and experiment technical and innovative solutions regarding the remediation of soils and sediments, as well as the waste repurposing into materials and energy. Certified by the competitiveness cluster AXELERA in 2008, PROVADEMSE has been highly supported since its creation by the Ministry of Industry, DRRT, the Region Rhône-Alpes-Auvergne, the Metropole of Lyon and the FEDER funds.

Research areas:

PROVADEMSE expertise covers the entire technical process from on-site sampling to support for implementation on an industrial

¹³ French Scientific Research National Center

scale, providing concrete solutions in the following areas:

- Waste characterization and management
- Environmental characterization
- Soil and sediment decontamination
- Waste recovery into new materials
- Valorization of waste into energy resources
- Industrial and territorial ecology

Expertise

- Characterization of waste with a view to optimizing their management
- Soil and sediment treatment feasibility study
- Assessment of the potential for integrating waste into new construction materials for building or civil engineering
- Production of alternative energies from waste by thermal or biological means

Means

The technological platform has substantial equipment available for studies from a laboratory scale to a trial scale. This allows them to carry on to the industrialization scale. PROVADEMSE provides the skills of engineers, researchers and technicians on one hand, and technical resources, laboratories, testing platforms and equipment on the other.

Technical means:

- Equipment for sorting, grinding, drying on an industrial scale, bio-physico-chemical and ecotoxicology laboratory
- Heat treatment pilot (desorption, pyrolysis), biological treatment pilot, washing pilot
- Leaching and percolation laboratory, pilot scale and demonstrator evaluation devices (lysimeters, road boards)
- Pre-industrial scale gasification pilot and methanization pilot

Web:

<https://recherche.insavalor.fr/plateformes-technologiques/provademse>

<https://www.provademse.com/homepage>

SOLAGRO

Solagro is an association company specializing in engineering, consulting and training in the fields of agriculture, environment and energy. Their approach combines support for achievements (studies and project management assistance), foresight, training and R&D.

The diversity of their levels of intervention, from individual projects to European public policies, allows Solagro to combine proximity and perspective in the advice they provide to their contacts. Their independence from any equipment supplier or manufacturer guarantees their sponsors results guided exclusively by sustainability objectives (economic, social and environmental).

Study: Towards 100% renewable gas in France in 2050? (2018)

At the start of 2018, ADEME, GRDF and GRTgaz published the results of a study on the feasibility of a “100% renewable gas mix in 2050” (cited in part I.1 of this document). Solagro carried out this work with great interest with the support of an expert in “gas” infrastructures. This study is a continuation of ADEME's work to concretely explore the feasibility and conditions for implementing the energy transition in France.

The summary of the study is available on the ADEME website¹⁴.

More information:

<https://solagro.org/index.php>

¹⁴ <https://www.ademe.fr/>

<https://solagro.org/vers-un-gaz-100-renouvelable-en-france-en-2050-40-actu-81>

University of Lorraine - LERMAB

LERMAB is a multidisciplinary research laboratory of the University of Lorraine linked to INRAE Nancy-Lorraine as USC (Unit under contract). It has two main locations in Vandoeuvre within the Faculty of Science and Technology and Epinal in the ENSTIB (Engineer's school of Wood Science and Timber technology), and partly in Longwy in IUT.

The permanent staff consists of just over 40 academics with expertise in different scientific fields (physical and organic chemistry, mechanics, chemical engineering, biology). The non-permanent staff has about 40 graduate students, post-docs, contract scientists and undergraduate trainees (BS and MS).

With the various scientific skills of the staff, LERMAB is developing a research on wood and natural fibers, ranging from the molecular level to the macroscopic level of the material, even til wooden structures.

By its specific position related to the multidisciplinary nature of its research on wood, LERMAB is playing a special role as an interface between academic research and wood industries. Basic and applied research is developed through collaborations with different Technology transfer centers such as Critt Bois or CETELOR (for textile industry) within the cluster 'Fibers'.

Research activities:

The laboratory's activities structured around wood material are divided into three main research axes in which each LERMAB teacher-researcher is involved according to their skills and initial training.

- "Materials and Processes" axis
- "Chemical Valorization, Energy and Processes" axis
- "Energy, Mechanics, Wood Construction" axis

The consistency of this structuring lies in the fact that each of the proposed axes brings together research activities with relatively similar purposes based on a well-identified disciplinary skills base providing scientific cohesion to each axis. Transversal actions between each of these axes then come to complete the device allowing to have a multidisciplinary multi-scale and multi-physical approach of a research project when this proves necessary.

Chemical, Energy and Process Recovery

The "Chemical, Energy and Process Recovery" axis aims to replace part of fossil fuels with renewable resources. The common point of the research carried out in this area concerns the valorization of lignocellulosic biomass for applications in the energy and chemical fields. The research themes included in this axis concern the biorefinery, the development of building blocks for chemistry, the synthesis of bio-based molecules (surfactants, solvents, etc.), the chemical recovery of extractables, the production of energy by dry routes (combustion, gasification and pyrolysis) and wet routes (liquefaction, bioethanol...).

More information:

<http://lermab.univ-lorraine.fr/>

<http://lermab.univ-lorraine.fr/presentation-generale>

Further information regarding the commercial gasification projects and implementation in France can be found in the Country report France 2020¹⁵.

¹⁵ http://www.task33.ieabioenergy.com/app/webroot/files/file/country_reports/2021/Country%20report%20France.pdf

GERMANY

The German Biomass Research Centre (Deutsches Biomasseforschungszentrum - DBFZ)

It 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 "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).

More information:

<https://www.dbfz.de/en/>

Address:

Torgauer Str. 116, 04347 Leipzig, Germany

Contact:

Prof. Dr. Daniela Thrän: info@dbfz.de

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

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 is on entrained flow gasification. Lab-scale reactors like the PiTER, BabiTER, Wire Mesh Reactor 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 NH₃, being a nutrient for gas fermentation.

PyroGa

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.

More information:

<https://www.es.mw.tum.de/>

Address:

Boltzmannstr. 15, 85748 Garching

Contact:

Prof. Dr.-Ing. Hartmut Spliethoff: spliethoff@tum.de

Friedrich-Alexander University 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

More information:

<https://www.evt.tf.fau.eu/>

Address:

Fürther Straße 244f, 90429 Nürnberg, Germany

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Prof. Dr.-Ing. Jürgen Karl: sekretariat-evt@cbi.uni-erlangen.de

TU DRESDEN, Institute of Process Engineering and Environmental Technology

University of Technology Dresden (TUD) is one of the largest technical universities in Germany and one of the leading and most dynamic institutions in the country.

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 and pilot scale facilities are available for fuel characterization and determination of reaction kinetic data.

More information:

www.energieverfahrenstechnik.de

Address:

George-Bähr-Straße 3b, 01069 Dresden, Germany

Contact:

Prof. Dr.-Ing. Michael Beckmann

Dr.-Ing. Daniel Bernhardt

daniel.bernhardt@tu-dresden.de / evt@mailbox.tu-dresden.de

Research Centre on Environmental Engineering Clausthal-Zellerfeld (Clausthaler Umwelttechnik Forschungszentrum (CUTEC)/TU Clausthal-Zellerfeld)

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.

More information:

<http://www.cutec.de>

Address:

Leibnizstraße 23, 38678 Clausthal-Zellerfeld, Germany

Contact:

Dr.-Ing. Stefan Vodegel

Dipl.-Ing. Felix Müller: felix.mueller@cutec.de

Fraunhofer Institute for Factory Operation and Automation IFF Magdeburg

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.

More information:

<https://www.iff.fraunhofer.de/>

Address:

Sandtorstraße 22, 39106 Magdeburg, Gemany

Contact:

Prof. Dr. Julia C. Arlinghaus

ideen@iff.fraunhofer.de

Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT

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.

More information:

<http://www.umsicht.fraunhofer.de>

Address:

Osterfelder Straße 3, 46047 Oberhausen, Germany

Contact:

Prof. Dr.-Ing. Eckhard Weidner

tim.schulzke@umsicht.fraunhofer.de

University of Technology Darmstadt, Energy Systems and Technology (EST)

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.

The institute has expertise in the modelling and simulation of multiphase flows. 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.

Actual projects

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.

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.

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.

More information:

<https://www.est.tu-darmstadt.de/>

Address:

Otto-Berndt-Straße 2, 64287 Darmstadt, Germany

Contact:

Prof. Dr.-Ing. Bernd Epple

info@est.tu-darmstadt.de

University of Stuttgart, Institute of Combustion and Power Plant Technology (IFK)

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.

More information:

<https://www.ifk.uni-stuttgart.de/en/>

Address:

Pfaffenwaldring 23, 70569 Stuttgart, Germany

Contact:

Univ.-Prof. Dr.-techn. Günter Scheffknecht

M.Sc. Max Schmid

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University of Technology Bergakademie Freiberg, Institute of Energy Process Engineering and Chemical engineering (IEC)

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.

There are several research plants in operation¹⁶:

- FlexiSlag pilot plant (a next generation slagging fixed-bed gasifier)
- FlexiEntrained pilot plant

More information:

<https://tu-freiberg.de/en/iec/evt>

Address:

Fuchsmuehlenweg 9D, 09599 Freiberg, Germany

Contact:

Prof. Dr.-Ing. Bernd Meyer

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RWTH Aachen, Unit of Technology of Fuels (TEER)

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.

TEER's technical center is equipped for the operation of pyrolysis, gasification and combustion tests on a semi-industrial scale.

More information:

¹⁶ <https://tu-freiberg.de/fakult4/iec/evt/downloads/publikationen>

<http://www.teer.rwth-aachen.de>

Address:

Wüllnerstraße 2, 52062 Aachen, Germany

Contact:

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OTH Amberg-Weiden, Institute of Energy Engineering

The Ostbayerische Technische Hochschule Amberg-Weiden (OTH AW) is a young, up-and-coming and innovative University of Applied Sciences.

Center of Excellence for Cogeneration Technologies (CoECogen)

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.

One area of the CoECogen's research over the years has focused on the utilization of products from 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 bio-waste.

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 works 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.

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.

More information:

<https://ifeam.de>

Address:

Kaiser-Wilhelm-Ring 23, 92224 Amberg, Germany

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The Karlsruhe Institute of Technology (KIT)

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.

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 (TRL 6) with 2 MWth fast pyrolysis for biosyncrude production and 5 MWth 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.



Figure 3: The bioliq®-Pilot plant

More information:

www.bioliq.de

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

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.

More information:

<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.

More information:

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

Contact:

Prof. Dr.-Ing. Jörg Sauer

office@ikft.kit.edu

More information regarding research projects as well as commercial ones could be found in detail in Country Report Germany 2021.¹⁷

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http://www.task33.ieabioenergy.com/app/webroot/files/file/country_reports/2021/2022_01_24%20Country%20und%20Statusreprot%202021%20Germany%20final_1.pdf

INDIA

In the three decades between 1980 to 2010, research and development in the area of biomass gasification was at its peak in India with involvement of several research institutions, industries and implementing agencies. There were about 25 biomass gasifier manufacturers to cater the needs of thermal and power requirements with about 4 engine manufacturers involved in the commercial operations. Focus on biomass gasification has been reduced in the last decade except for a few institutions which has pursued their ongoing research activities. Details of some of research institutes currently pursuing research in gasification area through student and industry collaboration are given below. Exact information about the research area is not available.

Table 1: Overview on research institutions in India

Institute name	Research group details
Indian Institute of Science, Bangalore	Dr. S. Dasappa Professor Centre for Sustainable Technologies, Combustion, Gasification and Propulsion Laboratory http://cgpl.iisc.ernet.in/dasappa/
Indian Institute of Technology, Bombay	Sanjay M Mahajani Professor, Dept. of Chemical Engineering https://www.che.iitb.ac.in/web/faculty/sm/index.htm
	Srinivas Seethamraju Assistant Professor Dept. of Energy Science and Engineering https://www.es.e.iitb.ac.in/faculty/srinivas-seethamraju
	Sandeep Kumar Assistant Professor Dept. of Energy Science and Engineering https://www.es.e.iitb.ac.in/faculty/sandeep-kumar
Indian Institute of Technology, Guwahati	Prabu Vairakannu Associate Professor Dept. of Chemical Engineering https://www.iitg.ac.in/chemeng/faculty_profile.php?name=pv
	Vijay S Maholkar Professor Dept. of Chemical Engineering https://www.iitg.ac.in/chemeng/faculty_profile.php?name=vsm
	Pinakeswar Mahanta Professor Dept. of Chemical Engineering https://www.iitg.ac.in/mech/faculty/pinak/
Indian Institute of Technology, Roorkee	Sonal K Thengene Assistant Professor Dept. of Hydro and Renewable Energy https://bwrl.iitr.ac.in/
	N Siva Mohan Reddy Associate Professor, Dept. of Chemical Engineering https://www.iitr.ac.in/~CH/N_Siva_Mohan_Reddy
Indian School of Mines, Dhanbad	I M Mishra Professor Dept. of Chemical Engineering ISM Dhanbad https://iitism.irins.org/profile/97595#personal_information_panel
	Shalini Gautam Associate Professor Department of Fuel, Minerals and Metallurgical Engineering https://www.iitism.ac.in/index.php/Departments/faculties_detail_fme

BITS Pilani, Pilani Campus	Pratik N Sheth Associate Professor Dept. of Chemical Engineering https://www.bits-pilani.ac.in/pilani/pratik/Profile
Tezpur University	Sadhan Mahapatra Associate Professor Department of Energy http://www.tezu.ernet.in/dener/people/SM_index.htm
University of Petroleum and Energy Studies(UPEs), Dehradun	Pankaj Kumar Sharma Professor Dept. of Mechanical Engineering https://www.upes.ac.in/schools-faculty/engineering/mechanical/dr-pankaj-kumar-sharma

Research project:

Combustion, Gasification and Propulsion Laboratory (CGPL) division of Indian Institute of Science (IISc), Bangalore has reoriented its research on biomass gasification in recent years. It initially started research on air blown biomass gasification in 1982 and developed technology packages to meet power and thermal requirements; and the developed technology was also transferred to US and Europe. With the objective of producing advanced biofuels from biomass, CGPL has worked extensively on oxy-steam biomass gasification process to generate hydrogen rich syngas from a range of biomass based feed stocks. It has recently demonstrated proof of concept for production of 99.97% purity hydrogen at 2 kg/h scale. Plant data indicates that developed technology can produce around 100 g of hydrogen per kg of biomass. The technology is now in an advanced stage for demonstration at 10 kg/hr PEM fuel cell quality hydrogen production.

Contact:

Mr. Rahesh M Badhe
Alternative Energy
Research and Development Centre
Indian Oil Corporation Ltd.
Sector-13, Faridabad, Haryana (India) -121007
badher@indianoil.in

Mr D Mohana Rao
Sector-85, Faridabad, Haryana (India) -121007
mohanrd@indianoil.in

More information regarding the gasification status in India could be found in Country report India 2021.¹⁸

¹⁸ http://www.task33.ieabioenergy.com/app/webroot/files/file/country_reports/2021/India_2021.pdf

ITALY

Several research institutes are working on gasification in Italy. The figure below gives an overview of the actors involved in R&D programmes on the topic and which have significant infrastructures for conducting experimental activities.



Figure 4: Research organization and institutions involved in R&D activities on gasification in Italy

In addition to these players, there are several other R&D groups connected to technical universities and universities, such as PoliTo, PoliMI, PoliBa, UniBO, UniPI, UniPG/CRB, UniCal. They are mainly involved in conducting gasification-related topics, such as gas stream exploitation and conversion, modelling, LCA and techno-economic assessments.

Italian National Agency for new Technologies, Energy and Sustainable Economic Development (ENEA)

The Agency's activities are mainly focused on Energy Efficiency, Renewable Energy Sources, Nuclear Energy, Climate and the Environment, Safety and Health, New Technologies. R&D activity related to the exploitation of biomass feedstocks and biogenic fractions via thermochemical processes are carried out at Trisaia Research Center (Rotondella, Italy) within the mission and scope of the Division of Bioenergy, Biorefinery and Green Chemistry.

Research areas:

- Gasification reactor design (Fixed bed and fluidized bed gasifiers)
- High temperature gas cleaning and conditioning
- Small scale CHP plant
- Hydrogen and biofuels production from biomass
- CFD simulation of gasification reactors
- Process modelling
- Life cycle and technical-economic assessments

At Trisaia Research Center a technology park dedicated to biomass gasification is present (Figure 4). The activity of R&D is focused on the development of small to medium sized technologies for several applications (e.g. CHP, BTL, SNG, H₂). The gasification plants available are based on gasification reactors of different design (i.e. fixed beds, fluidized beds and multi stage), and are equipped with sections for gas cleaning and conditioning.

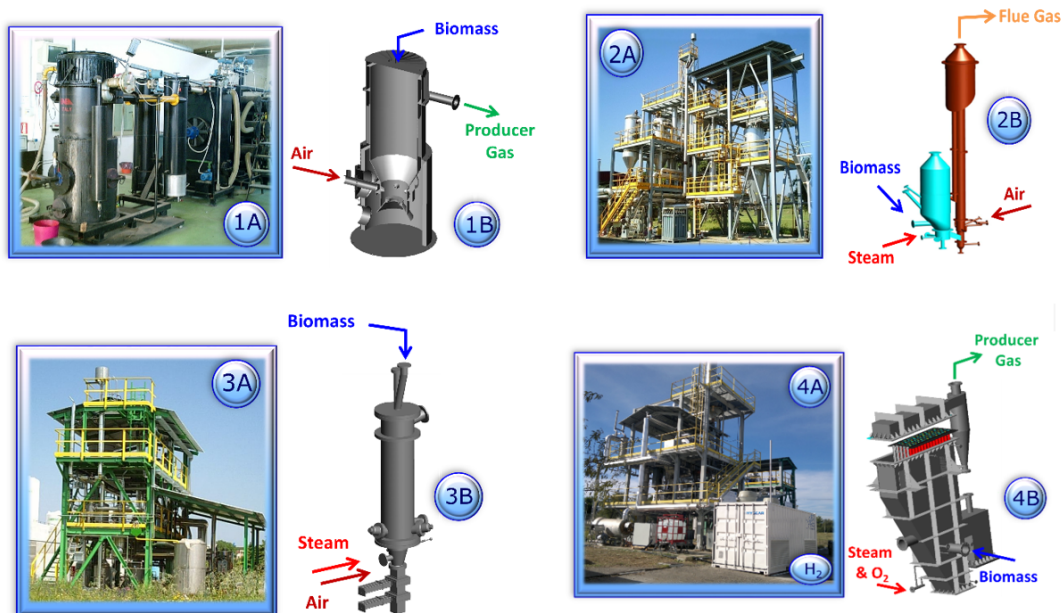


Figure 5: Pilot facilities at ENEA

1A, 1B - Air-Blown Downdraft Fixed Bed Gasification Plant (120 kWth), with Conventional Gas Cleaning: Filtration Units and Water Scrubber, combined to Internal Combustion Engines (30-80 kWe).

2A, 2B - Dual Fluidised Bed Steam Gasification Plant (500 kWth) with Hot Gas Cleaning via an Adsorbing Reactor and a Filtration Unit: Cyclone plus Ceramic Filter.

3A, 3B - Air/Steam-Blown Updraft Fixed Bed Gasification Plant (150 kWth) with Wet Gas Cleaning: Bio-Diesel Scrubber coupled with Coalescent Filters.

4A, 4B - Internally Circulating Fluidised Bed Steam/O₂ Gasification Plant (1 MWth) with integrated Catalytic Ceramic Candles system for In-Situ gas filtration and conditioning.

More information:

<http://www.enea.it/en> - <http://www.trisaia.enea.it/en/home>

Address:

SS Jonica 106, km 419 + 500 - 75026, Rotondella (MT) - Italy

Contact:

Donatella Barisano - donatella.barisano@enea.it

Interuniversity Centre for Biomass Research for Energy Purposes (CIRBE) and Guglielmo Marconi University

CIRBE is an inter-university consortium established between University of L'Aquila and University of Teramo. Together with Guglielmo Marconi University, these three bodies have long been engaged in activities devoted to development of technologies based on fluidized bed gasifiers for biomass and waste gasification.

Research areas:

- Gasification reactor design (mainly fluidized bed)
- Fluid-dynamic behaviour of fluidized bed chemical reactors, under high temperature and pressure conditions
- CFD simulation of fluidized bed equipment and heterogeneous reaction systems
- Catalytic biomass steam gasification
- Hot gas cleaning and conditioning
- Power plant and process simulation

- Small scale CHP plant
- Technical-economic analysis of innovative systems

The laboratory of Chemical Reaction Engineering and Fluidization Dynamics (CRE&FD) of the University of L'Aquila and the Laboratory of Energy and Environmental Research (EERU) of the University of Teramo have been active in fluidized bed biomass gasification research since more than 20 years. The CRE&FD of the University of L'Aquila has experience in the investigation of fluidized bed chemical reactors and multiphase reactors by means of: i) cold model testing and ii) CFD simulations; in particular, for fluidized bed reactor and catalytic system for syngas hot gas cleaning and conditioning. At Guglielmo Marconi University most recent activity are related to the exploitation of syngas via SOFC for high efficiency energy conversion.

More information:

University of Teramo - Laboratory of Energy and Environmental Research

https://www.unite.it/UniTE/Bioscienze_e_tecnologie_agro-alimentari_e_ambientali

Address:

Via Renato Balzarini 1, 64100 Teramo - Italy

Contact:

Prof. Sergio Rapagnà - srapagna@unite.it

More information:

University of L'Aquila - Laboratory of Energy and Environmental Research

<http://diie.univaq.it/index.php>

Address:

Via Giovanni Gronchi, 18 - Zona industriale di Pile, 67100 L'Aquila - Italy

Contact:

Prof. Pier Ugo Foscolo - pierugo.foscolo@univaq.it

More information:

Guglielmo Marconi University - Laboratory of Applied Sciences and Technologies

<https://www.unimarconi.it/en/sezioni-di-ricerca>

Address:

Via Plinio, 44, 00193 Rome, Italy

Contact:

Prof. Enrico Bocci - e.bocci@unimarconi.it

info@unimarconi.it

National Research Council (CNR)

At Consiglio Nazionale delle Ricerche (CNR), studies in the field of biomass and waste gasification are focused on process studies and technologies development and are carried out at both experimental and theoretical levels. The R&D activities cover the whole process chain, from gasification reactors of different configuration and size, also considering local feedstocks availability, to gas end-use.

The main research groups involved on these subjects are the "Istituto di Ricerche sulla Combustione" (IRC), which works in

close collaboration with the “Dipartimento di Ingegneria Chimica, dei Materiali e della Produzione Industriale” (DICMaPI) of University of Naples-Federico II and with the “Istituto Motori” (IM), and the “Istituto di Tecnologie Avanzate per l’Energia” (ITAE).

Research areas:

- Study and development of gasification technologies based on slagging entrained-flow, fluidized-bed and fixed-bed reactors
- Small scale cogeneration (CHP) plant
- Gas cleaning and conditioning
- Solid fuel characterization and densification pre-treatments
- Thermochemical equilibrium and kinetic models of biomass gasification and overall energy balance
- CFD 1D models (phenomenological) of biomass gasification in fluidized and fixed beds
- Syngas combustion performance characterization and modelling in spark ignition (SI) and compression ignition (CI) engines
- System analysis of biomass powered cogeneration (CHP): analysis and optimization of integrated processes of syngas production and internal combustion engine powering

More information:

<http://www.irc.cnr.it/>

Address:

Istituto di Ricerche sulla Combustione
Piazzale Tecchio, 80 - 80125 - Napoli- Italy

Contact:

Giovanna Ruoppolo - g.ruoppolo@irc.cnr.it

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Università degli Studi Federico II - Dipartimento di Ingegneria Chimica dei Materiali e della Produzione Industriale
Piazzale V. Tecchio 80, 80125 Napoli, ITALIA - Italy

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More information:

<https://www.im.cnr.it/>

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Istituto Motori
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Contact:

Michela Costa - m.costa@im.cnr.it
direttore@im.cnr.it

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<http://www.itae.cnr.it/en/>

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Istituto di Tecnologie Avanzate per l'Energia
Salita Santa Lucia Sopra Contesse, 5 - 98126 - Messina - Italy

Contact:

Salvatore Freni - salvatore.freni@itae.cnr.it
info@itae.cnr.it

Free University of Bozen-Bolzano (UNIBZ)

The research of the Bioenergy & Biofuels Lab deals with the experimental and modelling characterization of thermochemical conversion processes applied to lignocellulosic biomass. The main investigated processes are gasification and pyrolysis, but also traditional processes such as combustion, as well as innovative valorization pathways such as hydrothermal carbonization. Besides, possible syngas upgrading routes such as reforming, methanation and Fischer-Tropsch synthesis are also investigated.

Research areas:

- Characterization and prototype development of gasification and pyrolysis reactors;
- Innovative filtering systems;
- On-site monitoring and diagnostics of gasification and pyrolysis systems;
- Analysis and optimization of technologies for the combined production of heat and electricity;
- Valorisation of agricultural waste and by-products;
- Biofuels production by means of Fischer-Tropsch synthesis, reforming and methanation;
- Chemical-physical characterization of fuels, catalysts and residues.

More information:

<https://bnb.groups.unibz.it/>

Address:

NOI Techpark, Via Alessandro Volta, 13 - 39100, Bolzano - Italy

Contact:

Marco Baratieri - marco.baratieri@unibz.it
Francesco Patuzzi - francesco.patuzzi@unibz.it

University of Modena and Reggio Emilia - Bio-Energy Efficiency Laboratory (BEELab)

The Bio-Energy Efficiency Laboratory - BEELab, is part of the Engineering Department "Enzo Ferrari" of the University of Modena and Reggio Emilia. BEELab is the result of the experience and knowledge gained throughout the years by the research group of energy efficiency in the field of biomass, renewable energies and thermo-fluid-science.

Research areas:

- biomass chemical and physical characterization
- biomass thermochemical valorization tests (torrefaction, pyrolysis, gasification)
- kinetic simulation of the gasification and combustion processes

- economical evaluation of power-plant ROI
- design and test of reactors of different design
- gaseous process stream characterization and biochar quality assessment

More information:

<http://www.beelab.unimore.it/site/home.html>

Address:

University of Modena and Reggio Emilia - Department of Engineering “Enzo Ferrari” Via Vivarelli 10/1 41125 Modena - Italy

Contact:

beelab@unimore.it

RE-CORD - Renewable Energy Consortium for Research and Demonstration

The RE-CORD consortium, funded in 2010 under the initiative of CREAR (University of Florence), carries out scientific and technological researches in the field of Renewable Energies and notably in the field of Bioenergy and related policies. RE-CORD is a no-profit independent research body, which merges competences and resources in the field of basic and applied research, engineering, and sustainable land planning and development. Members of RE-CORD are the University of Florence, Az. Agricola Montepaldi, Spike Renewables, ETA Florence, BioEnTech, GAL-START.

RE-CORD has extensive experience on technologies related both to biomass for solid biofuels and energy generation. The specific areas of competence range from technologies for energy generation, thermal and electric, through thermochemical processes, such as gasification and pyrolysis, to those for producing advanced biofuels to technologies for biomass densification (pellets and briquettes).

Research areas:

- Biomass Processing for CHP application and biofuels (gasification, pyrolysis, HTC, HTL);
- Performance assessment of small-scale CHP gasification plant;
- Process for advanced biofuel production;
- Biochar production, functionalization and use;
- EU single-market policy development for biofuels market uptake and deployment;
- Technical-economic analysis and LCA;
- Catalytic conversion processes

RE-CORD owns and operates a state-of-the-art chemical and analytical laboratory fully dedicated to biofuels and bioenergy and runs an experimental area where a significant number of research and demonstration facilities are available.

More information:

<http://www.re-cord.org/>

Address:

Viale Kennedy, 182, 50038 Scarperia e San Piero (FI), Italy

Contact:

Andrea Maria Rizzo - andreamaria.rizzo@re-cord.org

info@re-cord.org

SOTACARBO SPA - Società Tecnologie Avanzate Low Carbon SPA

SOTACARBO - Società Tecnologie Avanzate Low Carbon SpA is a public research centre (owned by Enea and the Regional Government of Sardinia) active, since 2003, in the field of low carbon technologies, including biomass and coal gasification and CO₂ capture, utilization and storage (CCUS).

Research areas:

- Fixed bed and bubbling fluidized bed gasification technologies
- Medium- and small-scale CHP generation
- Gas cleaning and conditioning
- Integration with CO₂ capture, utilization and storage

The R&D activities performed by Sotacarbo are focused on the experimental development of specific gasification technologies for small- and medium-scale commercial applications for combined heat and power (CHP) generation from biomass and mixtures of biomass and coal. Most of the research activity is carried out in three different experimental unit: a bench-scale bubbling fluidized-bed (BFB) reactor, a pilot-scale (500 kWth) BFB unit and a demo-scale (5 MWth) fixed-bed up-draft unit.



Figure 6: Pilot scale bubbling fluidized bed unit (500 kWth) - left side, demo-scale fixed bed gasification unit (5 MWth) - right side

Sotacarbo laboratories are also equipped with several instruments for fuel characterization (proximate, ultimate and calorimetric analyses and kinetic studies through thermogravimetric approaches) and tar analysis.

More information:

<http://www.sotacarbo.it/>

Address:

Sotacarbo SpA - Grande Miniera Serbariu - 09013 Carbonia (CI) - Italy

Contact:

Alberto Pettinau - alberto.pettinau@sotacarbo.it

sotacarbo@sotacarbo.it

University of Campania “Luigi Vanvitelli” - Department of Environmental, Biological and Pharmaceutical Sciences and Technologies

The Chemical Engineering research group that is active at the University of Campania “Luigi Vanvitelli” since 2000 has a recognized international competence in environmental, technological, economic and social aspects of energy generation from biomass and waste by means of the thermal-chemical conversion processes of combustion, gasification and pyrolysis. The research group manages two laboratories - the laboratory of Chemical Plants for Resource Recovery from Biomass and Waste and the laboratory of Environmental Sustainability of Processes and Services.

Research areas:

- Bubbling fluidized bed gasification technologies,
- Innovative technologies for material and energy recovery from alternative fuels,
- Technological, economic, social, and environmental aspects in the field of resource recovery
- LCA of different management options for municipal solid waste

At University of Campania, the main pilot plants of relevance for carrying out R&D activities are the Pilot-scale fluidized bed reactor, the Pre pilot-scale fluidized bed reactor and the Bench scale apparatus for hot syngas cleaning.

More information:

<http://www.distabif.unicampania.it/>

Address:

Via Vivaldi, 43 - 81100 Caserta, Italy

Contact:

Prof. Umberto Arena - umberto.arena@unicampania.it

Further information regarding the research, programmes, industries and implementation of gasification in Italy can be found in the Country report Italy¹⁹.

¹⁹ http://www.task33.ieabioenergy.com/app/webroot/files/file/country_reports/2019/ITALY2018.pdf

NETHERLANDS

The Netherlands has three important Technical Universities that offer a curriculum with a direct link with thermal systems. Eindhoven, Delft and Twente are the locations for these universities. Over the years the R&D with respect to gasification is varying a bit, with at the moment virtually no R&D in relation to gasification at the Technical University Eindhoven and at the University of Twente the focus is more on pyrolysis. Delft University is at the moment still performing R&D in relation to gasification.

Delft University of Technology

At the TUD an Indirectly Heated Bubbling Fluidized Bed Steam Reformer (IHBFSR) is present. The heat in this system is provided by two radiant tube burners placed vertically inside the reactor. One at the top and one at the bottom.

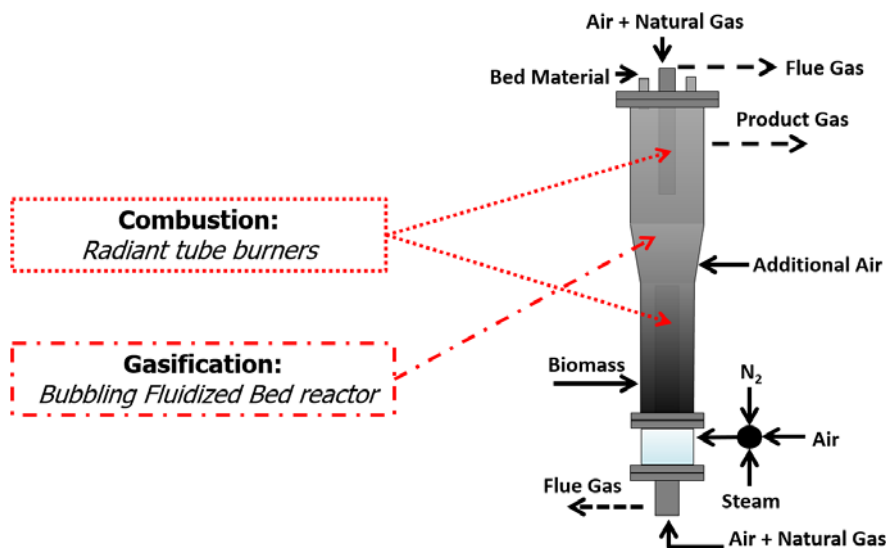


Figure 7: Schematic overview of the IHBFSR reactor at the TU Delft

The installation has been tested with pellets made from saw dust/wood shavings, woodchips and miscanthus. The bed material used was Corundum with kaolin as additive. Within the IHBFSR project the experimental work was supported with an Aspen model showing good correlation for the relation between the equivalence ratio and the main gas constituents (CO, CO₂, H₂ and CH₄), with a maximum error of max 3% on CO.

More information:

info@tudelft.nl

Address:

Postbus 5, 2600 AA Delft, The Netherlands

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Prof. Wiebren de Jong - Wiebren.deJong@tudelft.nl

TNO

TNO is the largest Dutch R&D organization, with a scope that covers and supports the entire span of the Dutch industry. The different domains (energy, health care, ICT, industry etc.) are covered within the different units of TNO. The work at TNO is the continuation of the work programme of ECN, a different R&D organization that merged with TNO in 2018. The unit Energy Transition is where most gasification R&D takes place.

Research areas:

- Biobased fuels and chemicals
- Circular plastics through thermal cracking

These focus areas help to transform the Dutch industry from a fossil based system to a biobased and circular based system. The biobased activities have a strong focus on producing advanced biofuels and biochemicals. For this an extensive research infrastructure has been build up over the past 2 years, with support of the ministry of Economic Affairs.

Dividing the capabilities into the following 4 topics, conversion, cleaning, catalysis and support units.

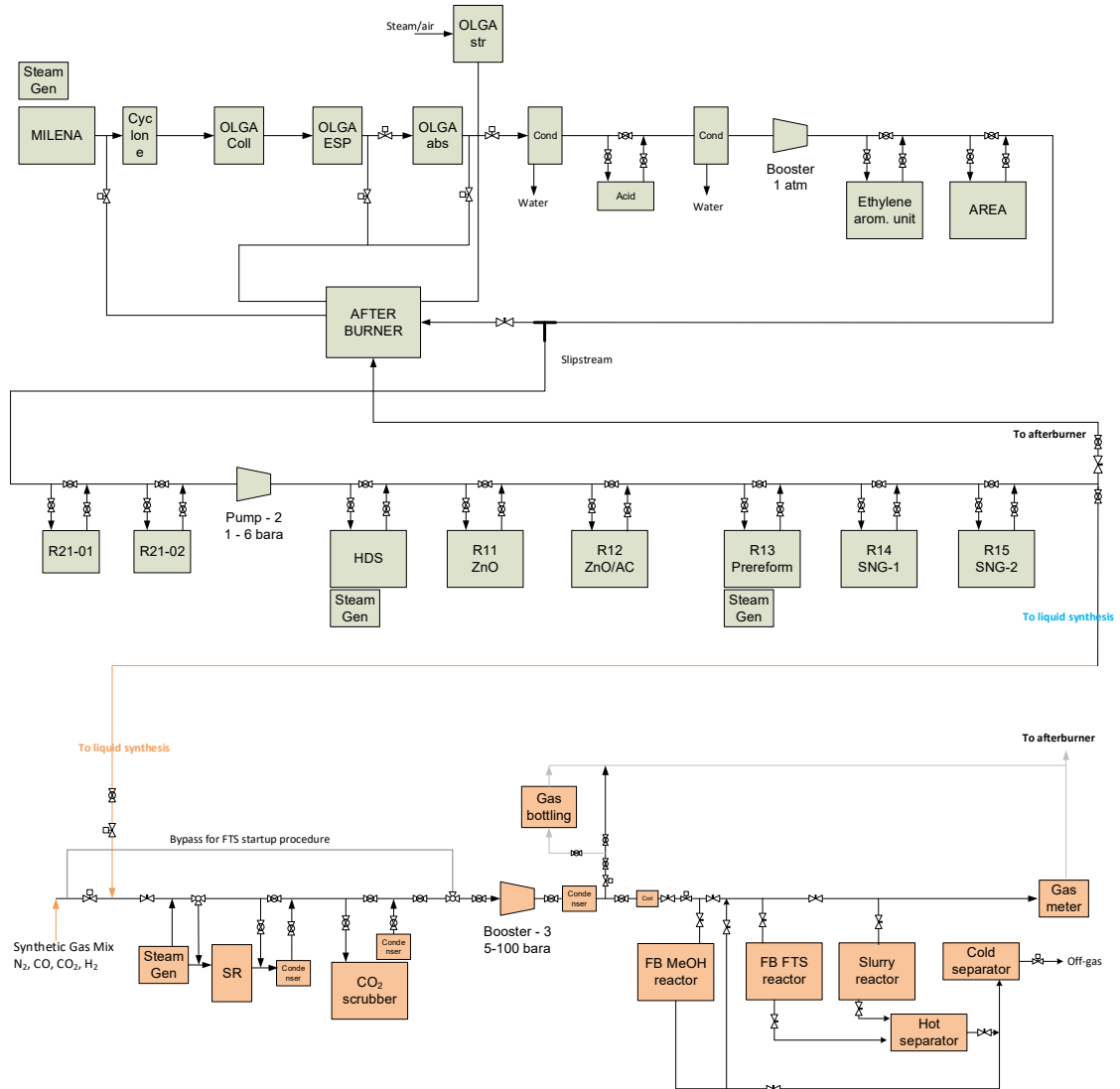


Figure 8: Integrated sustainable biofuels lab at TNO Energy Transition laboratories

More information:

<https://www.tno.nl/en/>

Address:

Westerduinweg 3, 1755 LE Petten, NL

Contact:

Berend Vreugdenhil: berend.vreugdenhil@tno.nl

SPAIN

A few institutions have been actively working during the last two decades in thermal gasification of biomass and wastes, especially research centres and universities, but also the R&D departments of some companies, a few of them erecting bench and pilot plants to demonstrate some key aspects of the technology.

The main R&D institutions and companies that have worked in biomass/waste gasification and related activities are reviewed in this section. Only a few of them remains active after 2015 due to lack of incentives for electricity production in Spain and the technical difficulties using wastes.

University of Seville

The Chemical and Environmental Engineering Department at the University of Seville has worked during the last 25 years on thermochemical conversion of biomass and waste (gasification, pyrolysis and combustion), synthesis of biofuels and bio products and bio-refineries. More recently new developments are being carried by hybridization of biomass and waste in high-temperature solar technologies and solar reactors for thermochemical conversion and solar fuels. The institution has assisted and advised leading industrial companies in the energy sector such as Abengoa, Inerco, Cepsa, Total Petrochemical, BP, etc.

Research areas:

- Steam gasification of biomass using solar energy and dual fluidized beds. Solar chemical looping gasification for hydrogen production. Hybridization of biomass in concentration solar power plants (CSP)
- New design of gasifiers (staged gasification). Tar conversion using char for syngas cleaning for small and medium electricity plant gas engines
- Fluid-dynamics of fluid bed gasifiers for improved operation of FBG (gasification performance, optimized char conversion system with recirculation)

To main facilities for thermochemical conversion belong:

- Pilot plant: 100 kWth bubbling FB gasification of biomass and waste using different gasification agents: steam / O₂ / CO₂ / air and blends
- Pilot plant: 50 kWth staged FBG consisting of a bubbling biomass devolatilizer and a moving bed char filter for char and tar conversion
- Bench scale plant for tar scrubber (1-3 Nm³/h syngas)

Current Projects and interest of biomass gasification (2018-2022)

- Solar Gasification of Biomass and Waste in a novel integrated system for renewable fuel production. Convocatoria MIT (Massachusetts Institute of Technology). Fundación La Caixa. Project no. LCF/PR/MIT18/11830011 2018-2020
- Calcium looping gasification of biomass assisted by solar energy (CALGASOL) (P18-RT-4512). PAIDI 2020: Proyectos I+D+I (Junta de Andalucía, Consejería de Economía y Conocimiento) 2020-2022
- Optimal design of fluidized bed reactors for thermochemical storage systems in concentration solar energy plants Ministerio de Ciencia, Innovación y Universidades of Spanish government. 2019-2020 (Massachusetts Institute of Technology).
- Desarrollo de una Tecnología para la Valorización Material y Energética de Residuos Urbanos Mediante Optimización Simultánea de la Gasificación y Estabilización de las Cenizas. Plan nacional. CTM2016-78089-R. 2016-2019
- Estudio y Puesta al Día de Tecnologías Termoquímicas e Hidrotermales para la Valorización Energética de la Fracción de Rechazo de Residuos Sólidos Urbanos (ETVERU-3) Contrato 68/83 (ES-2039/35/2020) (2020) Company: TRAGSATEC
- Diseño de un Sistema de reintroducción de carbonizado para un gasificador de lecho fluido burbujeante. (CHAR RECYCLE - BFB) Contrato 68/83 (2018) (ES-1793/35/2018). Company: Waste to Energy Advanced Solutions SL (WtEnergy)

The University of Seville is a scientific partner of companies WtEnergy and Inerco.

More information:

<https://ics-seville.org/university-of-seville/>

www.grupobioenergia.com

Address:

c/ Porvenir, 15 - 41013 Seville, SPAIN

Contact information:

Prof. Alberto Gomez Barea: agomezbarea@us.es

CIEMAT (Madrid, Soria)

CIEMAT (Centre for Energy, Environmental and Technological research) is a public research body assigned to the Ministry of Science and Innovation under the General Secretariat for Research, focusing on energy and environment and the technologies related to them. It collaborates with other R&D&I institutions, universities and business in the sector to transfer the knowledge and technology that it has generated, supporting and encouraging innovation and changing the economic model. The studies developed in CIEMAT range from laboratory scale to semi-industrial size plants (in the latter case in collaboration with the Thermal Conversion Processes Unit of CEDER (Centre for the Development of Renewable Energy Sources), which is located a few kilometres from Soria.

Research areas:

- Evaluation of biomass and waste in gasification processes to obtain a gas for thermal applications (heat and steam), internal combustion engine and for value chemical products (hydrogen, synthetic methane, hydrocarbons, biofuels, etc.)
- Study of waste derived from the process, gaseous emissions (H₂S, HCl, NH₃), tars, ashes, their sampling, analysis and diagnosis
- Characterization and preparation at semi-industrial scale of solid feedstocks from biomass and wastes (classification, size reduction, drying and palletization) for thermal conversion

To most important equipment belong following facilities:

- 150 kWth pilot auto-thermal bubbling fluidized bed gasifier (for biomass and wastes) CEDER-CIEMAT - Soria
- 500 kWth pilot auto-thermal circulating fluidized bed gasifier (operational, but out of work the last three years) CEDER-CIEMAT - Soria

Main Projects and interest of biomass gasification (last years)

- LIFE DRY4GAS Project: Waste Water sludge solar DRYing FOR energy recovery through gasification GAS (LIFE Programme of the European Union)
- HIBRI2: "Integrated System for Renewable Energy Production in Isolated Areas in Cuba. Phase II". AECID, Cooperation Actions for Development Call 2018, 2019-2021. (<http://projects.ciemat.es/web/hybridus>)
- ECOSGAS, PE-Retos, ENE2016-75811-R, 2017-2020: Removal of organic Sulphur compounds from gasification gases by adsorptive reaction at high temperature for integration in renewable fuels production (SNG, biofuels, DME)
- RETOPROSOST, CM S2013/MAE-2907, 2014-2018: Sustainable production and industrial symbiosis within the Autonomous Community of Madrid; wastes valorization through gasification
- Collaboration with Companies
- Aitesa (www.aitesa.es) partner in LIFE DRY4GAS Project where a solar drying and gasification prototype will be installed in the WWTP located in San Javier (Murcia). The gasifier will be a 220 kWth pilot bubbling fluidized bed gasifier (for drying sewage sludge). Expected launch in 2022.

Ciemat has a collaboration with company Aitesa (www.aitesa.es).

More information:

www.ciemat.es

<http://rdgroups.ciemat.es/web/valer>

www.ceder.es

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Contact:

Jose Maria Sanchez Hervas: josemaria.sanchez@ciemat.es

contacto@ciemat.es

University of Basque Country (Bilbao)

The Department of Chemical Engineering investigates fundamental processes for producing raw materials and fuels using biomass and wastes, the development of sustainable refineries to produce fuels and raw materials providing an alternative to petroleum by using biomass and other waste materials like plastics, tyres, etc. Conical spouted beds are the key to the high energy efficiency of these refineries.

Research areas:

- Steam gasification of biomass and wastes
- Bio-oil steam gasification
- Hydrogen production by a two-step process of pyrolysis and steam reforming
- Spouted bed gasifier design and development
- Primary catalysts for tar elimination

Current Projects and interest of biomass gasification (2018-2022):

- Biomass gasification with negative carbon emissions through innovative CO₂ capture and utilisation and integration with energy storage. European Commission. HORIZON H2020-MSCA RISE-2018-Grant N° 823745. 1/1/2019-31/12/2022.
- Development of fountain confined spouted bed technology for the valorization of biomass and waste by steam gasification. RTI2018-098283-J-I00. Spanish Ministry of Science, Innovation and Universities. 1/10/2019-30/9/2022.
- Integrated process for the oxidative reforming of the volatile stream from the pyrolysis of biomass and plastics. PID2019-107357RB-I00. Spanish Ministry of Science and 2020-2023.
- New raw materials based on technologies and processes for the chemical recycling of plastics from the industrial sector in the Basque Country by following the concept of circular economy. KK-2020/00107. Basque Government. ELKARTEK strategic projects. 2020-2021.

Partner Company (company manufacturing/operating gasifier to which the R&D centre technically assist) is the company W.R. Grace & Co.

More information:

<https://www.ehu.eus/en/en-home>

Address:

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Contact:

Prof. Martin Olazar: martin.olazar@ehu.es

Further detailed information regarding research and implementation in Spain can be found in Country Report Spain 2021²⁰

²⁰ http://www.task33.ieabioenergy.com/app/webroot/files/file/country_reports/2021/Spain.pdf

SWEDEN

Swedish Gasification Centre (SFC)

The Swedish Gasification Centre was initiated in 2011 as an academic research organization (Centre of Excellence). The formation of the centre was a way of overcoming fragmentation and overlaps of the research and to closely connect the research to industrial needs.

In total, 19 companies, 8 universities and 1 research institute are currently active in the centre. The funding is provided in equal shares by the Swedish Energy Agency, industrial partners and the universities engaged.

Each of SFC specializes in one generic gasification-related technology, entrained flow (EF) coordinated by Luleå University of Technology, indirect gasification coordinated by Chalmers (CIGB Centre of Indirect gasification of Biomass) and gas cleaning coordinated by KTH Royal Institute of Technology (Cleansyngas).

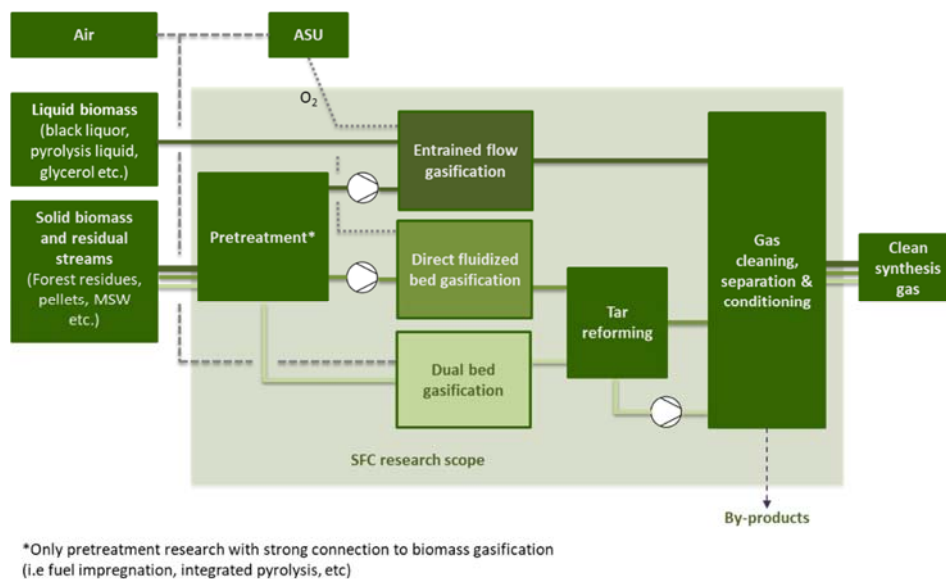


Figure 9: The technical structure of SFC

The technical activities and resources of the universities involved in the currently ongoing SFC program are in the following further described for each of the participating universities and institutes.

More information:

<https://www.sfc-sweden.se/>

Contact:

joakim.lundgren@ltu.se

Chalmers University of Technology

Chalmers has a long history and tradition in CFB combustion systems, where most of the research findings came from the experiments on the semi-industrial scale unit used to produce heat to the campus.

From a relatively small start, the activities in the Chalmers gasification group have expanded such as that now over twenty researchers are directly engaged. The CFB unit has since the start of operation in 2007, operated for several thousands of hours in gasification mode and with far more hours with sand circulation in as CFB boiler. From the original idea of retrofitting gasifiers onto existing CFB boilers, the goal is now the scale up of indirect gasifiers to unit sizes of 100 MW or more.

In addition, several smaller scale reactors, in the W to kW size, have been designed and successfully operated for the

purpose of raw gas upgrading. To address the utilization of the produced gas, a separate line of the research at Chalmers has been studying gas cleaning. A chemical looping reactor (CLR) was developed as means of reducing the tar content of the gas.

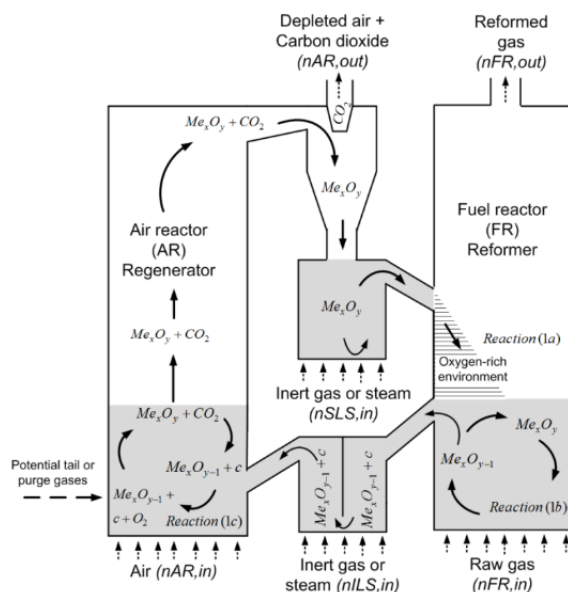


Figure 10: CLR concept for secondary upgrading of biomass producer gas

Chalmers has also in the past had activities in black liquor gasification in association with other organizations and is also engaged in modelling of gasification energy cycles as well as in catalysis research for gas cleaning and synthesis processes.

Since the commissioning start of the GoBiGas project, researchers at Chalmers have supported the commissioning and the operating staff with measurements and other activities to facilitate the plant start-up and have also been successful in resolving some of the critical issues encountered. Chalmers is also a partner in the BioProGRess project, which had the main objectives to develop, implement and demonstrate new innovative syngas cleaning methods in both pilot and industrial-scale gasification facilities.

The importance of the support from Chalmers has been also widely acknowledged by the plant owner Göteborg Energi AB. Following the operational stop of the GoBiGas plant in 2018, Chalmers is reorienting its research towards thermal recycling through the gasification of waste materials.

More information:

<https://www.chalmers.se/en/>

Address:

Chalmers University of Technology, Department of Space, Earth and Environment, SE-412 96 Gothenburg, Sweden

Contact:

Prof. Henrik Thunman: henrik.thunman@chalmers.se

University of Gothenburg

The activities of the Gothenburg University within the SFC program relates to inorganic chemistry, particles, and measurements techniques. Extensive work on measurement techniques was made within the CIGB node, principally for on-line quantification of alkali, tars and particulates tested and used at the Chalmers facilities but also in the GoBiGas plant.

More information:

<https://www.gu.se/en>

Address:

University of Gothenburg, BOX 100, SE-405 30 Gothenburg, Sweden

Contact:

Prof. Jan Pettersson: janp@chem.gu.se

KTH Royal Institute of Technology

Gasification activities at KTH are mainly carried out at the Division of Process Technology of the School of Engineering Sciences in Chemistry, Biotechnology and Health at KTH and to some extent also at the Division of Processes (Energy and Furnace) of the School of Industrial Engineering and Management.

The Division of Process Technology has extensive experience in thermochemical conversion of solid fuels, starting with MSW pyrolysis in the early 1970's. A gasification research program has been in continuous operation since 1974. Early studies of waste, biomass and peat gasification (1975-85) were process-oriented and used to develop a pressurized oxygen-blown process known as MINO, a process subsequently evaluated in a pilot plant at TPS. Later, also CFB gasification systems (TPS and Kværner, today part of Valmet) were studied. The research today mainly concerns gasification of biomass, predominately chemical kinetics in fluidised bed gasification and gas cleaning. In the first two phases of the SFC program, this was strongly linked to the plans of E. ON and Andritz/Carbona to use this technology commercially. In the third phase of SFC, downstream gas cleaning has come into the focus to the extent that the node name was changed to Cleansyngas. Examples of the research areas are the basic course of events in pyrolysis, gasification kinetics, tar analysis, thermal and catalytic tar decomposition, alkali analysis and gas cleaning.

One important part of the research has been the development of sampling and analysis methods of tar. One of these being the so-called solid phase absorption (SPA) technique, i.e., the collection of a sample by adsorption and condensation at room temperature on an SPE (solid phase extraction) column.

Finally, there is a development of on-line techniques for tar measurements based on photoionization, e.g., as part of an ERA-NET Bioenergy and BRISK projects. In addition to the techniques for tar measurement, on-line alkali measurement techniques are also being developed. These activities are now being developed further via a spin-off company, Verdant Chemical Technologies AB.

Experiments are primarily conducted in a combination of an atmospheric fluidized bed gasifier and a pressurized bubbling fluidized bed, both 75 kW_{th} and being connected to a downstream filter and an electrically heated reformer.

There is also a fluidized bed, 5 kW_{th} equipped with a filter and reformer

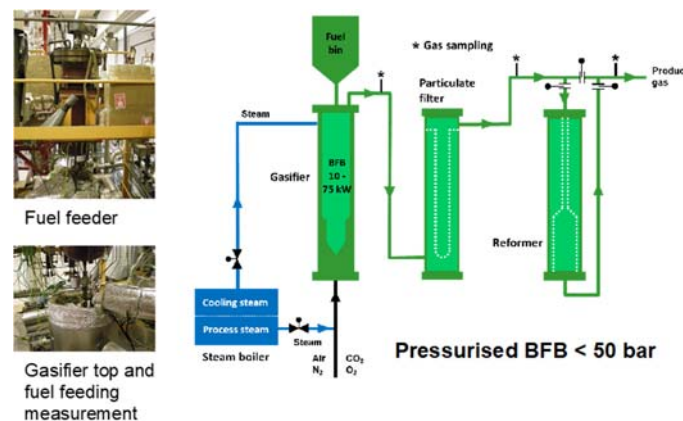


Figure 11: The 75 kW_{th} pressurized bubbling fluidized bed gasifier coupled to particulate filter catalytic tar reformer

Process Technology at KTH is also supporting Cortus Energy on various research issues such as modelling of a drum paralyzer using basic data from e.g., TGA tests and a model developed at KTH. In the gas cleaning area, gas filtration and catalytic stabilization of pyrolysis gas have been addressed. R&D activities have also been established in cooperation with MEVA Energy on gas cleaning and fluidised beds.

Future research will mainly focus on gas cleaning and conditioning to support the commercialization of emerging gasification technologies. The activities will, for example, focus on issues related to dry high temperature purification, using additives and advanced high temperature filters combined with catalytic tar conversion. Finally, research aimed at developing instruments for process monitoring and accurate measurements in relation to different processes for gasification as well as gas cleaning and conditioning, emphasizing development of standard instruments and methods, is planned.

More information:

<https://www.kth.se/en>

Address:

KTH - Royal Institute of Technology, Process Technology, Teknikringen 42, SE-100 44 Stockholm, Sweden

Contact:

Prof. Klas Engvall: kengvall@kth.se

Linnaeus University

Linnæus University (LNU) was formed because of a merger between the universities of Växjö and Kalmar. At the Faculty of Technology, the R&D program “Wood Design and Technology” is directed towards forestry, logistics, industrial production economy for forestry and marketing of wood and wooden products, including also the thematic area “Wood and Energy Technologies” where the use of the forest and its residues as a source of energy is studied.

The university is a partner in the Cleansyngas node of SFC. Their gasification-related research covers mainly particulate characterization and aerosol sampling.

One development being studied is a novel aerosol-based method to be applied for online investigation of steam gasification kinetics of suspended biomass char particles and can in combination with thermogravimetric analysis, generate accurate data for gasification chemical kinetics at high temperature 800 to 1300 °C, which is not possible by means of traditional TGA.

Experiments are carried out in various experimental apparatus specialized for extracting various aspect of fuel conversion, such as a Single Particle Converter (SPC) in which single biomass particles with fuel particle sizes relevant for entrained flow gasifiers can be inserted and exposed to a hot reactive gas flow.

In addition, and outside SFC, projects relating to gas cleaning and upgrading R&D and on system analysis are performed. System analysis projects focuses on techno-economic assessments and opportunities for integration of gasification technologies in existing industries, in particular in paper and pulp industry via black liquor gasification but also in sawmills and steel and metal making.

As one of the scientific partners, LTU participates in the Austrian COMET project “Waste2Value”.

More information:

<https://lnu.se/en/>

Address:

Linnæus University, Universitetsplatsen 1, 352 52 Växjö, Sweden

Contact:

Prof. Michael Strand: michael.strand@lnu.se

Luleå University of Technology

Luleå University of Technology (LTU) is the coordinator of the SFC and the owner of the LTU Green Fuels Plant. The activities at LTU within the SFC Bio4Gasification node are focused on entrained flow biomass gasification, including thermochemistry and associated modelling, gasifier process modelling and ash-related issues. The goal is to provide methods, models and knowledge about entrained flow gasification that can be used to design and optimize full size entrained flow gasifiers. The ambition is also to find ways to maximize the number of different biomass feedstocks that can be gasified.

Experiments are carried out in various experimental apparatus specialized for extracting various aspect of fuel conversion, such as a Single Particle Converter (SPC) in which single biomass particles with fuel particle sizes relevant for entrained flow gasifiers can be inserted and exposed to a hot reactive gas flow. By filming biomass particles during reactions, the change in temperature and size of particles during fuel conversion can be estimated. Additionally, a Flat Flame Pulverized Burner (FFPB) used for measuring how particle interactions affect ignition and burnout of particles as well as a Drop Tube Reactor (DTR) for parametric studies and kinetic studies.

The university is a partner in the Cleansyngas node of SFC. Their gasification-related research covers mainly particulate characterization and aerosol sampling.

On this place one successful project should be mentioned.

LTU GREEN FUELS AB

Luleå University of Technology is also, as mentioned the owner of LTU Green Fuels AB (fka Chemrec black liquor gasification and Bio-DME pilot). Chemrec (www.chemrec.se) was formed in the 1980's to develop black liquor gasification. In comparison to conventional Kraft recovery boilers, the recovery of chemicals can be more flexible while the energy contained in the black liquor is more efficiently recovered, either as power or heat or as a synthesis gas.

The core of Chemrec Kraft Recovery is the Chemrec gasifier - a refractory-lined entrained bed reactor in which concentrated black liquor is gasified under reducing conditions at around 1 000°C. The liquor is decomposed in the reaction zone into melt droplets consisting of sodium compounds, and a combustible gas containing H₂ and CO.

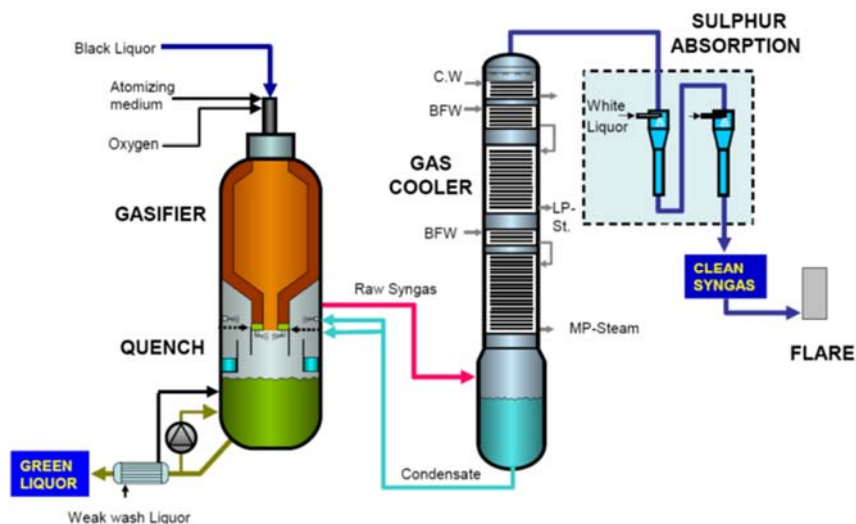


Figure 12: CHEMREC™ black liquor gasifier

The smelt droplets and the combustible gas are separated in a quench dissolver where they are simultaneously brought into direct contact with a cooling liquid. The melt droplets dissolve in the liquid to form a green liquor solution. The gas leaving the quench dissolver is cooled producing LP and IP steam. The cooling is done in counter current mode which means that the gas is efficiently washed of particulate matter. The gas is then free of melt droplets and can be scrubbed for H₂S removal and then used as a clean fuel or syngas.

The construction of a pressurized development plant, DP-1 of 20 tons dry substance per day capacity was by Chemrec made in 2005 at RISE ETC, close to the host mill Smurfit Kappa Kraftliner in Piteå from where the black liquor is obtained.

The plant was used for the Chemrec development program, but also for research in two black liquor gasification (BLG) programs from 2004 to 2010. In 2008, the FP7 Bio-DME project was launched which included the construction of a 4 ton per day BioDME plant based on Haldor Topsøe technology to be connected to the DP-1 gasification plant. The DME was used by Volvo Trucks to operate eight DME heavy-duty trucks for use by different transport companies in four locations in Sweden. DME was produced for the first time in 2011, and the plant was operated by Chemrec up to the end of 2012 within this project. Close to 400 tons of DME was produced and truck operation for over 1 500 000 km resulted from the project.

The pilot plant was in mid-2020 saved from being demolished via regional funding efforts and is currently in good stand-by condition waiting for tests of new concepts or process demonstrations together with interested partners from industry, academia & institutes, the public society and other financiers.

More information:

<https://www.ltu.se/?l=en>

Address:

Luleå University of Technology, Universitetsområdet Porsön, SE-971 87, Luleå

Contact:

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Lund University/LTH

Gasification research started at the Department of Chemical Engineering, LTH in 1975 with work focused on oil shale gasification. This resulted in the development, construction and operation of a laboratory-scale fluidized bed gasifier at atmospheric pressure. Gradually, the work focused more and more on biomass and peat fuels.

In 1991, pressurized biomass gasification research was started as R&D support for the Värnamo plant, which was then in the planning phase. A biomass PICFB (Pressurized Internal Circulating Fluidized Bed) gasifier test rig was built, and the project group was involved in several EC-sponsored R&D projects. However, by the end of 2000, all the gasification activities at LTH were stopped.

However, more recently, some activities were restarted. Within the SFC framework, researchers at Lund are engaged on work on particulate measurements and characterization in cooperation with GU, RISE and LNU.

More information:

<https://www.lth.se/english/>

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Lund University/LTH, Faculty of Engineering, Box 118, 221 00 Lund, Sweden

Contact:

Prof. Per-Erik Bengtsson: per-erik.bengtsson@forbrf.lth.se

Mid-Sweden University

Within the Department of Natural Sciences, Engineering and Mathematics at Mid-Sweden University, the research organization Fibre Science and Communication Network FSCN has a Bioenergy Gasification Group. The group has for almost a decade engaged in biomass gasification activities and is a participant in one of the nodes of the Swedish Gasification Research Centre. The activities are supported by local and regional organizations, which include forest industries, communities, and a regional environmental initiative, Biofuel Region North.

Based on previous funding from the Swedish Energy Agency, EU regional support grants and from other local sources, a 150

kWth indirect type, sand circulation pilot gasifier for oxygen-free generation of synthesis gas was constructed in 2005-2006 at the Härnösand campus. Current research focuses on synthesis gas production from biomass for automotive fuel production and the development of technology for biomass to synthetic fuels (BTS), including DME, FT fuels, ethanol, synthetic natural gas (SNG) and hydrogen. In the recent years, the use of catalysts in the bed for decomposition of tars and other hydrocarbons has been studied. Apart from the experimental work, modelling activities are also part of the research program.

In 2017 MiUn and local partners initiated a project with a budget of 0.9 M€, of which 50 % was from the EC Regional Fund, aiming to increase the production of bio-methane for use as transport fuel. The project included work on AD biogas production but also the part of MiUn on the gasification of biomass to synthesis gas, and its conversion to methane by catalytic or biochemical methods.

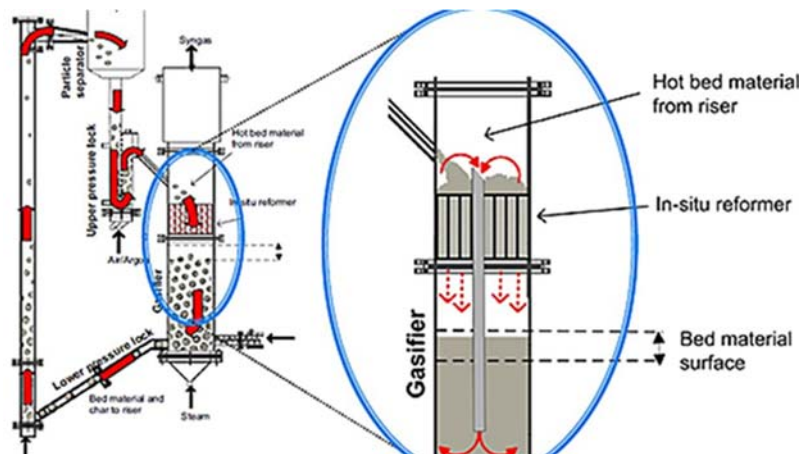


Figure 13: The CFB gasification unit at MiUn

More information:

<https://www.miun.se/en/>

Address:

Mid-Sweden University, Campus Sundsvall, SE-851 70 Sundsvall, Sweden

Contact:

Dr Wennan Zhang: wennan.zhang@miun.se

RISE ETC

The Energy Technology Centre (ETC), a foundation based in Piteå, was formed in 1989. The activities at ETC were boosted in 1993 when Assi Domän Kraftliner (presently, Smurfit Kappa) made their old laboratory available to ETC and a close collaboration with the universities in Umeå (UmU) and Luleå (LTU) was initiated. ETC is a research organisation that provides both research work and professional services to the academia, public agencies, and industry. The main areas of research were thermochemical conversion of biomass and services provided are related to applications in combustion, gasification, and bio-refining processes. The site is located right next to Smurfit Kappa Kraftliner mill in Piteå, Sweden.

From the end of 2014, ETC became a part of the RISE framework (Research Institute of Sweden) as a separate non-profit legal entity within the RISE Bioeconomy Division as RISE ETC AB, and with the same activity profile as ETC had before.

The main areas of activity are:

- Sustainable hydrocarbon fuels (syngas from various residues, pyrolysis oil, co-refining biocrudes)
- Carbon free energy solutions (fossil free iron and steel, metallic energy carriers, northern solar PV)
- Computer based process optimization (ProcessAI, CFD simulations, non-intrusive diagnostics)

- High value-added materials (green carbon nanomaterials)
- Provision of client-oriented professional services for industry, public agencies and academia

In addition, RISE ETC has other units for thermochemical and chemical treatment of biomass, as well as analytical and laboratory equipment as required for the research.

In addition to the activities in black liquor gasification, solid biomass has also been addressed. The cyclone gasifier concept, on which work was initiated by LTU 1994, has been developed further since 2006 together with MEVA Energy AB, previously under the name “VIPP” Vortex Intensive Power Process.

RISE ETC also studies entrained flow gasification of solid fuels. The VAFF unit of 0.5 MWth was complemented by a unit with more of a process development purpose, PEBG (Pressurized Entrained flow Biomass Gasifier) in 2011. The PEBG development is a cooperation between RISE ETC and a local engineering company IVAB for the purpose of generating synthesis gas for the manufacture of e.g., methanol. This unit has since its commissioning been used for fuel tests comprising wood pellets, hydrothermally treated wood and peat as well as pyrolysis oil and biorefinery lignin, the latter two fuels being part of the FP7 Suprabio project.

In addition, in the area of process control and monitoring, RISE ETC has developed a number of laser-based measurement devices for the purpose of optical in situ measurements of soot particle concentration, particle size measurements, weighted temperature average, major gas component concentrations and alkali in the gas phase.

In addition to RISE ETC, other departments within RISE also work together with the CIBG node, in particular to the theoretical and experimental studies of release of inorganic components in the ash during devolatilization and gasification and also regarding particle measurement techniques.

More information:

<https://www.ri.se/en>

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RISE Energy Technology Centre (ETC), Industrigatan 1, 941 38, Piteå, Sweden

Contact:

Dr Fredrik Weiland: fredrik.weiland@ri.se

Umeå University (UmU)

Umeå University is engaged in research in gasification and combustion, specializing mainly in the inorganic chemistry of ash constituents and its impact on bed materials and agglomeration, slagging and fouling properties. Through the Bio4Energy research environment, and in the gasification area within the Bio4Gasification node, it also works with LTU, MiUn and RISE ETC on biomass conversion technologies.

Since entrained flow gasifiers operate in a slagging mode the thermochemistry of the ash-forming components and how this influences other properties such as e.g. viscosity of the slag. Interactions between the slag with e.g. refractory materials in the gasifier is another aspect. The activities at UmU provide the theoretical basis for modelling e.g. slag deposition while many of the validation experiments are made by LTU or RISE ETC. As previously mentioned, collaboration with KTH on the chemistry of alkali in a gasification environment is ongoing.

More information:

<https://www.umu.se/en/>

Address:

Umeå University, KBC-huset, 901 87 Umeå, Sweden

Contact:

Prof. Markus Broström: markus.brostrom@umu.se

OTHER ACADEMIC ACTORS

Mälardalen University

School of Sustainable Development of Society and Technology program at Mälardalens University, campus Västerås, a research program, Mälardalen Energy & Resource Optimization (MERO). In this program, the group Process Development & Bioenergy, has some limited activity on black liquor gasification based on the fluidized bed process of ABB. In addition, there are activities relating to CFB gasification. These activities are both experimental, in a bench-scale CFB unit acquired, and theoretical in the form of system analyses of the use of CFB gasification systems integrated in conventional CHP plants to co-produce biofuels, bio-methane and power and heat in various configurations.

More information:

<https://www.mdu.se/en/malardalen-university?>

Address:

Mälardalens University, Box 883, 721 23 Västerås, Sweden

Contact:

Prof. Jinyue Yan: jinyue.yan@mdh.se

Further information regarding status of gasification in Sweden you can find in Country Report Sweden²¹ or Research Special²².

²¹ http://www.task33.ieabioenergy.com/app/webroot/files/file/country_reports/2019/CR_Sweden1.pdf

²² http://www.task33.ieabioenergy.com/app/webroot/files/file/country_reports/2021/Sweden.pdf

UNITED KINGDOM

There are several research institutions working on gasification topic in the UK. An overview can be seen in the figure below.

In 2019, the Supergen report²³ “Bioenergy and waste gasification in the UK: Barriers and research needs” provided a summary of relevant institutions undertaking gasification research in the UK, which are provided below.

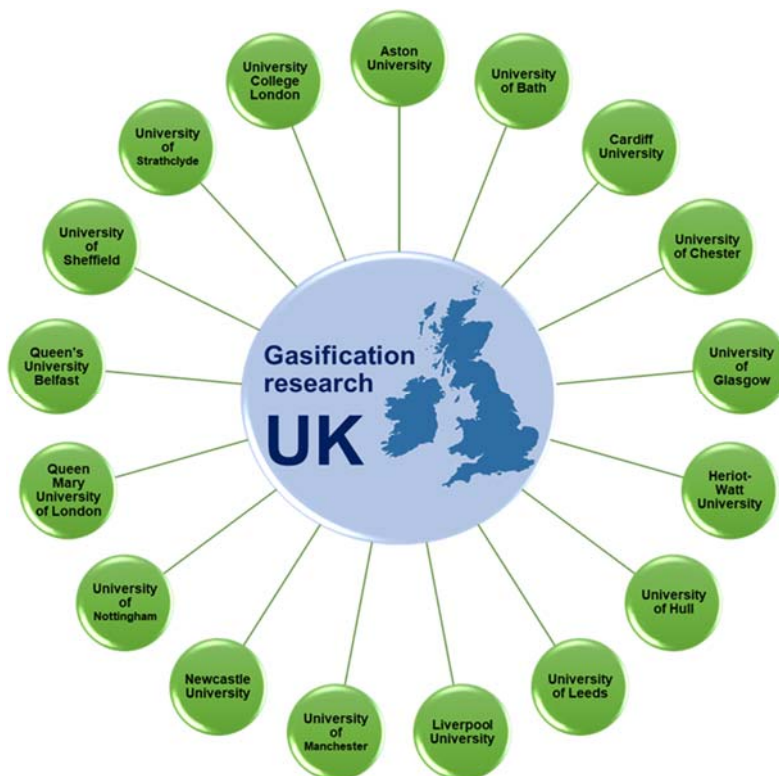


Figure 14: Research institutions in the UK

Aston University / Energy and Bioproducts Research Institute (EBRI)

EBRI conducts a wide range of bioenergy research activities from techno-economic analysis of bioenergy systems through to experimental research. Dr. Clara Serrano is the plant manager. EBRI has a wide range of experimental facilities including a 1MW fluidised bed gasifier. These are supported by a range of analytical equipment including gas chromatography and thermo-gravimetric instruments. Dr. Paula Blanco-Sanchez is involved in a range of related research, focussing on the use of different feedstocks and improving syngas properties (e.g. tar cleaning).

More information:

<https://bioenergy-for-business.org/about-ebri/>

Contact:

c.serrano@aston.ac.uk

²³ Cooper, S, P Blanco-sanchez, A Welfle, and M McManus. (2019). Bioenergy and Waste Gasification in the UK Barriers and Research Needs. Supergen Bioenergy Hub. <https://www.supergen-bioenergy.net/news/bioenergy-and-waste-gasification-in-the-uk-report-barriers-and-research-needs/>

University of Bath

Prof. Marcelle McManus researches the relative merits of a range of bioenergy technologies through techniques including Life Cycle Assessment and Techno-Economic Analysis.

More information:

<https://www.bath.ac.uk/>

Contact:

M.McManus@bath.ac.uk

Cardiff University

Dr. Agustin Valera Medina is using analysis from an experimental rig (1-2kW) with 1-D and 2-D CFD modelling to investigate reactor conditions and fuel characteristics. Cardiff University did have a 500kW to 1MW scale gasification setup but most interest from industry has been on results from the smaller scale modelling.

More information:

<https://www.cardiff.ac.uk>

Contact:

valeramedinaa1@cardiff.ac.uk

University of Chester

Prof. John Brammer is investigating the use of high-ash feedstocks and the scope to improve their characteristics with natural additives. They have two 25kW downdraft gasifiers and analytical equipment to measure the quality and tar content of the producer gas.

More information:

<https://www1.chester.ac.uk/>

Contact:

j.brammer@chester.ac.uk

University of Glasgow

Prof. Ian Watson is leading research into real-time control of gasifiers. This is being developed with a downdraft gasifier using varieties of miscanthus. Work is ongoing to characterize syngas produced from paper, plastic, solid and liquid feedstocks. There is also interest to look at split-bed (e.g. pyrolysis / gasification) options. There is a bubbling fluidized bed gasifier that might be used for other work. Dr. Siming You is involved in optimizing bioenergy systems, including gasification, in terms of techno-economics and environmental criteria.

More information:

<https://www.gla.ac.uk/>

Contact:

Ian.Watson@glasgow.ac.uk

Heriot-Watt University

Dr. Aimaro Sanna's group is investigating co-firing of biomass with coal, reaction kinetics and catalysts.

More information:

<https://www.hw.ac.uk/>

Contact:

A.Sanna@hw.ac.uk

University of Hull

Dr. Vicky Skoulou is researching the effect of different biomass and waste pretreatment options, with particular regards to the design of biomass and waste processing reactors, and the needs of downstream processing / use of the syngas. They currently have two lab-scale (1-3g/s) gasifiers with extensive TGA and other analytical gas, liquids and char monitoring capability. Further interest relates to analysis of products from steam gasification and the use of catalysts. Previous work has included design, construction and optimization of larger scale biomass / waste gasifiers.

More information:

<https://www.hull.ac.uk/>

Contact:

V.Skoulou@hull.ac.uk

University of Leeds

Prof. Paul Williams has been investigating the role of plasma gasification in ensuring cleaner syngas. They have achieved promising results both with and without a combination with catalysts. This work used a fixed-bed gasifier but they have a fluidised bed gasifier in commissioning and hope to use it for experimental work soon. Other experimental facilities include a pilot-scale pyrolysis plasma reactor, a screw-fed pyrolysis reactor and six desktop-scale reactors.

More information:

<https://eps.leeds.ac.uk/chemical-engineering>

Contact:

P.T.Williams@leeds.ac.uk

Liverpool University

Dr. Xin Tu is working on application of plasma catalysis tar cracking and the application of catalytic processing to gasification products.

More information:

<https://www.liverpool.ac.uk/electrical-engineering-and-electronics/>

Contact:

Xin.Tu@liverpool.ac.uk

University of Manchester

Prof. Ali Turan has experience of large- scale gasifier design and is looking at improving the available design methodologies from fundamentals. Particularly relating to off-design operation at lower output levels.

Dr. Samira Garcia-Freites is researching gasification integration and assessment, with application to agricultural residues.

More information:

<https://www.manchester.ac.uk/>

Newcastle University

Prof. Adam Harvey's group includes researchers investigating plasma catalysis as a means to treat syngas tar content. The group deals with process intensification and so also considers other technologies that are relevant to the further processing of gasification outputs.

More information:

<https://www.ncl.ac.uk/>

Contact:

adam.harvey@ncl.ac.uk

University of Nottingham

Prof. Hao Liu is investigating innovative approaches to syngas cleaning with specific applications to waste gasification. Other work has involved process simulation, NO_x reduction and development of absorbents for carbon capture. Some experimental work involves their 10kW prototype downdraft gasifier. Alison Mohr's research on biomass governance issues also touches on gasification.

More information:

<https://www.nottingham.ac.uk/>

Contact:

liu.hao@nottingham.ac.uk

Queen Mary University of London

Prof. Xi Jiang has conducted extensive physicochemical modelling of biogas combustion, with application to gasification. In particular, this has related to validation of models predicting reactor conditions and producer gas properties as operating parameters are varied.

More information:

<https://www.sems.qmul.ac.uk/>

Contact:

xi.jiang@qmul.ac.uk

Queen's University Belfast

Dr. Chunfei Wu is investigating a range of topics relating to the operation of gasifiers. These include the development of catalysts, the use of varied feedstocks and integration with carbon capture technologies.

More information:

<https://pure.qub.ac.uk/en/>

Contact:

C.Wu@qub.ac.uk

University of Sheffield

Dr. Yajue Wu is director of Sheffield University Waste Incineration Centre (SUWIC). The centre has ongoing collaborations with companies such as Veolia (investigating technical aspects of plant operation) and previously with Biomass Power. Her research interests include the effect of reactor conditions and feedstocks (e.g. adding plastics or contaminants) on the characteristics of the gasifier outputs and syngas. There is a wide range of experimental facilities at SUWIC including a co-flow pyrolysis unit, FBG and fixed bed gasifiers, and a 2m entrained flow gasifier which they have used with superheated steam flame fuel injection (sludge mix) and can track particles through. They also work with numerical simulation based on kinetics and CFD and analyse how design changes might affect the flow of particles through the gasifiers. Others in the group are researching issues relating to H&S, risk management and feedstock storage. Prof. Mohamed Pourkashanian's work covers a broader energy remit but also includes gasification, numerical modelling and carbon capture.

More information:

<https://www.sheffield.ac.uk/cbe>

Contact:

y.wu@sheffield.ac.uk

University of Strathclyde

Dr. Jun Li is working on models to predict reaction mechanics, for example modelling the effect of particle size on the gasification products and generation of ash. This has combined experimental work to characterize combustion products (e.g. in a large, high temperature dynamic gravimetric analyser). The results can be used to inform reactor design and process upgrading. In future, they would like to expand investigation to include the effect of different feedstocks and the inclusion of impurities).

More information:

<https://www.strath.ac.uk/>

Contact:

jun.li@strath.ac.uk University College London

University College London

Dr. Massimiliano Materazzi is looking at how variations in feedstock and gasifier conditions affect the properties of the gas

and other co-products. A small-scale FBG rig (equipped with analytical facilities such as X-ray and thermal imaging) is being used to investigate the fundamentals of feedstock introduction at high temperature and subsequent reaction behaviour. Plasma-assisted gasification is also subject of interest.

A benchtop facility is used to analyse the effect of temperature and plasma activated reactions on tar reforming and ashes stabilization. Results are directly related to experience with Advanced Plasma Power's pilot-scale facilities. Interest in use of plasma under different combinations of redox conditions, inputs, temperatures, plasma power and then investigating properties of resulting syngas and contaminants. Prof. Paola Lettieri is part of the same research group, focusing on questions relating to the bigger picture of gasification use and on LCA studies.

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The activities are summarized again in the following table. There is a variety of research topics ranging from lab scale up to pilot plant experimental facilities and a good combination with modelling approaches looking at the overall process optimisation.

Table 2: Summary of gasification research activities and equipment details per Institution

Institution	Activities linked to gasification
Aston University	Modelling (TEA/LCA); development of catalysts (i.e. tar cracking). Facilities: 1MW fluidised bed gasifier, analytic equipment.
University of Bath	Modelling (TEA/LCA).
Cardiff University	1-D and 2-D CFD modelling (reactor conditions and fuel characteristics). Facilities: 1-2 kW experimental rig.
University of Chester	Syngas quality & tar content. Facilities: Two 25kW downdraft gasifiers and analytical equipment.
University of Glasgow	Real-time control of gasifiers. Facilities: Lab-scale downdraft and fluidised bed gasifiers. TEA and environmental assessments.
Heriot-Watt University	Reaction kinetics and catalysts development; co-firing biomass-coal.
University of Hull	Biomass pretreatment; product analysis and upgrading. Reactor optimization. Facilities: Two lab-scale (1-3g/s) gasifiers with extensive TGA and other analytical gas, liquids and char monitoring capability.
University of Leeds	Catalytic and non/catalytic plasma syngas for syngas cleaning. Facilities: Lab-scale fixed-bed and fluidised bed reactors.
Liverpool University	Catalytic plasma syngas for syngas cleaning.
University of Manchester	Large scale gasifier design; off-design operation at lower output levels; gasification integration and assessment, with application to agricultural residues.
Newcastle University	Catalytic plasma syngas for syngas cleaning; process Intensification.
University of Nottingham	Novel approaches for syngas cleaning; carbon capture. Research on biomass governance issues. Facilities: 10kW prototype downdraft gasifier.
Queen Mary University of London	Physicochemical modelling of biogas combustion, with application to gasification. Modelling reactor performance (syngas composition and gasifier performance).
Queen's University Belfast	Operation of gasifiers: development of catalysts, the use of varied feedstocks and integration with carbon capture technologies.
University of Sheffield	Effect of reactor conditions and feedstocks on the characteristics of the gasifier outputs and syngas. Numerical simulation based on kinetics and CFD; Carbon

	capture; H&S, risk management and feedstock storage. Facilities: co-flow pyrolysis unit, FBG and fixed bed gasifiers, and a 2m entrained flow gasifier
University of Strathclyde	Modelling the effect of particle size on the gasification products and ash generation. Reactor design and process upgrading.
University College London	Feedstock and gasifier variations affect gasification products. Plasma for tar reforming and ash stabilisation; LCA. Facilities: small-scale FBG rig (equipped with analytical facilities such as X-ray and thermal imaging); bench-top plasma assisted gasification.

More information regarding the status of gasification in the UK can be found in the UK Country Report 2021.²⁴

²⁴ http://www.task33.ieabioenergy.com/app/webroot/files/file/country_reports/2021/UK_2021.pdf

UNITED STATES OF AMERICA

The National Renewable Energy Laboratory (NREL)

The National Renewable Energy Laboratory (NREL) was established in 1977 and is located in Golden, Colorado. NREL specializes in the research and development of renewable energy and energy efficient technologies. Research within NREL's Catalytic Carbon Transformation Center focuses on the conversion of biomass or waste carbon sources to transportation fuels and co-products and utilizes a variety of capabilities across laboratory-, bench-, and pilot-scales. The focus of this research is to explore and develop new technologies, understand process fundamentals, and de-risk integrated processes to support commercial adoption and market impact. Research covers a wide range of topics and specialties from fundamental chemistry and biology, materials characterization, catalyst design, analysis, computational modeling, and integrated process evaluation.

Testing facilities include NREL's Research Gasifier (NRG) - 0,5 kg/h, and the Thermal and Catalytic Process Develop Unit (TCPDU) - a 0.5 ton/day piloting facility.

NRG

Producing syngas from biomass sources results in a variety of challenges that cascade throughout the process from syngas makeup, associated clean-up steps (e.g., tar removal), and syngas catalytic conversion to fuels and chemicals. The NRG system consists of a dual-screw K-Tron hopper metered to provide ~0.5 kg h⁻¹ biomass into a 10 cm (ID) fluidized bed reactor utilizing an olivine bed material.

Thermal and Catalytic Process Development Unit (TCPDU)

The TCPDU is a 0.5 ton/day facility designed to de-risk thermo-catalytic processes based on pyrolysis and gasification technologies. In the gasification configuration, the TCPDU is composed of a 20 cm fluidized bed reactor for initial volatilization of biomass at 800 C, a thermal cracker to complete gasification at elevated temperatures, and back-end solids removal and gas cleanup options to produce a final syngas product. Solids removal systems include a dual cyclone arrangement with optional hot gas filtration. Multiple catalytic reforming reactors are available to support project needs. These reactors can be used independently, in parallel, or in series and include fluid beds, packed, bed, and recirculating regenerating reactors. Online analytical capabilities are available at multiple access points to monitor syngas quality and composition throughout the process. Analytical tools include molecular beam mass spectrometry, gas chromatography, thermal conductivity detection, and nondispersive infrared. The facility is designed to modular and allows for partners to evaluate their materials within our reactor systems, or to bring in their own reactor skids to evaluate unique unit operations.

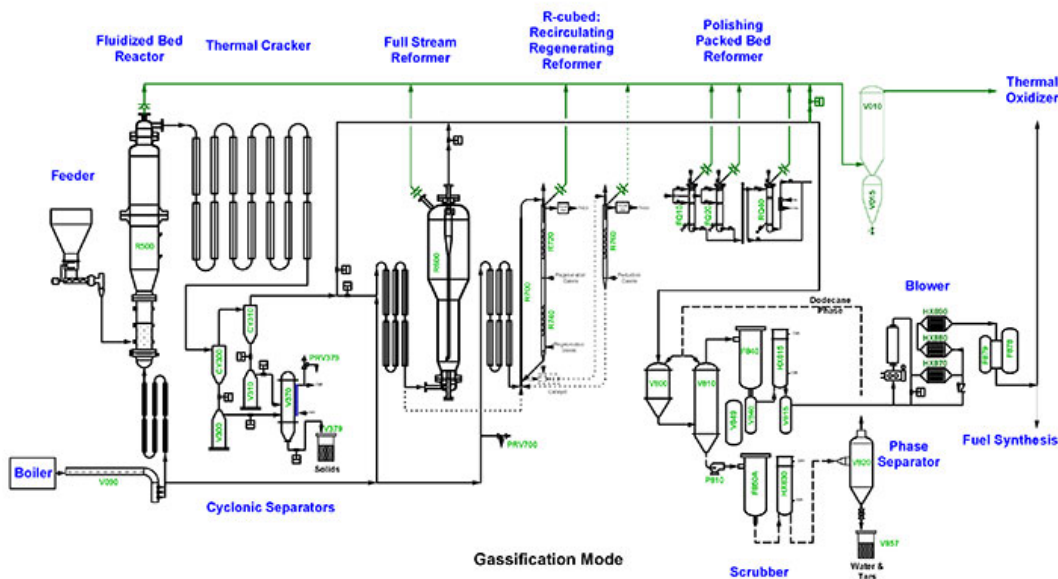


Figure 15: The TCPDU unit

Additional information regarding the TCPDU unit can be found at <https://www.nrel.gov/bioenergy/tcpdu.html>

More information:
<https://www.nrel.gov>

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 National Renewable Energy Laboratory, 15013 Denver West Parkway. Golden, Colorado 80401 (USA)

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Iowa State University

Iowa State University (ISU) has two biomass conversion pathways being demonstrated at throughputs greater or equal to 0.5 tons of dry biomass per day (TPD). A 0.7 TPD fluidized bed fast pyrolysis unit and a 0.5 TPD fluidized bed air blown gasifier are located at ISU’s BioCentury Research Farm (BCRF). Both conversion pathways utilize an on-site separate biomass preparation facility to size reduce and dry biomass as needed for the conversion.

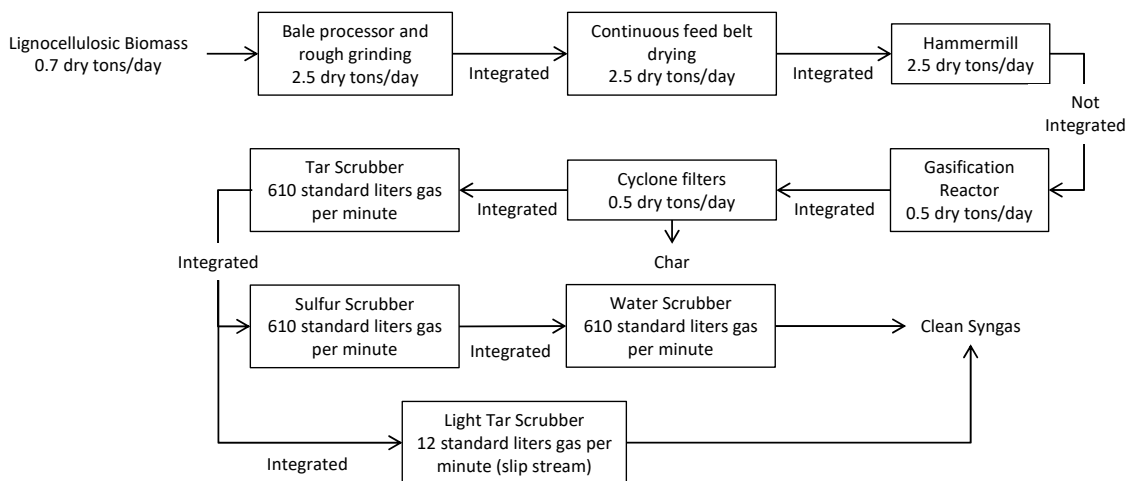


Figure 16: Iowa State University Gasification Block Flow Diagram

In the following table a gasification unit operation summary can be found.

Table 3: Iowa State University gasification operation summary

Unit Operation	Operating Conditions	Max Continuous Run Time	Feedstock Specifications	Throughput per day
Biomass feed system	Ambient Temperature, 0-20 psig	16 hrs	1/8"-minus herbaceous or woody feedstock at <15 wt% moisture	0.5 dry tons
Gasification reactor	700-850° C, 0-20 psig	16 hrs	1/8"-minus herbaceous or woody feedstock at <15 wt% moisture	0.5 dry tons
Cyclone filters	700-850° C, 0-20 psig	16 hrs	Syngas and char	0.5 dry tons
Tar Scrubber	90-200° C, 0-20 psig	16 hrs	Syngas	0.5 dry tons
Sulfur Scrubber	425° C, 0-20 psig	16 hrs	Syngas	0.5 dry tons
Oil Scrubber	65-425° C, 0-20 psig	16 hrs	Syngas	0.5 dry tons
Light Tar Scrubber	80-105° C, 0-20 psig	16 hrs	Syngas	12 SLPM slip stream

A state-of-the-art thermochemical products analysis laboratory is located in the Biorenewables Research Laboratory on the ISU campus. This facility houses a wide array of analytical instruments to perform qualitative and quantitative analysis of biomass, bio-oil, syngas and char.

More information:

<https://www.biorenew.iastate.edu/>

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Gas Technology Institute

GTI is an independent, non-profit research, development and training organization addressing global energy and environmental challenges to enable a secure, abundant, and clean energy future. For 75 years, GTI has been developing technology-based solutions for industry, government, and consumers at every phase of the technology development cycle, from concept to commercialization.

GTI has a unique set of pilot-scale syngas production facilities with wideranging capabilities. These facilities can satisfy the testing requirement of TRL 5 and beyond. It can host pre-combustion technology validation in a relevant environment using syngas derived from the thermochemical gasification of a wide range and combinations of coals, petcoke, biomass, and natural gas feedstocks. GTI's seasoned operating and analytical staff provide for safe operation 24/7 during your testing campaigns. GTI operates a pressurized fluidized-bed (U-GAS™) and an advanced pressurized entrained-flow gasifier (R-GAS™), air- or oxygen-blown.

Table 4: Operation conditions of the gasification units

OPERATION CONDITIONS	U-GAS®	R-GAS™
Nominal feed rate	20 tpd	18 tpd
Capacity	6 MWth	5 MWth
Syngas Production	3000 lb/hr	2500 lb/hr
Pressure	8-15 bar	15-27 bar
Nominal Temperature	1400°F - 1800°F	2500°F - 4000°F
Diameter	11 in	6 in
Technology	Fluidized bed	Entrained flow
O ₂ - Blown Tests	Yes	Yes
Air - Blown Tests	Yes	No

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Auburn University

Figure below shows the Auburn University (AU) pilot scale pressurized fluidized bed gasification system. A pilot-scale bubbling fluidized bed gasification system allows extensive research on gasification of biomass feedstocks and conditioning of biomass-derived synthesis gas. The one-ton-per-day pressurized reactor operates with air, oxygen, or steam as oxidants. Downstream facilities allow warm gas filtration followed by gas conditioning through multiple flexible fixed bed reactors.

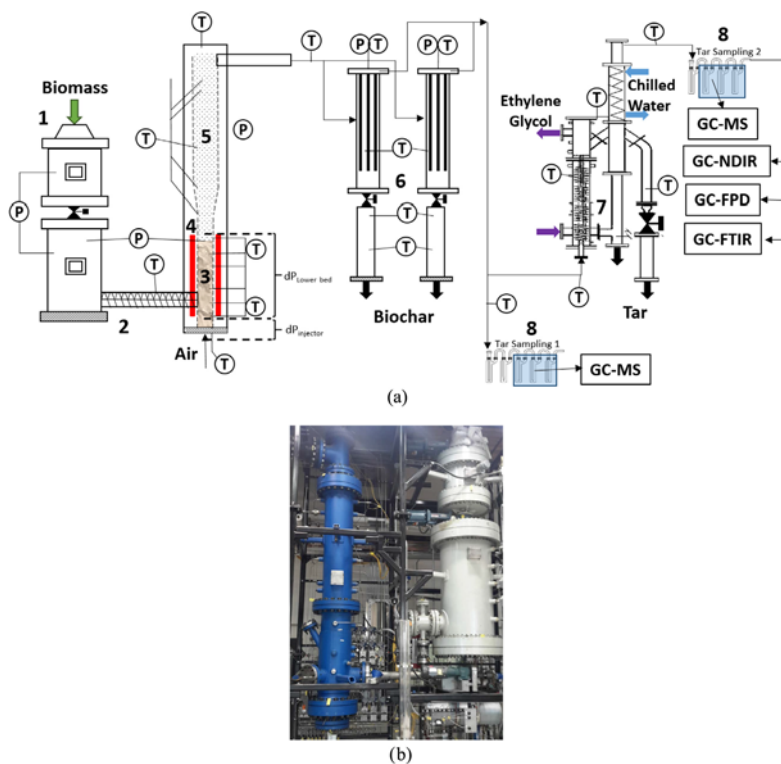


Figure 17: Pilot scale pressurized gasification system

(a) schematic diagram: 1. biomass hopper; 2. injection screw; 3. fluidized bed gasifier; 4. gasifier heater; 5. freeboard; 6. high temperature filter; 7. wet scrubber; 8. tar sampler 1 and tar sampler 2; P stands for pressure transducer and T stands for temperature transducers; dP stands for differential pressure

(b) actual reactor (blue) and hopper (white).

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More information regarding the status of gasification in the USA can be found in Country Report USA 2019²⁵. An actual update can be found in form of presentation.²⁶

Conclusions

This Status report focuses on research activities on gasification of biomass and waste in Austria, France, Germany, India, Italy, the Netherlands, Spain, Sweden, UK and USA.

It is obvious, that the feedstock variations, producer gas utilization and negative CO₂ emissions is the main focus of research on thermochemical gasification.

In order to implement the gasification process into circular economies, the waste materials are used as a feedstock for production of value-added products. As an example, the research project Waste-2-Value project should be mentioned. In this case the waste streams are used as a feedstock for production of FT liquids (kerosene, diesel, gasoline) and other products through gasification and synthesis process.

Producer gas utilization, purpose respectively have shifted during the last years; earlier the CHP applications were in focus, nowadays, the production of biofuels and biochemicals is getting much more attractive. A good example is the project LTU Green Fuels. Based on black liquor gasification and synthesis process Bio-DME was produced and tested for many hours as a fuel for trucks.

Green hydrogen, it means the hydrogen from biomass is the other way, how to utilize the gas from the gasification process. Also this topic is covered by actual research activities as well as production of SNG, which could substitute fossil natural gas.

The next issue are the negative emissions of CO₂; in this case e.g. biochar production as a by-product of gasification and its utilization should be mentioned.

The gasification as a thermochemical conversion offers a great potential regarding feedstock variations, process parameters, products and by-products. It is technology, which is independent on weather conditions (as an opposite to wind power and PVs). Furthermore, this technology could be a stand-alone one or could be implemented into other processes for production of value-added products.



IEA Bioenergy
Technology Collaboration Programme