Deliverable D 20b
Report on the second European Workshop

On the way to safe and eco-friendly biomass gasification

Date: Thursday, 3rd of September 2009
Integrated within the ICPS conference 31th - 2nd of September
Venue: Vienna, Austria

Authors: Michael Fuchs, Hermann Hofbauer
Vienna University of Technology
Getreidemarkt 9/166
1060 Vienna
Austria

John Vos, Harrie Knoef
BTG biomass technology group
P.O. Box 217
7500 AE Enschede
The Netherlands

The project is co-funded by the European Commission.
Introduction
Dissemination, considered as a whole of all marketing issues to promote several topics and therefore to rise up sensitivity for future challenges are getting more and more important in all fields of scientific work. The taken actions should transport the results of research and remark the level of best available technique.

Generally, poor awareness and lack of understanding of health, safety and environment (HSE) hazards in development, planning, designing, engineering, construction, operation and maintenance of gasification plants is recognized a major non-technical obstacle to the market penetration of small-to-medium scale biomass gasifiers for power generation.

The project "Guideline for Safe and Ecofriendly Biomass Gasification" aims to effectively tackle this barrier and therefore accelerate the market penetration of small-to-medium scale biomass gasifiers by the development of a Guideline and Software Tool for easy and simple assessment of HSE risks. The tools are intended for use by manufacturers, developers, implementers, owners, financiers, investors, researchers and others interested in biomass gasification systems. To promote the use of the designated project output by the target groups several workshops, articles, conference contributions and presentations have been organized.

History - the 1st European workshop
First of all it has to be underlined that the HSE subject was already on the agenda of international networks since early 2000. This back-up support form recognized international experts in biomass gasification were an important reason to the EC to support the gasification guide project financially. IEA Bioenergy Task 33 on Biomass Gasification and the European ThermalNet network should reasonable are also directly linked to the further project progress. So it was a great opportunity to organize the first workshop sandwiched by the IEA Bioenergy - Task 33 on Biomass Gasification and the Thermal Net meetings in Vienna, Austria in April 2008.

The Organization of the 2nd European workshop
The strategy of organizing the 1st European workshop in close junction with other topic related meetings in 2008 brought a lot of advantages especially in attracting a great number of interested attendees of the several target groups of the gasification guide project. Therefore Technical University of Vienna decided to keep on with that strategy. Since the ThermalNet project had ended in 2008 it was quite difficult to get another high ranking meeting, ThermalNet had been the only real “network”, to Vienna. So we decided to organize the 2nd European Workshop on Health, safety and Environmental issues of biomass gasification in junction with a new established conference, the “International Conference on Polygeneration strategies” arranged in Vienna starting with 31st of August 2009 with a duration of 4 days.

The Integration of the workshop in the conference seemed to be necessary to attract the aspired number of attendees and therefore get the desired impact of this dissemination activity. Furthermore the bonding of the framing HSE issues to the basic techniques outlined the potential of the biomass technology presented via an integrated perspective from development respectively research to “safe, healthy and environment friendly” application and could therefore also be taken as a sign to permitting authorities and future investors.
Workshop program structure and number of attendees

After month of preparations and PR activities, primarily mailings to an address database of more than 2000 potential attendees and the appliance of a conference/workshop homepage an overall number of 141 attendees could be welcomed at the 2nd European workshop.

In the morning session the focus was on presenting the technical output and the experiences gained from experimental, demonstration and economical operating small to middle scale biomass gasification plants to frame the HSE topic and to clearly underline the already reached level in technical, especially HSE related fields (see next section part one).

The afternoon session was dedicated to a panel discussion which were introduced by the presentation of the final guideline and the software tool (see next section part two).

The agenda respectively the program of the whole conference is attached in Annex A.

Statistics

Over 3000 persons had been invited to the event and 141 people of 23 nationalities attended the conference and the workshop.

The workshop, see Annex B. There background categorized to target groups are listed below:

- Industry: 23
- Designers, Consultants, etc.; - 11 - 6 of them from big energy suppliers
- Universities: 60 – 14 of them PhD or diploma Students
- Researchers: 42
- Public bodies: 5 – authorities, etc.
Annex
The Annexes are categorized by the level of accordance to the milestones of this deliverable resp. the milestones covered within.

Annexes categorized by a number contain additional information to show and document the made efforts in this dissemination activity.

Annexes categorized by an alphabetic ranked character are necessary documents to prove the completion of the claimed milestones.

All presentations are available at the project website www.gasification-guide.eu respectively the homepage of the ICPS conference www.icps09.org.

Promotional material
- General Flyer – Gasification Guide – Annex O.1
- Announcement – WS (stand alone) and Conference (integrated) – Annex O.2

Program
- Program – Annex A

Objective evidence (milestone)
- List of attendees – Annex B

Publications
- Presentations (Workshop Thursday 3rd of September 2009) – Annex C
- Book of abstract (covering the whole conference) – Annex 0.3
Promotional material

Annex O.1 - General Flyer – Gasification Guide
Actual Status
Recent information on the project progress will be published on the project homepage.

Project output
The main outputs of the project are:
- A guideline for safe and eco-friendly biomass gasification that is suitable for use across Europe
- A Software Tool facilitating the assessment of health, safety and environment hazards by manufacturers, developers, implementers, owners, financiers, investors, researchers and others interested in biomass gasification.

Target Groups
The Main target groups of this project are:
- Manufacturers of biomass gasification plants
- Technical advisers to biomass gasification plants developers, implementers, owners, financiers, and investors, and
- Authorities charged with permitting biomass gasification plants and regulating health, safety and environment issues.

Further Information:
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Mr. Harrie Knoef — knoef@btgworld.com
BTG biomass technology group BV
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Fax: +31-53-4861180
P.O. Box 217
7500 AE Enschede
The Netherlands

Gasification guide
“Bringing Safe and Eco-friendly Biomass Gasification into practice”

Gasification Guide
“Guideline for safe and eco-friendly biomass gasification”
Gasification Guide

Project Overview
Poor awareness and lack of understanding of health, safety and environment (HSE) hazards in development, planning, design, engineering, construction, operation and maintenance of gasification plants is recognised as a major non-technical obstacle to the market penetration of small-to-medium scale biomass gasifiers for power generation. The project "Guideline for Safe and Eco-friendly Biomass Gasification" aims to effectively tackle this barrier and aims to accelerate the market penetration of small-to-medium scale biomass gasifiers by the development of a Guideline and Software Tool for easy and simple assessment of HSE risks. The tools are intended for use by manufacturers, developers, implementers, owners, financiers, investors, researchers and others interested in biomass gasification systems.

Background
Biomass gasification experts have found HSE issues to be an important barrier to the market uptake of biomass gasification technology. Pilot and prototype gasifiers often operate under temporary (trial) environmental licenses for which emission limits are usually somewhat relaxed. For gasifiers intended for commercial operation permitting authorities have a tendency to impose unreasonably strict emission limits and safety measures due to their lack of familiarity with and understanding of the technology. For permitting authorities and other key market actors it is difficult to appreciate the HSE risks correctly.

Perspective
The development of a practical biomass gasification guideline in close consultation with a leading HSE authority and based on realised and planned biomass gasification plants will help to ensure that in future permitting authorities draw up reasonable and fair HSE requirements, thus effectively removing an identified barrier to the market uptake of this technology.

Objectives
The main objective is to accelerate the market introduction and commercialisation of biomass gasification plants of up to about 5MWth capacity by developing an accepted guideline how to assess potential HSE hazards of biomass gasifiers.

Specific objectives
The specific objective is the removal of one of the most important non-technical barriers for widespread market introduction of biomass gasifiers, i.e. the awareness of HSE hazards. This includes:
- Identification of possible HSE hazards associated with construction, operation and maintenance of biomass gasifier plants, and making recommendations to reduce these hazards;
- Simplify administrative procedures;
- Stimulate the market implementation;
- Raise the awareness of communities, (potential) customers and public authorities on HSE issues with a view to reducing objections to the construction of biomass gasifiers and the shortening and simplifying of permitting procedures;
- Guide manufacturers and technology developers in the development of safe designs and safe operation & maintenance of biomass gasification plants;
- Disseminate the guideline and spin-off results to the target groups and other stakeholders to help remove the non-technical barriers;
- Decrease the financial risks of investors
- Remove associated non-technical factors like the sometimes unfavourable public perception of bioenergy;
- Benchmark legal framework of plant permission & operation, and best practices;
- Propose changes to (and help harmonise) EU-legislation in favour of biomass gasification;
- Create a framework for the further development of the guideline to an international accepted standard, which can be used for commissioning/guarantee/acceptance testing and certification;
Promotional material

Annex O.2 - Announcement – WS (stand alone) and Conference (integrated)
Health Safety Environment Workshop

www.gasification-guide.eu

"On the way to safe and ecofriendly biomass gasification"

3rd of September 2009
University of Technology
Vienna, Austria

as a part of the:

ICPS 09
International Conference on Polygeneration Strategies
Vienna University of Technology
1st to 4th of September 2009
Vienna - Austria

www.icps09.org
CHARGES
Regular: € 450,--
Students: € 300,--

INFORMATION
Vienna University of Technology
Institute of Chemical Engineering
Department of Chemical Process Engineering and Fluidization
ICPS ’09 Organization Committee
Getreidemarkt 9/166
1060 Vienna
+43 1 588 01-15954
www.icps.org

Please register at WWW.ICPS09.ORG

The Gasification Guide Project
is funded by the European Union

CALL FOR PAPERS

www.icps09.org
Aim of the Conference

Biomass gasification is a key technology for biomass utilization in the future. All forms of energy currently used can be produced via conversion of solid biomass into syngas: heat, electricity and synthetic biofuels. In former years, the main focus of R&D in the field of biomass conversion was on heat and electricity production. This was the topic of several conferences.

Today, things have changed. Syngas production, syngas cleaning and syngas utilization are subject of research programs in several countries and enormous progress has been achieved in this field in the recent years. Furthermore, polygeneration is the key word for future efficient and sustainable biomass utilization.

The main aim of the conference is to present the current state-of-the-art of syngas production, syngas cleaning and syngas utilization. Furthermore, to offer a platform for exchange of information, results and experiences as well as networking.

Therefore, national and international researchers as well as industrial representatives from the manufacturer and utility side are invited to contribute to the success of the conference.

Scientific Committee

Hermann Hofbauer
Martin Kaltschmitt
Johan Einar Hustad
Pier Ugo Foscolo
Samuel Stucki

Program

The three-day program for the conference includes:

- Overview lectures describing the state-of-the-art in different technologies
- Oral presentations on research, development and demonstration projects
- Poster presentations on research, development and demonstration projects
- A Workshop on Health, Safety and Environment aspects of biomass gasification plants - this workshop is jointly hosted by the EU project “Gasification Guide”
- An excursion to demonstration plants - optionally on the fourth day

Timeline

- 2nd of February 2009: Timeframe for electronic abstract submission opens
- 13th of March 2009: Deadline for Submission of Abstracts - Papers and Posters
- 30th of April 2009: Notification of Acceptance and Request for Full Paper
- 30th of June 2009: Deadline for paper submission
- 1st - 3rd of Sept. 2009: Conference
- 4th of Sept. 2009: Excursion to demonstration plants (optional)

Agenda Item

<table>
<thead>
<tr>
<th>Monday</th>
<th>Tuesday</th>
<th>Wednesday</th>
<th>Thursday</th>
<th>Friday</th>
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</table>

Agenda Item

- Conference
- Workshop and Conference
- Closure

Organizational Issues

- Registration
- Dinner
- Dinner

Social Events

- Barbecue
- Dinner
- Dinner

1 The ICPS'09 is organized as an abstract reviewed conference
Program

Annex A - Program
Aim of the conference

Biomass gasification is a key technology for biomass utilization in the future. All forms of energy currently used can be produced via conversion of solid biomass into syngas: heat, electricity and synthetic biofuels. In former years, the main focus of R&D in the field of biomass conversion was on heat and electricity production. This was the topic of several conferences.

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### Topics

- Gas production
- Gas cleaning
- Syngas utilization
- Life cycle analysis

### Charges

<table>
<thead>
<tr>
<th></th>
<th>Regular:</th>
<th>€ 450,--</th>
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<tbody>
<tr>
<td>Students:</td>
<td>€ 350,--</td>
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</table>

### Scientific Committee

- Hermann Hofbauer
- Martin Kaltschmitt
- Johan Einar Hustad
- Pier Ugo Foscolo
- Samuel Stucki
ADRESS

Vienna University of Technology
Karlsplatz 13
1040 Wien

CONFERENCE VENUE

SOCIAL EVENTS

Tuesday
1st of September 2009
start time: 19:30pm
Rathaus - Vienna City Hall
Lichtenfelsgasse 2
1010 Wien

Wednesday
2nd of September 2009
Heurigenrestaurant
“Schübl Auer”
Zahnradbahnstrasse 17
1190 Wien
<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
<th>Speaker(s)</th>
<th>Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>08:00</td>
<td>Registration</td>
<td></td>
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<tr>
<td>09:00</td>
<td>Initial welcome</td>
<td>Hofbauer H.</td>
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<tr>
<td>09:10</td>
<td>Gas Production – Key Note Lecture</td>
<td>Foscolo P.U.</td>
<td>University of L’Aquila (Italy)</td>
</tr>
<tr>
<td>09:40</td>
<td>The new Chalmers research-gasifier</td>
<td>Seemann M. C., Thunman H.</td>
<td>CHALMERS Technical University</td>
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<tr>
<td>10:00</td>
<td>Pressurized Entrained Gasification of Slurries from Biomass</td>
<td>Stahl R., Henrich E.</td>
<td>Forschungszentrum Karlsruhe</td>
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<tr>
<td>10:20</td>
<td>Influence of operating conditions on gas composition, soot and tar in entrained flow gasification of biomass</td>
<td>Ke Q., Weigang L.</td>
<td>Technical University of Denmark</td>
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<tr>
<td>10:40</td>
<td>Coffee break</td>
<td></td>
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</tr>
<tr>
<td>11:15</td>
<td>Study of pressure effect in steam gasification of biomass</td>
<td>Ravel S., Valin S.</td>
<td>CEA Grenoble</td>
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<tr>
<td>11:35</td>
<td>The Development and Operation of a 100kW Dual Fluidised Bed Biomass Gasifier for Production of High Quality Producer Gas</td>
<td>Bull D. R., Gilmour I. A.</td>
<td>Iowa State University</td>
</tr>
<tr>
<td>12:15</td>
<td>Gasification characteristics of biomass/coal blend in a dual circulating fluidized bed reactor</td>
<td>Seo M. W., Goo J H.</td>
<td>Korea Advanced Institute of Science and Technology</td>
</tr>
<tr>
<td>12:55</td>
<td>Lunch</td>
<td></td>
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<tr>
<td>14:00</td>
<td>Gas Cleaning and Gas Utilization – Key Note Lecture</td>
<td>Hansen J. B., Højlund-Nielsen P. E.</td>
<td>Haldor Topsøe A/S</td>
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<tr>
<td>14:40</td>
<td>POX Steam Reforming in a Plasma-Assisted GliAD Arc Reformer</td>
<td>Owrang F., Foong C.</td>
<td>Department of Energy and Process Engineering, NTNU</td>
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<tr>
<td>15:00</td>
<td>High Temperature Gas Treatment for the Operation of a Solid Oxide Fuel Cell (SOFC)</td>
<td>Martini S., Kleinhappl M.</td>
<td>Bioenergy 2020+</td>
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<td>15:20</td>
<td>Coffee break</td>
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<tr>
<td>15:50</td>
<td>Flexible dry high temperature syngas cleaning</td>
<td>Leibold H., Mai R.</td>
<td>Forschungszentrum Karlsruhe</td>
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<td>16:10</td>
<td>Novel Bio-syngas Cleanup Process</td>
<td>Leppin D., Basu A.</td>
<td>Gas Technology Institute (GTI)</td>
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<tr>
<td>16:30</td>
<td>Experiences on tar removal strategies in a 3 MWth fluidised bed gasification unit</td>
<td>Gomez-Barea A., Campoy M.</td>
<td>University of Seville</td>
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<tr>
<td>16:50</td>
<td>Catalytic Ceramic Filters Integrated in a Fluidized Bed Biomass Gasifier</td>
<td>Rapagnà S., Gallucci K.</td>
<td>University of L’Aquila</td>
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<td>19:30–22:30</td>
<td>Social program</td>
<td>Reception at Vienna City hall</td>
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<tr>
<td>08:00</td>
<td>Registration</td>
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<td>09:00</td>
<td>Opening</td>
<td>Hofbauer H.</td>
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<tr>
<td>09:10</td>
<td><strong>GAS UTILIZATION</strong></td>
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<tr>
<td>09:10</td>
<td><strong>Allothermal gasification of biomass into chemicals and secondary energy carriers</strong></td>
<td>Zwart R. W. R., Van der Drift A.</td>
<td>Energy research Centre of the Netherlands (ECN)</td>
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<tr>
<td>09:30</td>
<td><strong>From SynGas to Fuels – Microreactor Technology in Fischer-Tropsch (FT) Synthesis</strong></td>
<td>Lukas M., Tekautz G.</td>
<td>Joanneum Research</td>
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<tr>
<td>09:50</td>
<td><strong>Bio-SNG from biomass - First results of a demonstration plant</strong></td>
<td>Rehling B., Hofbauer H.</td>
<td>Vienna University of Technology</td>
</tr>
<tr>
<td>10:10</td>
<td><strong>Long-term tests on methanation with tar and sulphur loaded syngas</strong></td>
<td>Kienberger T.</td>
<td>Graz University of Technology</td>
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<tr>
<td>10:40</td>
<td>Coffee break</td>
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<tr>
<td>11:25</td>
<td><strong>Production of DME from wood</strong></td>
<td>Mevissen N., Schulzke T.</td>
<td>Fraunhofer UMSICHT</td>
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<tr>
<td>11:55</td>
<td><strong>Poster session</strong></td>
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<tr>
<td>12:35</td>
<td>Lunch</td>
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<tr>
<td>13:45</td>
<td><strong>LIFE CYCLE ANALYSIS, SIMULATION AND TECHNO ECONOMICAL STUDIES</strong></td>
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<tr>
<td>13:45</td>
<td><strong>Life Cycle Analysis, Simulation and Techno Economical Studies – Key Note Lecture</strong></td>
<td>Kaltschmitt M.</td>
<td>Technical University Hamburg-Harburg</td>
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<tr>
<td>14:25</td>
<td><strong>Life Cycle Assessment of the Polygeneration of FT-Fuels, SNG, Electricity and Heat via Gasification of Wood and Straw – Examples from Austria</strong></td>
<td>Jungmeier G., Lingitz A.</td>
<td>Joanneum Research</td>
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<tr>
<td>14:45</td>
<td><strong>Gasification and Green Gas development in the Netherlands</strong></td>
<td>van Asselt W. A.</td>
<td>SenterNovem</td>
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<td>15:05</td>
<td>Coffee break</td>
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<td>15:35</td>
<td><strong>Biomass versus bio-oil gasification for syngas production for BTL</strong></td>
<td>Bridgwater A. V., Dimitriou I.</td>
<td>Bioenergy Research Group Aston University</td>
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<td>15:55</td>
<td><strong>Small-Scale Generation of Substitute Natural Gas</strong></td>
<td>Karl J., Gallmetzer G.</td>
<td>Graz University of Technology</td>
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<td>16:15</td>
<td><strong>Bio-SNG concept development with focus on environmental aspects</strong></td>
<td>Rönsch S., Schmersahl R.</td>
<td>German Biomass Research Centre</td>
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<td>16:35</td>
<td><strong>Biomass gasification for ammonia production</strong></td>
<td>Gilbert P., Thornley P.</td>
<td>University of Manchester</td>
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<tr>
<td>19:30–23:30</td>
<td>Social program</td>
<td>Heuriger „Schübl Auer“ in Nußdorf</td>
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### Thursday, 3rd of September 2009

<table>
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<tr>
<th>Time</th>
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<tbody>
<tr>
<td>08:00</td>
<td>Registration</td>
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<tr>
<td>08:45</td>
<td>Welcome                  Hofbauer H.</td>
</tr>
<tr>
<td>09:00</td>
<td><strong>Small and Middle Scale Gasifiers – From Experiment to Practice</strong></td>
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<tr>
<td>09:00</td>
<td>Experiences and results derived from the gasifier at the TUV</td>
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<td></td>
<td>Pfeifer C, Vienna University of Technology</td>
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<tr>
<td>09:20</td>
<td>Design, construction and operational experiences with a 3 MW Torbed wood gasifier in the Netherlands</td>
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<td></td>
<td>Poldervaart J, van Doorn J, Polow Energy Systems</td>
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<tr>
<td>09:40</td>
<td>Preliminary Results with a 450kWth Bubbling Bed Gasifier</td>
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<td>Ufuk K, Serhat G, Hayati O, TUBITAK MAM Energy Institute</td>
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<tr>
<td>10:00</td>
<td>‘Ankur’ Biomass Gasification Technology - Field Experiences</td>
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<td></td>
<td>Jain B C, Ankur Scientific Energy Technologies Pvt. Ltd.</td>
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<tr>
<td>10:20</td>
<td>Safety relevant experiences on Biomass gasifier CHPs</td>
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<tr>
<td></td>
<td>Seifert U, Fraunhofer UMSICHT</td>
</tr>
<tr>
<td>10:40</td>
<td>Coffee break</td>
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<tr>
<td>11:15</td>
<td><strong>Gasification Guide</strong></td>
</tr>
<tr>
<td>11:15</td>
<td>Introduction</td>
</tr>
<tr>
<td></td>
<td>EU project “Gasification Guide” - Project Team</td>
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<tr>
<td>11:35</td>
<td>Presentation of the final Guideline</td>
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<tr>
<td></td>
<td>Voss J., Knoeff H., BTG Biomass Technology Group, Netherlands</td>
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<tr>
<td>12:15</td>
<td>Further Developments</td>
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<td>EU project “Gasification Guide” - Project Team</td>
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<td>12:35</td>
<td>Lunch</td>
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<tr>
<td>13:45</td>
<td>Plenary Discussion</td>
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<td>EU project “Gasification Guide” - Project Team</td>
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<tr>
<td>14:45</td>
<td>Summing up</td>
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<td>EU project “Gasification Guide” - Project Team</td>
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### ICPS 2009

<table>
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<tr>
<td>15:05</td>
<td>Compendium of the 1st International conference on Polygeneration Strategies</td>
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<td></td>
<td>Hofbauer H., Kaltschmitt M., Hustad J. E., Foscolo P. U., Stucki S.</td>
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### Friday, 4th of September 2009

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
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<tbody>
<tr>
<td>08:00–12:00</td>
<td>Excursion                Visitiation of the CHP Oberwart</td>
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<tr>
<td>12:00–13:00</td>
<td>Lunch</td>
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<tr>
<td>13:00–18:00</td>
<td>Excursion                Visitiation of the CHP Güssing (Technikum, BioFT, BioSNG)</td>
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EXCURSION

Friday the 4th of September 2009

During the excursion the following places of interest will be visited

- The new biomass gasifier (CHP) plant in Oberwart
- The biomass gasifier CHP plant in Güssing
- The BioSNG demonstration plant
- The BioFiT (Fischer Tropsch) research plant
- The new Bioenergy 2020+ competence center in Güssing

PLACES OF INTEREST

The new Bioenergy 2020+ competence center
The CHP Güssing and the BioSNG plant nearby
The CHP Güssing in front of the history castle
CHARGES

Regular: € 450,-
Students: € 350,-

INFORMATION

Vienna University of Technology
Institute of Chemical Engineering
Department of Chemical Process Engineering and Fluidization
ICPS ’09 Organization Committee
Getreidemarkt 9/166
1060 Vienna
+43 1 588 01-15954
www.icps.org

Please use the quick link to the secured confernece booking page at our homepage: www.icps09.org
Objective evidence (milestone)
Annex B - List of attendees
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<td>De Smet Engineers &amp; Contractors</td>
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Publications

Annex C - Presentations  (Workshop Thursday 3rd of September 2009)
Experiences and results derived from the gasifier at the TUV

Christoph Pfeifer
Vienna University of Technology

Content

• Dual fluidised bed (DFB) steam gasification
• Design development
• 100kW process development unit
• Experimental results
• Summary/Conclusion

3rd of September 2009
DFB steam gasification: Principle of the process I

Producer Gas (CH₄, CO, H₂, CO₂, H₂O) Flue gas

Gasification (~ 850 °C) Combustion (~ 920 °C)

Biomass Steam Heat Air add. fuel

Circulation (bed material, char coal)

DFB steam gasification: Principle of the process II

<table>
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<th>Component</th>
<th>Conventional process</th>
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<td>H₂O, vol%</td>
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<td>CH₄, vol%db</td>
<td>10…11</td>
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<tr>
<td>C₂H₆, vol%db</td>
<td>2…2.5</td>
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<td>C₃-Fract., vol%db</td>
<td>0.5…0.7</td>
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<td>CO, vol%db</td>
<td>24…26</td>
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<tr>
<td>CO₂, vol%db</td>
<td>20…22</td>
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<tr>
<td>H₂, vol%db</td>
<td>38…40</td>
</tr>
<tr>
<td>Tar g/m³, db</td>
<td>2…5</td>
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<tr>
<td>LHV MJ/m³, db</td>
<td>12.9…13.6</td>
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</table>
Design development I: DFB cold flow model

- Full set of scaling criteria applied
- Hot conditions: 850-950°C, atmospheric pressure, olivine particles
- Cold flow model: air, ambient temperature and pressure
- Linear scale 1:4
- Bronze particles in CFM

Design development II

1993-1996, „FICFB gasifier“

1995-1999
Design development III

Floshheet of the DFB pilot plant
Variation of the fuel water content I

Product gas composition vs. fuel water content, gasification temperature 810°C

Product gas composition vs. fuel water content, gasification temperature 850°C

Variation of the fuel water content II

Tar content in the product gas vs. fuel water content, gasification temperature 810/850°C

Christoph Pfeifer 3rd of September 2009
**Variation of the steam-to-fuel ratio**

$$sfr = \frac{m_{\text{water\_in}} + m_{\text{fluid\_in}}}{m_{\text{fuel\_dry\_in}}}$$


**Variation of the gasification temperature**

Product gas composition vs. gasification temperature, fuel: wood pellets.
Variation of the fuel

Product gas composition for different fuels

Summary

• Cold flow models and pilot plants are powerful tools for process development
• Fuel flexibility is an important issue
• Higher steam-to-fuel ratios lead to lower tar levels
• Higher gasification temperature lead to lower tar levels
• Increased steam-to-fuel ratio and increased gasification temperature decrease the overall efficiency
• Drying of biomass is energetically as well as economically advantageous
• The dual fluidised bed gasification technology is demonstrated commercially (Guessing since 2001, Oberwart since 2007)
Thank you for your attention.
Design, construction and operational experiences with a 3 MW\textsubscript{th} Torbed wood gasifier in the Netherlands

Jacques Poldervaart, Joep van Doorn, Otto Coops
ICPS, Vienna, 3 September 2009

Polow Energy Systems over 20 years of experience in thermal process engineering

- Founded in 1987 (development of new installations for thermal processing)
- Cooperation with Torftech Ltd. since 1999 (development of new applications for TORBED technology in processing biomass)
- First commercial installation in 2004
- Today’s turnover Euro ~ 2.5 mln
- Staff: ~ 6 members direct and 12 indirect
Polow in development

- Founding PES
- Gasification of demolition wood 3.5 MW
- Combustion of wet paper sludge 12 MW
- First vision on TORBED
- Development torrefaction with the TORBED
- Test plant torrefaction in operation

Experiences / approach

- Polow has experience with sludges, manure, wood, biomass and slob oil
- Polow has its own test reactor to do test work on new feedstock or even on new processes or to resolve operational problems if any on existing installations through Torftech
- Testing of new control systems are possible
Development trajectory

All new processes are tested on our test installation

Proven track record in Torbed® energy applications

- Tielen in Castenray, The Netherlands (2001)
- Pilot plant for gasifying chicken manure
- Sappi in Maastricht, The Netherlands (2006)
- Process installation for drying paper pulp & sludge
- Process installation for gasifying wood as replacement for natural gas
- Atlantic Packaging in Toronto, Canada (2008)
- Process installation for combusting paper sludge and raising steam
- Topell in Essen, Germany (2009)
- Pilot plant for torrefaction of biomass
- Topell in Duiven, Netherlands (2010)
- Plant for production of torrefied wood (60,000 tons/yr)
Why is a Torbed® reactor different?

- Heat/mass transfer rates per unit volume higher than existing technologies
- Particles are processed faster and with more precision
- High velocity gas streams are used without high system pressure losses
- Lower capex and lower operating costs
Advantages of a Torbed®

- Reaction kinetics
- Precise control
- Simple scaling up
- Can process a large variety of particle sizes
- No moving parts in the reactor
- Relatively low pricing
- Low on maintenance

Comparison of various gas/solid reactor technologies

<table>
<thead>
<tr>
<th>Gas Flow</th>
<th>Solids Flow</th>
<th>Recycle Ratio</th>
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<tbody>
<tr>
<td>Classical Fluidised Bed</td>
<td>Fast Circulating Fluidised Bed</td>
<td>Increased Expansion</td>
</tr>
</tbody>
</table>

- Classical Fluidised Bed: $0 < R < 1$
- Fast Circulating Fluidised Bed: $1 < R < 10$
- Increased Expansion: $R > 10$

Limits for Classical and Torbed Reactors
Industrial drying process Vlissingen
original situation

Drying of waste from food processing industry
Rotary drum drier fired with natural gas

Reasons for installation of gasifier:
- Odour nuisance
- Dust nuisance
- Emissions
- Emission reduction measures
- Use of renewables
- Reduction in costs for fuel (NG)
Industrial drying process: Situation with Torbed® gasifier

Industrial drying process: Torbed® gasification plant
Industrial drying process: Torbed® gasification plant

Gasifier results

Fuel: shredded waste wood (12 wt% moisture)
Max. dimensions: 70 x 10 mm
Fuel flow: 800 kg/hr

Fuel gas composition:
- CO: 14 vol %
- H₂: 6 vol %
- CO₂: 14 vol %
- CH₄: 3.5 vol %
- H₂O: 11 vol %
- N₂: balance

Fuel gas flow: 2,400 Nm³/hr
Gasifier results

Fuel gas composition:

Total tar: 3,000 mg/Nm³
Tar dew point: ca. 200 °C

Main tar components:
Benzene
Toluene
Naphtalene
Acenaphtylene
Phenanthrene

Bottlenecks

Integration of in-line shredder with gasifier
Solution: off-line feedstock preparation

Tar deposition
Solution: better insulation of valves

Operational issues
Solution: automation
Results integral installation

Flue gas composition:

- $O_2$: 15.6 mol%  
- $CO_2$: 4.1 mol%  
- NOx: 70 ppm  
- dust < 25 mg/Nm$^3$

Results integral installation

Dust and odour emissions are within limits

- Saving on natural gas (300 m$^3$/h)  
- Heat production from wood  
- Operation relatively simple  
- Easy procedure for start-up and shut-down
Present activities

- Design CHP based on Torbed® gasification for a number of clients
- Start of construction end of 2009

- Use of Torbed® reactor for torrefaction
  - Tests at 50 kg batch scale with different types of biomass
  - Design of full-scale torrefaction plant for wood in the Netherlands completed
  - Start of construction end of 2009

Polow Energy Systems

- www.polow.nl
- info@polow.nl

Polow Energy Systems
P.O.box 230
2501 CS The Hague
The Netherlands
To rbed® or not To rbed® –
It is not the question,
it is the solution!
Preliminary Results with a 450 kWth Bubbling Fluidized Bed Gasifier

U. Kayahan, S.Gül*, H.Olgun, B.Bay, Y.Cetin, E.Caglayan, A.Unlu, H.Karatas, A.Yazar
TUBITAK MAM, Energy Institute, Kocaeli, Turkey

S.Ozdogan
Marmara University, Faculty of Engineering, Istanbul, Turkey

Scope of Presentation

- Introduction
- Pilot Scale Gasification System Description
- Experimental Results
- Operational problems
- Conclusion
- Future Plans
- Related Project
Introduction

TUBITAK MARMARA RESEARCH CENTER

Marmara Research Center is government institution and has 8 Institute located at Kocaeli where the nearby of Istanbul.

One of these Institute is Energy Institute and has 7 different research group.

One of these group is “Gasification/Combustion of Biomass/Coal Group” and has 13 researcher.

Introduction

Gasification/Combustion of Biomass/Coal Group Activities

Group is focusing on the combustion and gasification technologies of solid fuels. Auxiliary infrastructure for gasification has been developed. (fuel preparation,)

Gas cleaning technologies are developed. (particle, tar)

Power application is studied with the integration of gasifier unit with gas engine.
Gasification/Combustion of Biomass/Coal Group Activities

Introduction

Group has been started its activities at 2005 with EU project “BIGPOWER” with the aim of being the excellence center of gasification/combustion process in Turkey.

In parallel to this project, nationally funded project has been started and laboratory scale and pilot scale test facilities has been constructed.

Current Laboratory Scale Test Facilities;
- Bubbling fluidised bed gasifier (20 kWfuel)
- Fixed bed gasifier (40 kWfuel)
- Circulating fluidised bed combustor (20 kWth)

Current Pilot Scale Test Facility;
- Bubbling fluidised bed gasifier (450 kWfuel)

Under construction test facilities;
- Circulating Fluidised bed combustor (35 kWth)
- Circulating Fluidised bed combustor (750 kWth)
- Fixed bed gasifier (350 kWfuel)

450 kWth Pilot Scale Gasification System Description

System concept according to multipurpose design;

<table>
<thead>
<tr>
<th>Capacity (kWth)</th>
<th>450</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel feeding (kg/h)</td>
<td>100</td>
</tr>
<tr>
<td>Cross section</td>
<td>Circular</td>
</tr>
<tr>
<td>Diameter (cm)</td>
<td>45</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>650</td>
</tr>
<tr>
<td>Refractory (cm)</td>
<td>12,5</td>
</tr>
<tr>
<td>Pressure</td>
<td>Atmospheric</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Capacity (kWth)</th>
<th>130</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel feeding (kg/h)</td>
<td>30</td>
</tr>
<tr>
<td>Cross section</td>
<td>Square</td>
</tr>
<tr>
<td>Length (cm)</td>
<td>26</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>550</td>
</tr>
<tr>
<td>Refractory (cm)</td>
<td>-</td>
</tr>
<tr>
<td>Pressure</td>
<td>Atmospheric</td>
</tr>
</tbody>
</table>
Pilot Scale Gasification System Description

System concept according to operation;

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Gasifier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel feeding (kg/h)</td>
<td>50</td>
</tr>
<tr>
<td>Gasification agent</td>
<td>air</td>
</tr>
<tr>
<td>Fuel type</td>
<td>Hazelnut shell</td>
</tr>
<tr>
<td>Bed Material</td>
<td>sand</td>
</tr>
<tr>
<td>Static Bed height (cm)</td>
<td>50</td>
</tr>
<tr>
<td>Pressure</td>
<td>+ 15 mbar</td>
</tr>
<tr>
<td>Superficial velocity (m/s)</td>
<td>0.7</td>
</tr>
</tbody>
</table>

| Fuel feeding               | calibration data                              |
| Air flowrate               | orifice meter                                  |
| Pressure                   | 6 point                                        |
| Temperature                | 5 point                                        |
| Gas composition            | CO, CO2, H2, CH4, N2, O2                      |
| Tar measurement            | Not yet                                        |

Experimental Results

Materials;

- Gasification agent: Atmospheric air with flowrate of 70 – 130 Nm³/h.
- Bed material: Silica sand with particle size distribution from 0.18 mm to 0.85 mm. Average is 0.45 mm.
- Fuel: Hazelnutshell with particle size distribution 1 – 2 mm.

<table>
<thead>
<tr>
<th>Proximate Analysis</th>
<th>As fed basis</th>
<th>Dry basis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Moisture, wt%</td>
<td>11.97</td>
<td>11.97</td>
</tr>
<tr>
<td>Ash, wt%</td>
<td>1.96</td>
<td>1.73</td>
</tr>
<tr>
<td>Volatile matter, wt%</td>
<td>64.73</td>
<td>73.54</td>
</tr>
<tr>
<td>Fixed Carbon, wt%</td>
<td>21.77</td>
<td>24.74</td>
</tr>
<tr>
<td>Lower Heating Value, kcal/kg</td>
<td>4925</td>
<td>5215</td>
</tr>
<tr>
<td>Higher Heating Value, kcal/kg</td>
<td>4688</td>
<td>5518</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ultimate Analysis</th>
<th>Dry basis</th>
</tr>
</thead>
<tbody>
<tr>
<td>C, wt%</td>
<td>55.77</td>
</tr>
<tr>
<td>H, wt%</td>
<td>5.40</td>
</tr>
<tr>
<td>N, wt%</td>
<td>0.50</td>
</tr>
<tr>
<td>O2, wt% (by difference)</td>
<td>27.98</td>
</tr>
<tr>
<td>S, wt%</td>
<td>0.92</td>
</tr>
</tbody>
</table>
Experimental Results

Operational values and results:

<table>
<thead>
<tr>
<th>Air flow rate (Nm³/h)</th>
<th>Fuel flow rate (kg/h)</th>
<th>ER</th>
<th>CO (%)</th>
<th>CO₂ (%)</th>
<th>CH₄ (%)</th>
<th>H₂ (%)</th>
<th>O₂ (%)</th>
<th>N₂ (%)</th>
<th>LHV (MJ/Nm³)</th>
<th>Syngas flow rate (Nm³/3%)</th>
<th>Cold gas efficiency (%)</th>
<th>Carbon conversion (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>66</td>
<td>50</td>
<td>0.3</td>
<td>11.90</td>
<td>15.92</td>
<td>4.38</td>
<td>9.12</td>
<td>0.57</td>
<td>57.11</td>
<td>4.05</td>
<td>92</td>
<td>39.36</td>
<td>66.71</td>
</tr>
<tr>
<td>77</td>
<td>50</td>
<td>0.35</td>
<td>13.81</td>
<td>17.44</td>
<td>4.98</td>
<td>8.73</td>
<td>0.60</td>
<td>54.44</td>
<td>4.47</td>
<td>112</td>
<td>53.00</td>
<td>88.92</td>
</tr>
<tr>
<td>89</td>
<td>50</td>
<td>0.4</td>
<td>13.90</td>
<td>16.50</td>
<td>4.42</td>
<td>7.17</td>
<td>0.32</td>
<td>57.69</td>
<td>4.11</td>
<td>122</td>
<td>53.66</td>
<td>92.98</td>
</tr>
<tr>
<td>100</td>
<td>50</td>
<td>0.45</td>
<td>12.14</td>
<td>15.86</td>
<td>3.91</td>
<td>5.17</td>
<td>0.23</td>
<td>62.69</td>
<td>3.49</td>
<td>126</td>
<td>46.54</td>
<td>88.02</td>
</tr>
</tbody>
</table>

Operational Problems

- Feeding problems;

The pressure inside reactor is +15 mbar, there is backflow of hot gas to the hooper. Heat up the screw feeder and starts to pyrolysis of fuels and becomes sticky. Rotary air lock is not a solution alone. The system was modified with ID fan and pressure becomes – 5 mbar.

- Start up burner problem;

The start up burner that is run with propone, is mounted on the reactor just above the distributor and because of the wild enviroment of the fluidised bed, it is frequently failed. System will be modified with mounting the burner before the distributor plate. For this purpose, start up burner has to be suitable for high pressure application.

- Temperature distribution problem;

The temperature distribution along the gasifier is not homogenous. The difference between bottom and top of the gasifier is 500 C. Free board region is at 400 – 600 C. In order to increase this temperature, secondary air injection will be applied.
Conclusion

- The main focus of this study is preliminary aspects of gasification process.
- Hazelnut shell has been gasified and acceptable LHV of syngas was achieved.
- There is no agglomeration observed during the hazelnut shell gasification.
- The maximum LHV is achieved at ER: 0.35, however, the maximum efficiency is achieved at ER: 0.40.
- Carbon conversion is increased up to 0.40 and decreased at 0.45 which is considered as the effect of shorter residence time at fluidised bed region.
- Temperature difference along the gasifier is high without secondary air injection.

Future Plans

- Parametric studies will be performed to observe the effect of selected operational parameters such as;
  - Secondary air,
  - steam gasification,
  - bed height,
  - fuel feeding point,
  - bed residence time effect,

on gas composition, tar content of the gas yield, carbon conversion and cold gas efficiency.
- A catalytic bed for tar cracking will be applied.
- Wet electrostatic precipitator will be integrated to the gas clean up section.
- Integration of gas cleaning system to the gasifier and run the 50 kWe capacity diesel engine with the clean syngas.
Related Project - TRIGEN

Starting date: June 2009
Duration: 48 month
Coordinator: TUBITAK (GI)
Project partners: MRC, 2 Universities, 2 private company

General scheme of the project

Thank You...

View of Gasification system during operation

Serhat.Gul@mam.gov.tr
Safety-relevant Experience with Biomass Gasifier CHPs

Ulrich Seifert
ulrich.seifert@umsicht.fraunhofer.de

Fraunhofer-Institute for Environmental, Safety, and Energy Technologies UMSICHT
Scope

• Introduction

• Examples of fire incidents in biomass gasifier CHPs

• Analysis of focal points

• Fire protection recommendations from the "Gasification Guide"
Introduction

• Within the past few years, there have been a number of fire incidents in biomass gasifier CHPs in Europe.

• Thank you to all manufacturers, operators and other experts who have provided information about these incidents!

• Understandably, there are different views on these incidents; in some cases, the reported causes vary for the same incident.
Freiwillige Feuerwehr
Viele interessante Informationen über die Ortsfeuerwehr

Brand eines Holzvergaserkraftwerks

An frühen Morgen des 3. Septembers kam es zu einem Brand in einem Holzvergaserkraftwerk in [Ortsteil]. Ein Zeitungsartikel über die Feuerwehr meldet, dass der 4-Uhr-Fall sofort alarmiert und die Einsatzkräfte gut vorbereitet waren.


Die Einsatzkräfte der Freiwilligen Feuerwehr kamen kurze Zeit später wieder, der Einsatz wurde nach einer halben Stunde komplett beendet. Die Brandfälle wurden mit einem Frontlader auf die Baulinie transportiert und auf einem Feld abgelagert. Gegen 6:30 Uhr rückten die Einsatzkräfte wieder ab.

Weitere Informationen auch unter...

Eingesetzte Kräfte:
- TLF 16/25 - Besetzung 1/6
- LF 8 - Besetzung 1/6
- ELW 1 - Besetzung 1/7
- + weitere Kameraden mit privat PKW
Perception of Incidents and Consequences

- raising of awareness (investors, authorities, insurers)
- stop of operation of a plant in Germany due to requirements raised by fire insurance company
- number of "small incidents" (without serious damage) is unknown

- Increased need for explanations even for plants that have been unaffected so far
Examples of Fires in Biomass Gasifier Plants

• fire in ash / coke container of a gasifier starting from dust ignition (deflagration) in the ash / coke removal system

• fire starting at the wood chip feeding system of a gasifier after technical failure in feeding control system

• ignition of wood dust layers on (irregular) hot surfaces of equipment and resulting fire – several incidents –
Examples of Fires in Biomass Gasifier Plants

- air filter of a gas engine catches fire after backfiring into the fuel-air inlet line => resulting fire destroys plant

- deflagration of pyrolysis gas / air mixture in gasifier air supply line after a short (gas booster) standstill

- destruction of a gasification reactor and resulting fire after "clogging" of the reactor due to excessive amount of fine material in the fuel
Fires in Biomass Gasifier Plants: Focal Points

Interfaces between Subsystems

- fuel feeding to the gasification reactor
- ash removal from the gasifier
- dust removal from hot gas cleaning
- gas supply to CHP engine
Fires in Biomass Gasifier Plants: Focal Points

Reactive Solids

- wood dust
- carbon-rich gasifier ashes, "gasifier coke"
- residues from hot (dry) producer gas dedusting
Wood Dust Problem

Dust deposits on an open belt conveyor feeding a gasifier
Wood Dust Problem

- dust is released when handling (dried) wood chips
- formation of dust deposits
- self-ignition hazard with dust layers on surfaces of
  - hot equipment (e.g. reactor)
  - heat-releasing equipment (e.g. electrical engines)
- fire and (dust) explosion hazard

- preventive measure: routine removal of dust deposits ("good housekeeping")
Problem of Reactive Gasifier Residue (Gasifier Ash or Coke)

- carbon-rich residue (gasifier coke): reaction with air is similar to that of fresh charcoal / activated carbon
- risk of self-ignition of hot gasifier coke in case of contact with air
- fire and (dust) explosion hazard
- cooling down without air contact or wet coke / ash removal
- separation of coke/ash storage from hot reactor (cf. biomass storage)

for comparison:
low-carbon gasifier ash
Safe Storage of Biomass (Wood Chips)

Guidelines:

• "Merkblatt C.A.R.M.E.N. 01/07" (in German)

• NIC-Guideline NT ENVIR 010 (10/2008)
Excerpts from "Gasification Guide" regarding Fire

Section 5: Potential hazards and good design principles

• Primary safety considerations
• Good engineering and operation practice
• Safety related issues in practice
• Norms and standards
• Documentation
Gasification Guide, 5.3: Good Design Practice …

5.3.1: … related to plant building construction

- structural fire protection: separation between fuel storage and gasification building
- separation of control and staff rooms from remainder of the plant
- two escape routes should lead from each point within the gasifier building to the outside
Gasification Guide, 5.3: Good Engineering Practice …

5.3.2: … related to process equipment

- All air inlets and gas outlets to/from gasifier, including fuel feeding section, flare and engine should be equipped with block devices or anti-backfiring valves in series

- Pressure and temperature sensors included in the safety concept should be duplicated or tripled

- Temperature sensors should be installed before and after the main plant reactor system components

- Preferred and allowable operating temperatures shall be secured with proper alarm levels
Gasification Guide, 5.4: Safety related issues in practice

5.4.1: Explosion / deflagration

...

5.4.2: Fire

- When and where: ...
- What happens: ...
- Possible reduction measures: ...
Gasification Guide, 5.4.1: Fire

When and where

• after an explosion
• self-ignition of moist and high piles of biomass feedstock
• in cases where maximum allowable temperatures are exceeded
• sparks from hot work (welding, cutting, grinding and sawing)
• removal of hot ashes
• wrong gas engine ignition timing
• failure of anti-backfiring system due to unexpected foreign material, failure in fuel dosing routines and apparatus
Gasification Guide, 5.4.1: Fire

What can happen

• physical injury to human beings
• damage or destruction of the BGP and other buildings
• fire may act as an ignition source for an explosion
• release of toxic fumes
Gasification Guide, 5.4.1: Fire

Possible reduction measures

• fuel should be stored in a closed container, fire isolated, or in a separate room or building

• fire-resistant separation between the fuel storage and the gasifier (with a specified fire resistance time) may be required according to local fire-protection regulations

• installation of anti back-firing system at reactor, flare and the air inlet to the engine may be required according to national regulations

• humidification system at the ash removal in order to prevent fire hazard from glowing particles or nitrogen inerting on ash removal screws

• …
Thank you for your attention

Do you have any questions?
Introduction to the Gasification Guideline

Harrir Knoef

BTG Biomass Technology Group
The Netherlands

Content
- History and background
- Workplan of the project

Consortium
- BTG
- TU-Graz
- Frauenhofer-Umsicht
- TU-Vienna
- HSE
- COWI
- TU-Sofia
  - Umwelt+Energie
  - FEE
History and Background

- Introduction and history of the way so far
- With thanks to Ruedi Bühler, Umwelt + Energie, Switzerland
- Preliminary remark: Today's conference and Guideline refers to gasification plants up to about 5 MWth

HSE is an important topic

- HSE Barriers in implementation of small-scale biomass gasification:
  - Manufacturers do not know the risks
  - Manufacturers do not know how to assess HSE risks and how to minimise them
  - Manufacturers do not know the standards which have to be fulfilled
  - HSE permitting authorities are not familiar with biomass gasification
  - Different regulations in European countries
  - Different interpretations by different authorities
Problems

- Installed plants with insufficient (no) H+S protection measures
- Installed plant with expensive H+S protection measure, which might not be necessary or without or with negative H+S effect
- Inappropriate requirements
- Without detailed knowledge, which HSE requirements have to be fulfilled, a reliable offer to a client is not possible

Joint effort to solve these problems since 2002
(IEA Bioenergy Gasification and ThermoNet/ThermalNet)

Objectives of the joint tasks

- Improve / Create Awareness: HSE is important
- Establish a «state of the art procedure» to assess and avoid risks
- Harmonise and accelerate the permitting procedure
- Reduce objections against the use of biomass
- Initiate a Guideline for safe and eco-friendly Biomass Gasification Plants
Activities in 2002

- HSE expert presentation at Strasbourg
  - Guideline is important

- Questionnaire 1: What manufacturers know about Health and Safety
  - Result: Manufacturers have little knowledge as regards Health and Safety

Activities in 2003

- Questionnaire 2: Ask Manufacturers what they need as regards HSE

- Results of the questionnaire:
  - Most of them ask for support in HSE
  - Support the intention to develop a guideline
Activities in 2004

- Handbook of Gasification (H. Knoef, Editor), Sept. 2005
  «Health, Safety and Environmental Aspects of Biomass Gasification»
- Austrian HSE Project started
- EC project proposal: «Guideline for safe and ecofriendly Biomass Gasification and Pyrolysis»
  - Project proposal rejected

Activities in 2005

- Austrian HSE project finished — important input on European level
- Joint HSE workshop of GasNet and IEA: Innsbruck, 28th September 2005
  - gaseous emissions
  - waste water
  - risk assessment and risk management
  - permission procedure

Proceedings available: download from websites.
Activities in 2006

- Project accepted

Activities in 2007

- Project “Guideline for safe and ecofriendly biomass gasification” started
- Information exchange
  Gasification Guide - ThermalNet - IEA Biomass Gasification

Objectives

- Accelerate the market introduction of small scale biomass gasifiers (< 5 MWth) by developing an accepted guideline and software tool
  - Remove non-technical barrier (awareness HSE hazards)
  - Identify HSE hazards in construction and O&M
  - Guidance to manufacturers and technology developers
  - Dissemination to target group
  - Simplification of procedures
  - Propose harmonization in EU-legislation
  - Roadmap for standardisation of the Guideline

Project Overview

www.gasification-guide.eu
Workpackages and approach

WP 1 – Project Management

WP 2 - Legal frame of plant permission and operation

WP 3 - Risk assessment (Safety, Health and Environment)

WP 5 – Dissemination and Communication

WP 6 – Common Dissemination

Advisory Group (20 members)

- Review progress
- Guidance to the project
- Advise on encountered problems
- Different background and expertise
  - Risk assessment method
  - Description of HSE risks
  - Questionnaire for case studies
  - Legislation and harmonisation issues
  - (draft) Guideline and Software tool
WP2 - Legal frame + harmonization

Legal frame - European and national layer

- European & national Legislation
- Recommendations for a permission procedure
  - Environment
    - Emissions (exhaust gas, waste water etc.)
  - Health
    - Plant utilities (producer gas, condensates etc.)
  - Safety
    - (Explosion, Fire etc.)
- National/local permission
- Case studies
- Manufacturers
- Permitting authorities
- Operators

WP2 - Gasification and Permitting

- Unknown technology: time consuming
- Very strict regulation (WID)
- Local, state, national authority = f (scale)
- Different interpretation
- Similar procedure to combustion/incineration
- In most cases: fuel dependent
WP3 - Risk Assessment

- Risk assessment methods (identification/selection)
- Hazard identification
- Risk assessment and reduction
  - Risk = severity * frequency
  - Risk matrix: acceptable, unacceptable, ALARP
- Software Tool for Risk Assessment
- Potential hazards in practice
  - Listing of possible events
  - Listing of possible consequences
- Good design practice
WP4 - Case Studies and Validation

- **Existing plants**
  - Eqtec
  - Biomass Eng.
  - Xylowatt
  - ....
  - ....
  - ....
  - ....

- **Plants in preparation**
  - Eqtec
  - Pyroforce
  - Güssing
  - DTU
  - Biomass Engineering
  - Xylowatt
  - Other target groups

- **Data collection**
- **Guideline validation**

---

WP4: Case Studies - Results

- Risk assessment has been done in all cases
  - Using different methods
  - HAZOP was executed in at least 3 cases
  - One supplier constructs explosion proof (10 bar)
  - Leakages and mechanical failures are considered as most dangerous
  - Most of the potential hazards are controlled by automation (PLC)
  - All suppliers have CE mark on the installation

- Declaration of Conformity
  - “needed” on the whole installation
  - “not needed”, as long as the RA has been conducted and documented

- The conducted Case Studies do not represent most likely the average!

- Discussion on BAT is useless

- Difference between incineration and gasification should be explained more clear
WP4: Case Studies – Remarkable results

- Biomass gasification is a commercial activity
  - For at least three entrepreneurs it's their only business
  - New criteria for the discussion: what/when commercial
- Mass production of 12 + 16 units
- One manufacturer employed a professional safety expert
- Risk Assessment is an ongoing activity and will never be completed
- At least two customers demanded for a complete risk assessment, CE marking and proper documentation thereof.

WP5 - Communication and Dissemination

- Target group: manufacturers, technology and project developers, consultants, investors, permitting and legislation authorities, scientists, ….
- Networks: IEA Bioenergy Task 33, Thermalnet, national networks
- Website: www.gasification-guide.eu
- Workshops: 2 at EU level, 3 at regional level,
- 1 German workshop (January 2009, Stuttgart)
- Promotional material (flyers)
- Papers at EU conferences (Berlin, Valencia, Hamburg)
Remaining activities 2009

- 2nd EU conference in Vienna on 3 September 2009
- Regional workshop for New Member States in Plovdiv, Bulgaria on 29 September 2009; contact ivec@tu-sofia.bg
- Regional workshop for Nordic States in Stockholm, Sweden on 22 October 2009; contact TEP@cowi.dk
- Final progress meeting in Stockholm, 21 October 2009
- Existence and Acceptance of the Guideline and Software Tool
- Final report

Questions on the project overview

Short break
Presentation of the Guideline

• almost final version
• seventy pages
• 90 requests for the draft version
• collection of feedback

Content

- Preface with acknowledgement to those who contributed on a voluntary bases
- Abbreviations and Definitions
- 1. Introduction
- 2. Technology description
- 3. Legal Framework for Biomass Gasification Technology
- 4. Theoretical Aspects of Risk Assessment
- 5. Potential Hazards and Good Design Principles
- 6. Emission abatement in biomass gasification plants
- Annexes: checklist
**Target Groups**

- Views and needs may differ: ‘conflicting interest’
  - Manufacturer versus plant owner
  - End-user/manufacturer versus permitting authority

- Target groups needs to know
  - HSE risks during BGP operation
  - Risk reducing measures
  - Procedures to follow and documentation to prepare
  - Procedures to follow to get permit in compliance with legislation
  - Are measures incorporated, documentation up-to-date

---

**Technology description (Chapter 2)**

- Fuel supply/storage
- Gasifier
- Gas cooling & Gas cleaning
- Gas utilisation

- Process Automation System
  - Biomass storage
  - Utilities storage
  - Intermediate storage of gasification residues
  - Conveying technology
  - Input units or rotary valves, vibro conveyor etc.

- Fixed bed gasification
- Fluidized bed
- Gasification utilities (water vapour, air, additives)
- Gasification boundaries (pressurised, atmospheric)
- Cyclone
- Bag house
- Filtering
- Wet dedusting/cleaning
- Residues treatment
- etc.

- Gas engine
- Gas turbine
- Micro gas turbine
- Synthetic fuel applications
- etc.
Technology description

Reactor designs (small scale)

- Gas cooling
  - To allow gas cleaning (fabric/bag filter)
  - To utilize in the gas in engine (increase energy density)
  - Recommendation: recover heat by heat exchanger

- Gas cleaning
  - To meet specifications of engine supplier
    - Cyclone (primary de-dusting)
    - Bag filter (fine de-dusting)
    - Hot-gas filter (fine de-dusting)
    - Packed bed (sand, active coal, etc.)
    - Scrubbers (water, oil)
Technology description

- Gas utilisation
  - Gas engines: commercial commodity
  - Exhaust gas emissions due to ‘slip’ (about 1%)
  - CO and NOx reduction measures needed
    - Post-combustion
    - Catalytic converters
- Automation and Control
  - Unmanned operation
  - Safety procedures can be implemented in control system
    - Fuel feeding
    - Oxygen supply
    - Cleaning of filters
    - Air-gas ratio to the gas engine

Producer gas properties

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Producer gas</th>
<th>Biogas</th>
<th>Natural gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO (vol %)</td>
<td>12-20</td>
<td>&lt;1</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>H₂ (vol %)</td>
<td>15-35</td>
<td>&lt;1</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>CH₄ (vol %)</td>
<td>1-5</td>
<td>50-75</td>
<td>90-99</td>
</tr>
<tr>
<td>CO₂ (vol %)</td>
<td>10-15</td>
<td>20-50</td>
<td>&lt;1</td>
</tr>
<tr>
<td>N₂ (vol %)</td>
<td>40-50</td>
<td>&lt;1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Heating value MJ/Nm³</td>
<td>4.8-6.4</td>
<td>18-26</td>
<td>35</td>
</tr>
<tr>
<td>Explosion range (vol%)</td>
<td>5-59</td>
<td>3-14</td>
<td>4.5-15</td>
</tr>
<tr>
<td>Air to gas ratio</td>
<td>1.1-1.5</td>
<td>5-7.5</td>
<td>10</td>
</tr>
</tbody>
</table>

Explosion range: lowest and highest fraction of the combustible gas that is still flammable
Legal Framework for Biomass Gasification (Chapter 3 with thanks to Ulrich Seifert)

- Scope and main tasks
  - Analyse and compare the legal framework for biomass gasification in a number of European states
  - Give hints to manufacturers and operators of biomass gasification plants on relevant legal requirements
  - Describe gaps or contradictions in the legal framework and make suggestions how to resolve them
  - Assume 31/12/2007 as the reference date for regulations

Benchmark of legal framework

- Key Results
  - With regard to European directives for manufacturing, there is no evidence of any problems with national implementation
  - European directives on environmental protection and on health and safety at work (with regard to operation of plants): considerable variation in the ways of implementing these directives at national level has become apparent
  - Key problem: various classification schemes for different aspects of HSE protection, even within a single Member State
### European Directives applicable to manufacturing of BGPs

<table>
<thead>
<tr>
<th>Directive: Number, Scope</th>
<th>Examples of application (BGP equipment)</th>
</tr>
</thead>
<tbody>
<tr>
<td>73/23/EEC: Low voltage equipment [2006/95/EC]</td>
<td>electrical instruments, drives, control systems, generator</td>
</tr>
<tr>
<td>98/37/EC: Machinery [2006/42/EC]</td>
<td>drives, pumps, blowers, moving mechanical parts, gas engine, fuel feeding system, ash removal system</td>
</tr>
<tr>
<td>94/9/EC: Equipment for use in potentially explosive atmospheres (ATEX directive)</td>
<td>blowers, measuring devices, flame arrestors</td>
</tr>
<tr>
<td>97/23/EC: Pressure equipment</td>
<td>heat exchangers/boilers, compressed air system</td>
</tr>
</tbody>
</table>

**Examples**

- Application of Directive 94/9/EC (ATEX-95) to BGPs
  - Contains requirements concerning equipment for use in potentially explosive atmospheres (+ protective equipment)
  - Devices with permanent sources of ignition (e.g. gas boilers) are not in the scope of directive 94/9/EC
  - Installations are not in the scope of directive 94/9/EC (but assemblies are)

- Application of Pressure Equipment Directive
  - Equipment that can be pressurised (> 0.5 bar g) in case of explosions only:
    - Does the Pressure Equipment Directive (PED) apply?
  - Suggestion from explosion experts:
    - Explosion pressure resistant equipment [druckfest] => PED equipment
    - Explosion pressure surge protected equipment [druckstoßfest] => no PED equipment
    (such equipment may be damaged by explosion pressure surge, which requires inspection and may lead to replacement, but this damage may not pose an immediate HSE hazard)

- Should be clarified between PED experts and explosion experts at European level
Regulations concerning construction and operation of BGPs

Occupational safety
- Health and safety at work, general
- Substances hazardous to health
- Fire and explosion hazards
- Installations subject to monitoring
- Pressure equipment
- Electrical equipment
- Explosion protection
- Machinery

Environmental impact
- Permit requirements (Integrated pollution prevention and control)
- Major Accident Hazards
- Waste treatment
- Handling of substances constituting a hazard to water
- Emissions to atmosphere: gases, dust, smell
- Noise emission
- Waste production
- Waste water

Other Regulations
- Renewable Energies / Biomass
- Fire safety of buildings
- Land use planning

Classification criteria
- Type of gasifier feedstock: waste biomass or natural biomass
- Thermal input or output rating (thermal capacity)
- Electrical rating of the CHP gas engine
- Operation as a stand-alone unit or as part of a larger installation
- Gas engine type (e.g. compression ignition, spark ignition)
- Operating time per year (peak load or continuous operation)
- Properties of the plant location (e.g. industrial, commercial, agricultural, or residential area)
- Date of putting the plant into service
Permit procedures

- Requirements have been collected in EU countries
- Procedures are country specific in terms of
  - Competent authorities
  - Information to be provided in written application
  - Application forms to be used
- Basic information in written applications include:
  - Applicant (name, address, …)
  - Plant location
  - Plant description (flowsheet, equipment, fuel, emissions, waste)
  - Reference to relevant regulations

Consult the competent local authority at an early stage to identify the regulations that apply!

Occupational safety & health: employers’ duties

- prevent or minimise occupational risks
- provide information and training
- provide the necessary organization and means
- perform hazard identification and risk assessment
- draw up documents on the results, which include:
  - registry of hazardous substances
  - explosion protection document
  - written company-specific operating instructions
Emission limit values for BGPs in Europe

- In most European states, emission limit values (ELVs) **specific to biomass gasification plants with gas engines** have not been defined yet.

- Denmark: ELVs for gas engine exhaust gas in biomass gasification plants (reference state: dry exhaust gas at STP, 5% O₂)
  - NOₓ: 550 mg/m³
  - UHC: 1500 mg C/m³ (valid for 30% electrical efficiency) uncombusted hydrocarbons
  - CO: 3000 mg/m³

Best Available Techniques (BAT) issue

- The term "BAT" has been introduced within the IPPC Directive (96/61/EC) [integrated pollution prevention and control]
- Emission limit values (or equivalent parameters and technical measures) shall be based on the "best available techniques" for industrial activities listed in Annex I of the IPPC Directive
- Small and medium biomass gasification plants are not in the scope of the IPPC Directive (but may be in the scope of national transpositions of that directive)
- Emission limit values for small and medium BGPs to be based on BAT is
  - not required at European level, but
  - required at national level in some states
Risk Assessment (Chapter 4)

- Need for complete and well-documented RA:
  - Health: hazards to human health, toxic gases, …
  - Safety: human, explosion hazards, fire hazards, …
  - Environment: plant emissions, toxic substances, …
- Risk assessment has to be done by experienced team with different expertise and background
- Technology description
- Identification of possible hazards, malfunctions/events
- Risk consequences and assessment
- Risk minimization measures

Risk assessment procedures

- Check list
- Dow and Mond Index
- Preliminary Risk Analysis
- What-If-Method
- Hazard and Operability Studies (HAZOP)
- Failure Modes Effects and Criticality Analysis (FMEA)
- Fault tree analysis
- Event tree analysis
- PQM-method (Prognosis-Quantification-Minimization)
- Fault or failure simulation for process control units
- MOSAR-Method (Method Organized for a Systematic Analysis of Risk)
- Delphi Method
Systematic approach

1. Technology description and classification
2. Risks in biomass gasification plants concerning
   a) health (e.g. exposure, gaseous vaporized plant utilities during normal operation, emergency cases or maintenance work…)
   b) safety (e.g. explosion risks, risks from electric current…)
   c) environment (e.g. emissions from biomass gasification plants in shape of gaseous, liquid or solid utilities…)
3. Differentiation between event/malfunction/hazardous event and consequences (check list)!!!
4. Assessment of the risk
5. Counter measures to certain/uncertain risks
6. Implementation, updating and further development of safety routines
7. Documentation and update of documentation

Risk Matrix
Types of countermeasures

- Technical countermeasures
- Process control countermeasures
- Organisational countermeasures

Implementation of Risk Assessment is a software tool “Risk Analyser” (next presentation)

Potential hazards and good design principles (Chapter 5)
As low as reasonably practicable (ALARP)

- **Principle 1**: “HSE starts with the expectation that suitable controls must be in place to address all significant hazards and that those controls, as a minimum, must implement authoritative good practice irrespective of situation based risk estimates.”

- **Principle 2**: “The zone between the unacceptable and broadly acceptable regions is the tolerable region. Risks in that region are typical of the risks from activities that people are prepared to tolerate in order to secure benefits in the expectation that:
  - the nature and level of the risks are properly assessed and the results used properly to determine control measures;
  - the residual risks are not unduly high and kept as low as reasonably practicable (the ALARP principle); and
  - the risks are periodically reviewed to ensure that they still meet the ALARP criteria, for example, by ascertaining whether further or new controls need to be introduced to take into account changes over time, such as new knowledge about the risk or the availability of new techniques for reducing or eliminating risks.”

- **Principle 3**: “both the level of individual risks and the environment must be considered when deciding whether a risk is acceptable or not, and risk at the level of individual risk also give rise to risk to the environment, which is often deciding whether a risk is acceptable or not.”

**Good engineering and operation practice**

- A decent risk assessment is compulsory
- Good design practice related to:
  - Plant building construction (fuel storage, control rooms, escape routes, ventilation, warning signs, …)
  - Process equipment (material choice, gas tightness, valves, electrical devices, control/safety devices, rotating parts, hot surfaces, gas flaring system, …)
  - Operation and monitoring procedures (start-up/shutdown procedure, normal operation, emergency shutdown, …)
Safety related issues in practice

- Explosion / deflagration
- Fire hazards
- Toxic liquid escape
- Toxic gas escape
- Operator failures / neglectence

When can it happen?

Where?

What happens?

What can be done (countermeasures)?

Explosion / deflagration

- When?
  - Explosive mixture and ignition source
  - Explosive mixture: within certain oxygen concentrations (LEL/UEL)
  - Ignition source: glowing particles, sparks, very hot surfaces
  - Dust explosion in feeding section

- Where?
  - At almost every section of the plant
  - In case of air ingress or gas escape
  - Backfiring (flare, engine)
  - During repairs (welding, cutting, grinding, …)

- What happens?
  - Mostly minor explosion (Verpüffung)
  - Max. 8 bar (lowering at increasing temperature)
Explosion / deflagration

- Possible reduction measures (according ATEX)
  - Primary measures (avoidance explosive atmosphere)
    - Oxygen sensor inside the plant, CO sensor outside the plant
    - Inertise with nitrogen at start-up and shutdown
    - Secure technical gas tightness to avoid air intake or gas escape
    - Avoid bridging in the reactor?
  - Secondary measures (avoid ignition source)
    - Proper grounding and safe electrical installation
    - Water seal acting as flame arrestor
    - Permit to work system in case of repairs like welding
  - Tertiary measures (mitigate the explosion effect)
    - Explosion safe construction (max explosion pressure may be higher with interconnected vessels)
    - Water seal or rupture/bursting discs (not preferred)

Fire

- When and where?
  - After an explosion
  - Sparks / smoking
  - Ash removal
  - Self-ignition fuel storage
  - Bad ignition of gas engine
  - Failure of anti back-firing system

- What happens?
  - May act as an ignition source
  - Damage to installation / building
  - Physical injury
  - Release of toxic fumes
Fire

- Possible reduction measures
  - Fire resistant separation of fuel storage from gasifier according local fire protection regulations (60 minutes)
  - Fire extinguishing system (Sprinkler, manual fire extinguisher)
  - Anti backfiring system on gasifier (valve, double sluice)
  - Anti backfiring on air inlet to the engine
  - Spraying removed ashes
  - Monitoring temperature wood storage pile
  - Ample ventilation
  - Fire response plan

Toxic liquid escape

- When?
  - Leakages / maintenance in gas cooling section and storage tanks
- Where?
  - Wet scrubber / condensing heat exchanger
- What happens?
  - Physical contact may lead to injury, suffocation, irritation, …
  - Liquid may evaporise with risk of inhalation
  - Environmental pollution
- Possible measures
  - Wearing protective gloves, glasses, shoes
  - Storage in containers
  - Ample ventilation
Toxic gas escape

- When?
  - Leakages of gas or liquids
  - Maintenance
- Where?
  - Overpressure
  - Exhaust gas
- What happens?
  - CO poisoning, irritation, danger of suffocation
  - Some PAH are carcinogenic
- Possible measures
  - Protective measures: portable and online CO monitor
  - Gastight construction
  - Ample ventilation

Operator failures

- Unauthorised re-programming or re-arrange the alarm settings. Set-points must be reset
- Safety-related changes to the process control system must be performed by trained trained personnel only and documented properly
- Operational procedures should be in place, which indicates whether the plant should be operated by only one or two operators, or maybe unmanned
Norms and Standards

- BGPs must be approved for the design, construction and safe operation by the local fire department and permitting authority.
- Norm for gas tightness:
  - Norms applied in chemical industry may be applicable to BGPs.
  - Standards for gas tightness that might be applicable are listed in a Table in the Guideline document.
  - Guidance on explosion protection measures are listed in a Table in the Guideline document.

Documentation

- Operation and Maintenance Manual
  - To be supplied by the manufacturer.
  - To be kept updated by operator in case of modifications.
- Emergency procedures.
- Accident register.
- Training manual.
- Log book.
- Design book.
- Permits (building, environment, CE marking, ...).
Emission abatement techniques

- Fuel storage, pretreatment, transport, feeding
  - Store only dry biomass
  - Enclosed conveying systems
  - Good housekeeping
- Gasification reactor
  - Gas tight
  - Double sluice lock hoppers
  - Flaring system
  - Prevent self-ignition of ashes

Emission abatement techniques

- Gas cooling and gas cleaning
  - Recycling of hydrocarbons (tar)
  - Use activated carbon before discharge to sewage system
  - Off-site controlled treatment
- Gas engine and exhaust gas cleaning
  - Use silencers and sound-absorbing walls
  - Catalytic convertors
  - Post combustion
Emission limit values

- Do emission limit values established for ‘other’ gases like biogas reflect the best currently available techniques for emission reduction in gas engines using producer gas from BGPs?
  - Producer gas contains high volume percentage of CO
  - Emission limits based on BAT for CO-free fuel gas may not be applicable to BGPs
  - Recommendation: determine appropriate emission limits for small-scale BGPs from continued experience with plants in operation and from measurements performed at these plants; only very limited emission values have been measured in practice

- Specific emission limit values for gas engines using producer gas are established in Denmark only.
- In Germany some agreement is reached on emission limits by licensing authorities. One requirement is 1 mg/m³ for benzene, which is considered as problematic for gas engines operating on producer gas
Emission limit values

- Regulation in the Netherlands
  - White list fuels: “clean fuels”, meet the definition of biomass (2001/80/EG)
  - Yellow list fuels: “waste fuels”
  - Different emission regime
- VROM circular (2 October 2006):
  - fuels from the yellow list can be gasified producing a gaseous fuel which is clean and part of the white list
  - “Clean gas from waste wood”
  - → more favorable emission regime

Emission limit values

- Good news from US EPA
- EPA proposes to classify gasifiers as:
  - Fuel manufacturing facility
  - Safer, more efficient & distinguished from incinerators
- Even hazardous waste are considered fuel feedstock and not solid waste
- Gasification promotes the production of a “Marketable fuels and chemicals from materials that otherwise destined for waste treatment, disposal or a less benign recycling activity
Harmonization of legal framework

- New definition of activity 1.4 in Annex I of the proposed new IPPC Directive
- Current definition: coal gasification and liquefaction plants
- New definition: gasification or liquefaction of fuels
- Suggestion: Provide an indication to the European Commission about the unwanted side-effect of the new definition and include the suggestion to add a threshold value to this activity.
Feedback

- Benz(a)pyrene and dust are not problematic, only benzene, even after oxy-catalyst
- Benzene levels led environmental authorities to force the close down of 2 plants in Germany
- You need a driving license to drive your car!
- What is a safe shutdown procedure?
- Should the plant be equipped with explosion relief panels?
- One potential hazard can lead to more consequences in parallel and/or sequential
- All 90 contacts who requested the draft Guideline will be asked to give feedback

Feedback

Luis Sanchez, EQTEC, ES
- manufacturer
- positive feedback on technical contents of Gasification Guide
- Movialsa plant: commissioning of Jenbacher CHP engines is underway
- update on plant operation parameters
- no problems with emission limit values so far (producer gas is co-fired in heavy oil engines with 2,000 mg/m³ NOₓ limit)
Feedback

Des Mitchell, O-GEN UK

- operator, consultant, authority advisor
- O-GEN: timber resource recovery centres
- gasification of used timber (= "waste" according to WID)
- 3.6 MW electricity, 72 t/d wood
- gasifier + IC engines fulfil WID requirements
- O-GEN expect to set new standards for BGPs using waste wood in terms of BAT and BPEO ("best practicable environmental option")

Legal situation for gasification of used wood in the UK

- European Court decision on Lahti legal case (Dec. 2008):
  a) purified syngas from waste can be a product
  b) the waste gasifier is regarded as a waste incinerator
  c) WID does not apply to combustion of purified syngas from waste
- UK Environmental Agency does not accept this decision
- if an operator cannot guarantee that each single piece of wood will fulfil "biomass" specs, the BGP will be deemed a waste incineration facility (in the UK)
Feedback

Anja Nowack, Federal Environmental Agency (UBA), D

- authority (advising)
- compilation of state-of-the-art (BAT) for CHP engines is underway, including BGP gas engines (Mueller-BBM)
- project results expected in Aug./Nov. 2009
- apart from benzene, no other major concern components in exhaust gas have emerged so far
- benzene target value of 1 mg/m³ appears to be a challenge for BGPs

UBA urges to re-introduce permit requirements for small BGPs

while novel renewable energy technologies receive a bonus in terms of feed-in tariffs in Germany, there should be no "emission bonus" according to UBA
Involving permitting authorities

- Important to obtain approval of the Guideline
- Permitting authorities are mostly interested in safety
- HSL has been successful in establishing contact with UK authorities; they will provide feedback
- HSL has started to establish contact with Stazione sperimentale per i Combustibili (Italy)
- Project partners will establish contacts with authorities within their country

### Benzene problem, limit in Germany = 1 mg/m³

<table>
<thead>
<tr>
<th>Benzol im Holzgas</th>
<th>XXX</th>
<th>XXX</th>
<th>XXX</th>
<th>XXX</th>
<th>XXX</th>
</tr>
</thead>
<tbody>
<tr>
<td>[g/m³]</td>
<td>-</td>
<td>3.5</td>
<td>3.5</td>
<td>-</td>
<td>1.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Motorabgas</th>
<th>Gleichstrom</th>
<th>Gleichstrom</th>
<th>Gleichstrom</th>
<th>Gleichstrom</th>
<th>Gleichstrom</th>
</tr>
</thead>
<tbody>
<tr>
<td>O₂ [%]</td>
<td>M1</td>
<td>M2</td>
<td>M2</td>
<td>M1</td>
<td>M1</td>
</tr>
<tr>
<td>CO [g/m³]</td>
<td>3.6</td>
<td>3.6</td>
<td>3.6</td>
<td>3.6</td>
<td>3.6</td>
</tr>
<tr>
<td>NOₓ [g/m³]</td>
<td>0.18</td>
<td>0.18</td>
<td>0.18</td>
<td>0.18</td>
<td>0.18</td>
</tr>
<tr>
<td>GesamtC NMHC [mg/m³]</td>
<td>46</td>
<td>46</td>
<td>46</td>
<td>46</td>
<td>46</td>
</tr>
<tr>
<td>Formaldehyd [mg/m³]</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>Benzol [mg/m³]</td>
<td>&lt; 1</td>
<td>&lt; 1</td>
<td>&lt; 1</td>
<td>&lt; 1</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Staub [mg/m³]</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Nach Kat:

<table>
<thead>
<tr>
<th>Benzol im Holzgas</th>
<th>[g/m³]</th>
<th>-</th>
<th>0.44</th>
<th>0.44</th>
<th>0.18</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO [g/m³]</td>
<td>0.16</td>
<td>-</td>
<td>0.14</td>
<td>0.14</td>
<td>0.14</td>
</tr>
<tr>
<td>Gesamt C [mg/m³]</td>
<td>3.5</td>
<td>-</td>
<td>3.5</td>
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<td>3.5</td>
</tr>
<tr>
<td>NMHC [mg/m³]</td>
<td>31</td>
<td>-</td>
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<tr>
<td>Formaldehyd [mg/m³]</td>
<td>20</td>
<td>-</td>
<td>20</td>
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<tr>
<td>Benzol [mg/m³]</td>
<td>47</td>
<td>-</td>
<td>47</td>
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</tr>
<tr>
<td>Staub [mg/m³]</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
Guideline is available at www.gasification-guide.eu

English, German and French version will become available

Thank you for your attention

We are looking forward to welcome you at the regional workshops in

Plovdiv on 29 September
Stockholm on 21 October
Software Tool - “Risk Analyzer”

International Conference on Polygeneration Strategies  
GASIFICATION GUIDE  
3. September, Vienna, Austria  
Martin Hauth  
Institute of Thermal Engineering

Outlook

• Methodology of the Risk Analyzer
• Structural Approach of the Software Tool
• Risk Assessment
• Reporting and Documentation
• Illustration of using the Software Tool
Motivation

- Detailed Risk Assessment of Biomass Gasification Plants is a big challenge for small and medium enterprises
- Complexity => Barrier to market introduction
- Software Tool provides helpful and structured approach for risk assessment
- Software Tool as a supporting Guideline for Risk Assessment in companies

Preparation Analysis & System Description

- Ambience
  - Abutting owner (private person, industry, etc.)
  - Infrastructure
  - Meteorological and geographical basic data

- Plant
  - Technology description and Classification
  - Description of the actual plant state (existing plants)
  - Description of plant utilities

Risk Identification and Occurrence Probability

- Check list, What-if-Method, Dow and Mond Index
- Hazard and Operability Studies HAZOP
- Failure Modes Effects and Criticality Analysis
- Delphi Method, MOSAR Method

Consequence Analysis

- Effects
- Propagation
- Effect assessment
  - on people, animals, the environment, the plant side, ...

Risk Assessment

\[ \text{Risk} = f(\text{Effects or Consequences}, \text{Occurrence probability or frequency}) \]

Risk Minimization Measures

- Weak spot elimination, Gradual reduction of possible hazards, Consequence limitation, Package of technical and organisational measures
Institut für Wärmetechnik

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Function based identification of Hazards

1. Hazards and Consequences?
   - E.g.: Pressure drop too high?
     Analysis of the considered function
     and the involved parts/units/functions
     - Selection of a possible consequence
       (e.g. blockage) or creation of a new
       consequence
     - Application of the risk matrix
   2. Is the resulting risk...
     acceptable/ALARP or not?

   Risk Matrix

Event List
- Pressure drop too high

Consequence List
- Blockage

Process

Part 1
Part 2
Part 3
Part ....

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Hazard Identification - Events/Consequences List

Events
- Leaksages
  - Gas escapes
  - Air intake
  - Leakages steam system
  - Leakages in water caring system
  - temp. out of normal operation areas
  - pressure fluctuations
  - etc.

Consequences
- Explosion
- Fire
- Danger from electricity
- Poisoning
- Danger to health
- etc.

... a list of events and consequences are provided within the
guideline and are implemented in the software tool.
Approach during the use of the Software Tool

Step 1: Definition of the basic data of the plant

Step 2: Definition of the process units

Step 3: Definition of the functions of the process units

Step 4: Definition of the parts of the functions

Step 5: Definition of the plant utilities

Step 6: RISK ASSESSMENT PROCEDURE

Events / malfunctions

Consequences

additional to predefined events/sequences
Auditability of set Countermeasures during the Risk Assessment

Preventive measures (in advance of consequence) -> lowers frequency
- technical (e.g., CO-sensor)
- organisational (e.g., manual)
- constructive
- Process and Control System (e.g., additional temperature sensor)

Mitigation measures (due to consequence) -> lowers severity
- technical (e.g., CO-sensor)
- organisational (e.g., manual)
- constructive
- Process and Control System (e.g., additional temperature sensor)

Definition of the Frequency and Severity of a hazardous event

Frequency

- probable: > 1 x / year
- improbable: 10^-1 to 1 x / year
- unlikely: 10^-5 to 10^-3 x / year
- very unlikely: 10^-6 to 10^-4 x / year
- extremely unlikely: < 10^-6 x / year

Severity

- minor
- significant
- severe
- major
- catastrophic

Example:

- Human beings
  - minor: light injury
  - significant: injury
  - severe: severe injury
  - major: disablement, death
  - catastrophic: death

- Environment
  - minor: olfactory pollution, elevated emissions (short time)
  - significant: long lasting olfactory pollution, slightly increased emissions
  - severe: emission of toxic substances of little amounts
  - major: emission of toxic substances of huge amounts
  - catastrophic: emission of toxic substances of huge amounts

- Property/ goods
  - minor: no plant shut down, online reparation possible, little costs
  - significant: plant stop, warm start necessary, standstill of the plant < 2 days
  - severe: plant damage, cold start necessary, standstill of the plant 3 to 6 weeks
  - major: critical plant damage concerning the whole plant or plant sections, standstill of plant
  - catastrophic: enormous plant destruction / damage concerning the whole plant
**Documentation and Reporting**

- Report of total risk assessment is automatically generated. (PDF file)
- Documentation to be used during licensing procedure.

**Illustration – Approach during risk assessment**

1. General Plant Data
2. Structuring into Process Units
3. Definition of Functions within the Process Units incl. description of the Operating Modes
4. Definition of the involved Parts within a Function incl. description of the Process Parameter
5. Risk Assessment and setting of Countermeasures
6. Reporting
1. General Plant Data

Plant manufacturer:
Address, manuf.

Plant operator:
Address, operator

Performance Data:
$P_{th}$, $P_{el}$, ....

2. Structuring into Process Units

Process Units:
Storage, auxiliary Aggregates, Flare, electr.
Switchboard, Reactor, Screw Conveyor,
Filter, ....
3. Definition of the Functions within the Process Units

Unit Filter: Purge Filter Material, Ash Removal, Gas Cooling, ….

Operating Modes:
- Normal Mode
- Start-Up
- Shut-Down
- Emergency Stop

4. Definition of the involved Parts within a Function

Function Purge Filter Material:
Drive, CO-Sensor, Pressure Cylinder, Gland Nut for Filter

Process Parameters of Function:
Stroke Distance, Pressure, Oil Content, Pressurized Air
5a. Risk Assessment within a Function

Risk Assessment

Frequency × Severity = Risk

5b. Setting Countermeasures

Original Risk before setting Countermeasures

Risk after setting Countermeasures

Risk Matrix with the stepwise illustration of the risk minimization
### 6. Reporting

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<th>Original Risk</th>
<th>Countermeasure</th>
<th>New Risk</th>
<th>Final Risk</th>
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<td>Vienna, September 3rd</td>
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- **Assessed Hazard**
- **Original Risk**
- **Countermeasure**
- **New Risk**
- **Final Risk**

**Software Tool - Summary**

- Software Tool free for download under: [www.gasification-guide.eu](http://www.gasification-guide.eu)
- Software Tool provides **structural approach** for a systematic segmentation of the plant in: Units/Functions/Parts
- Stepwise **selection and assessment** of the potential hazards and consequences
- Definition of the risk by the means of **severity and frequency** of the consequence (Estimation has to be done by oneself!)
- Placing **countermeasures** for risk reduction (Loop)
- Printing of a **report** to document the approach of the risk assessment

**Thank you very much for your attention**
Publications

Annex 0.3 - Book of abstract  (covering the whole conference)
ICPS 09
International Conference on Polygeneration Strategies

BOOK OF ABSTRACTS

www.icps09.org
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Der beste Sitz für Unternehmen.

www.viennaregion.at
Introduction to the ICPS09

It is generally agreed that biomass will contribute essentially to a future sustainable energy system worldwide. Furthermore, biomass gasification will be a key technology for such an energy system. By conversion of solid biomass into a producer gas heat and electricity can be generated efficiently. In former years combined heat and power (CHP) production was the main focus of R&D&D and also main topic of several conferences. Nowadays, CHP on gasification can be considered as commercial available technology although the number of plants in operation is still low. However, there are several plants with a lot of experience and more than 50,000 hours of successful operation.

In recent years things have changed. In all steps of the process chain e.g. gas production, gas cleaning and gas utilization enormous progress have been achieved. Furthermore, besides heat and power generation the production synthetic biofuels gain more and more interest in research as well as for industrial applications. Polygeneration is now the key word for future efficient and sustainable biomass utilization. Polygeneration in this sense means the production of at least three different products e.g. heat, electricity and biofuels. Polygeneration based on thermochemical biomass conversion can also be characterized as one type of a biorefinery, a so-called syngas platform based biorefinery.

The main aim of ICPS09 is to present and review the current state-of-the-art of syngas production, syngas cleaning and syngas utilization. Life cycle analysis, simulation and techno economic studies are further integrated parts of the conference. Numerous abstracts to all these topics from all parts of the world were presented to the conference organizers which show the necessity and importance of this conference. To keep up the focus, unfortunately not all abstracts could be accepted as some where not within the general idea and guideline of the conference.

This book contains a collection of the abstracts accepted for the ICPS09 conference in Vienna. The abstracts are classified according to the above mentioned topics which where already announced in the call for papers. For all these topics a sufficient number papers have been offered and some of them were selected for oral presentation. Almost all important developments currently under way in the field of polygeneration are included in the programme and are part of the oral or visual presentations. In this sense the main aim of the conference could be fulfilled, namely, to present the current state-of-the-art of polygeneration technologies and to stimulate discussion and information exchange and to contribute to a further development of polygeneration strategies.

Moreover it is a pleasure and honour for me to, beside of the explained scientific focus of this conference, grant for true Austrian hospitality in these days, which I hope you will enjoy during the 1st International Conference on Polygeneration Strategies.

Vienna, September 2009

Hermann Hofbauer
Chairman of the Conference
## Committees

### Scientific Committee

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<td>Hermann Hofbauer</td>
<td>Vienna University of Technology, Austria</td>
</tr>
<tr>
<td>Martin Kaltschmitt</td>
<td>Deutsches Biomasse Forschungszentrum, Germany</td>
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<tr>
<td>Johan Einar Hustad</td>
<td>Norges teknisk - naturvitenskapelige universite (NTNU), Norway</td>
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<tr>
<td>Pier Ugo Foscolo</td>
<td>Universita degli Studi dell’Aquila, Italy</td>
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<tr>
<td>Samuel Stucki</td>
<td>Paul Scherrer Institut, Switzerland</td>
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### Local Organizing Committee

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<td>Michael Fuchs</td>
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I

Gas Production
THE NEW CHALMERS RESEARCH-GASIFIER

Seemann M C, Thunman H

Department of Energy conversion, Chalmers University of Technology, Göteborg, Sweden

During summer 2007 a 2-4 MWth indirect gasification section was integrated into the loop of the existing 8-12 MWth circulating fluidized bed boiler at Chalmers University. With help of a particle distributor the gasification unit is connected to the loop after the cyclone. Hot bed material entrained from the boiler is so transferred to the gasifier providing the heat for the production of a nearly nitrogen free product gas. The non gasified char is recycled together with the bed material into the boiler and converted. Biomass can be fed into both sections; the boiler and the gasifier. The gasification is separated from the boiler via two loop seals. By means of the particle distributor, directing particles either back to the boiler or into the gasification section, the operation mode of the CFB installation can be changed anytime during full operation from only combustion to combined combustion/gasification mode. Due to that design the investment costs are considerably lower than for standalone gasification units of that size. This retrofit is an easy way to extend the potential of a CFB Boiler towards bi- and tri generation (heat, power, fuel).

The Chalmers gasifier is designated to research and therefore equipped with a multitude of sampling ports spread out over the front of the reactor. By means of different probes, sampling of gas and bed material is possible to acquire information about the progressing fuel-conversion.

The first two experimental seasons (winter 07/08 and winter 08/09) proved stable operation of both the boiler and the gasification. Furthermore tests with different feedstock, wood pellets, woodchips and bark were performed. Analysis of the producer gas composition shows high contents of methane, making the kind of installation a good match for power or substitute natural gas production.
PRESSURISED ENTRAINED FLOW GASIFICATION OF SLURRIES FROM BIOMASS

Stahl R, Henrich E, Raffelt K

Forschungszentrum Karlsruhe, Institut für Technische Chemie, CPV

The European Union intends to increase its biomass contributions in the energy mix up to several percent until the year 2010. To reach this goal the energy potential of the abundant lignocellulosic biomass residues from agriculture must be used covering about 10% of the European primary consumption. Mainly the production of chemicals and fuels provides to be much more effective than combustion. All fast growing biomass like straw and strawlike biofuels contains high ash, alkalis and chlorine however. The technology for its efficient energetical use is therefore difficult and not well developed. The bioliq process a new two stage pyrolysis/gasification concept has been developed in Germany at the Forschungszentrum Karlsruhe: In the first step biomass is liquefied by fast pyrolysis which produces a condensable pyrolysis oil and pyrolysis char as well as small amounts of gas. The pulverised pyrolysis char and the oil are mixed. In the second step the resulting slurry is transported from several small pyrolysis plants to a large central high pressurised entrained flow gasifier. There the slurry is used for the production of raw syngas. After gas cleaning the generated synthesis gas can be used for catalysed synthesis of chemicals or liquid fuels. Four experimental campaigns in the pressurised entrained flow pilot gasifier at Future Energy, Freiberg (formerly Noell company, today Siemens company), proved the feasibility on a reliably large 3 MW(th) scale. The gasifier, fitted with a special inner cooling screen in a pressure resistant steel shell allows the gasification of different feedstock’s with a large and fluctuating ash content and composition expected in the large spectrum of herbaceous biomass species. Compared to direct bio-oil combustion in diesel engines or turbines, the purity requirements for the gasification of bio-oil-slurry are very low. Several pyrolysis oils and char from beechwood pyrolysis for commercial charcoal production and intermediate pyrolysis of straw have been used for slurry preparation. Beechwood tar with a room temperature viscosity of 0.16 Pas, had a density of 1184 kg/m3 and a LHV of 19 MJ/kg. Charcoal was pulverised into different sizes between 10 and 100 um and had a LHV 31 MJ/kg. Stable slurries with different weight percents of charcoal dust have been prepared by mechanical mixing, without any stabiliser. To simulate the ash melting behaviour of straw slag, 3% straw ash and 0.3% KCl have been added. Slurry properties have been as follows: room temperature viscosity 2 – 5 Pas, density 1250+ kg/m3, LHV 21 – 22 MJ/kg. A slurry stream of ~0.4 – 0.6 t/h was transferred with a screw pump into the gasifier chamber at 25 bar and pneumatically atomised with pure oxygen in a special nozzle. With an O2-stoichiometry of λ = 0.4 to 0.5, gasification temperatures of 1100 – 1600°C and more than 99% carbon conversion have been attained. A molten slag layer drains down on the inner screen walls and protects the SiC-liner from corrosion. A suitable slag viscosity is adjusted with the O2-flow (temperature) and – if desirable – suitable inorganic additives in the feed to modify the slag composition. As the hot pressurised syngas is tar-free expensive efforts for tar removal or syngas compression can be avoided. The measured raw syngas composition indicate an approximate equilibration for the homogeneous shift reaction CO + H2O → CO2 + H2, as expected. Crude material and energy balances have been derived from the known feed composition The process concept and the results of the experimental gasification campaigns will be given in detail.
INFLUENCE OF OPERATING CONDITIONS ON GAS COMPOSITION, SOOT AND TAR IN ENTRAINED FLOW GASIFICATION OF BIOMASS

Ke Q, Weigang L, Peter A J, Anker D J

Department of Chemical and Biochemical Engineering, Technical University of Denmark

Gasification is one of the key technologies for utilization of biomass, especially in the field of integrated gasification combined cycle (IGCC) and production of liquid fuels and chemicals. In production of synthetic liquid fuels for transportation from biomass, one of the key problems to be solved is to control the syngas quality from gasification with respect to both the H2/CO ratio and the harmful impurities. Entrained flow gasifier has the advantage of high gasification efficiency with the possibility to run at high pressure, which fits the pressure in the downstream synthesis process. Although gasification of coal in entrained flow gasifiers been studied extensively, systematic studies on gasification of biomass in entrained flow gasifier are scarce. In addition the mechanisms during biomass gasification at temperatures relevant to the entrained flow gasifier are not fully understood.

In this work, gasification of biomass in a laboratory scale entrained flow reactor is presented, with a focus on the influence of the operating parameters, such as temperature, air ratio and steam to carbon ratio, on the gas composition, soot and tar in the producer gas. The entrained flow reactor has an inner diameter of 0.08 m and a length of 2 m. The reactor is externally heated by seven independent electric heating elements, with which a uniform temperature in the reactor can be realized and, the influence of temperature and air ratio on the composition of the syngas can be studied independently. Two typical bio-fuels (wood and straw) have been used in the study. The influence of air ratio, temperature and steam to carbon ratio is investigated. In the experimental study, the air ratio varied from 0. to 0.7, and a temperature in the range from 1000 to 1350°C was used.

The results show that the amount of producer gas increases with an increase in temperature at a fixed value of air ratio, for example, from 0.98 Nm3/(kg fuel) at 1000 °C to 1.54 Nm3/(kg fuel) at 1350°C, at an air ratio of 0.25. The amount of carbon monoxide and hydrogen increases at higher temperature. At a fixed temperature, the amount of carbon monoxide and hydrogen decreases with an increase of air ratio, for example, at 1350°C the hydrogen yield decreases from 27mole/(kg fuel) at air ratio of 0.2 to 18 mole/(kg fuel) at an air ratio of 0.5. It was found that the tar content in the syngas is very low at a temperature of 1350°C (<0.1mg/ m3) at an air ratio of 0.25. However, significant soot was produced at this temperature (40 g/ (kg fuel)). This trade off between tar and soot may result partly from soot formation by tar polymerization at high temperatures. With addition of steam, the hydrogen to carbon monoxide ratio increases as a result of the water shift reaction. The soot production can be reduced by addition of steam, but could not be eliminated in the present experiments with a maximum temperature of 1350°C. Moreover, it appears that the applied type of biomass (straw and wood) has little influence on the composition of the syngas. A good carbon mass balance closure is achieved from all conducted experiments.
In the scope of the production of SNG (Synthetic Natural Gas) from biomass, it could be interesting to gasify biomass at high pressure. Thermodynamical calculations predict an increase of CH4 production in the synthetic gas. The High Temperature Fluidized Bed facility implemented in CEA Grenoble (France) is able to perform tests at high pressure (up to 40 bars). Several tests at 800°C and different pressures from atmospheric pressure to 10 bars were performed with a continuous wood sawdust feeding of several kg/h. Percentage of steam in fluidization gas, steam/biomass ratio and fluidization velocity were kept constant for all tests. So, the effect of pressure during steam gasification was isolated from other relevant parameters influencing gasification. Gas, tars and char generated by the steam gasification were quantified and analysed. Mass balance and carbon conversion rate were calculated.
THE DEVELOPMENT AND OPERATION OF A 100KW DUAL FLUIDISED BED BIOMASS GASIFIER FOR PRODUCTION OF HIGH QUALITY PRODUCER GAS

Bull D R, Gilmour I A, Williamson C, Pang S

Chemical and Process Engineering Department, University of Canterbury, New Zealand


The production of high quality producer gas from a dual fluidised bed (DFB) gasifier fuelled with radiata pine wood pellets has been studied over the past four years at the University of Canterbury, New Zealand. Research has focused on the operational performance and commercialisation potential of advanced DFB gasification systems for New Zealand industrial settings.

Significant progress has been made towards stable and reliable gasifier operation, as well as the collection of extensive experimental data to benchmark the system’s performance regarding yield, composition, tar levels and water vapour content of the producer gas.
GASIFICATION CHARACTERISTICS OF BIOMASS/COAL BLEND IN A DUAL CIRCULATING FLUIDIZED BED REACTOR

Seo M W 1, Goo J H 1, Kim S D 1, Lee S H 2, Choi Y C 2

Department of Chemical and Biomolecular Engineering, Energy and Environmental Research Center, Korea Advanced Institute of Science and Technology (KAIST), 373-1, Guseong-dong, Yuseong-gu, Daejeon, 305-701 1
Thermal Process Research Center, Korea Institute of Energy Research, 71-2 Jang-dong, Yuseong-gu, Daejeon 305-343, Republic of Korea 2

A dual circulating fluidized bed reactor (riser: 0.04 m × 0.11 m × 4.5 m-high; gasifier: 0.04 m × 0.285 m × 2.13 m-high) was designed and constructed for gasification of biomass/coal blend. In a dual circulating fluidized bed reactor, the energy generated from combustion of fuel in the riser is transferred by circulating the bed material as heat carriers to endothermic steam gasification reaction in a gasifier.

In this study, the effects of reaction temperature (50–900 ℃), steam/(biomass or coal) ratio (0.2–0.8) and biomass/blend ratio (0, 0.25, 0.5, 0.75, 1) on the gasification characteristics have been determined. Indonesian tinto sub-bituminous coal and Quercus acutissima sawdust were used as coal and biomass materials, respectively. The compositions of the product gas from the steam gasification are H2 (coal: 31.3–47.2%, biomass: 18.3–26.4%, blend: 20.1–37.5%), CO (coal: 15.6–28.3%, biomass: 32.4–36.2%, blend: 24.5–43.3%), CH4 (coal: 5.0–8.0%, biomass: 11.4–14.3%, blend: 10.3–18.5) and CO2 (coal: 28.4–34.5%, biomass: 23.5–37.9%, blend: 12.7–33.4%). The product gas yields increase with increasing biomass/blend ratio, carbon conversion and cold gas efficiency of biomass are higher than that of coal. The maximum product gas yields were obtained at the biomass/blend ratio of 0.5 and 0.75. The calorific values of the product gas are 9.9–11.2 MJ/m3 for the coal, 12.0–13.9 MJ/m3 for the biomass and 12.1–16.4 MJ/m3 for the blend of coal and sawdust. Since combustion and gasification reactions take place in a separate fluidized bed reactor, the product gas has the medium calorific value gas without nitrogen dilution.
STOICHIOMETRY ADJUSTMENT OF BIOMASS STEAM GASIFICATION IN DFB PROCESS BY IN SITU CO2 ABSORPTION


ZSW, Zentrum für Sonnenenergie- und Wasserstoff-Forschung, Baden-Württemberg, Industriestr. 6, D-70565 Stuttgart
Vienna University of Technology, Getreidemarkt 9/166, A-1060 Vienna
BKG, Biomasse Kraftwerk Güssing, Europastr. 8, A-7540 Güssing

The steam gasification of solid biomass by means of the absorption enhanced reforming (AER) process yields a high quality product gas with an increased H2 concentration and a reduced content of CO, CO2, and tars. On the basis of allothermal steam gasification in a dual fluidised bed reactor, the biomass conversion reactions are coupled with in situ CO2 removal by using a CaO-containing sorbent bed material. This bed material takes-up CO2 in the gasification zone and is regenerated in a second fluidised bed reactor by calcination of the formed CaCO3. The product gas is suitable for a wide range of applications, which covers combined heat and power (CHP) production as well as the generation of liquid or gaseous fuels (e.g., substitute natural gas (SNG), H2).
II

Gas Cleaning
COMPARATIVE ASSESSMENT OF POLYGENERATION STRATEGIES

Hansen J B, Højlund-Nielsen P E

Haldor Topsøe A/S

The Topsoe Group has for several decades developed catalysts and technologies applicable for polygeneration based on biomass. Amongst the most pertinent ones can be mentioned:

- Tar Reforming
- Ammonia Decomposition
- Shift (Sour as well as sweet)
- Desulfurisation
- Methanol
- DME
- Synthetic Gasoline
- Synthetic natural Gas

Topsoe Fuel Cell A/S is developing SOFC technology, which is uniquely suited for polygeneration schemes.

The paper will provide a comparative assessment with respect to efficiency, synergies and adaptability to different gasifier types and feedstocks.
IIo2

POX STEAM REFORMING IN A PLASMA-ASSISTED GLIDARC REFORMER

Owrang F ¹, Guitard F ¹, Rafiq H ¹, Hustad J ¹, Grønli M ¹, Czernichowski A ², Olsson J ³, Pedersen J ³

Department of Energy and Process Engineering, NTNU ¹
ECP, France ²
Arealia AB, Sweden ³

Small and medium sized reformers are frequently used for converting propane (the main LPG product) to syngas for a wide range of applications. The cost, optimal operation and especially the stability of these reformers are the most important factors. In this study, a relatively cheap small scale catalytic reformer the so called GlidArc based on high-voltage discharges, has been used for conversion of propane to syngas. The maximum energy produced in this reformer is 15 kW corresponding to the lower heating value (LHV) of the syngas produced. The aim is to experimentally study the effect of steam on stability, conversion and product selectivity of this reformer. Normally in the steam reformers, the steam is pre-generated in a steam generator before injection into the reaction zone. In this study, the steam is generated by the waste heat produced from the reformer. The gliding arc formed between two high-voltage diverging electrodes (knives) is powered by a single-phase transformer. The discharges form at the closest points of the electrodes with a very short contact time, spread by gliding along the edges of the electrodes. The arc disappears then at the end of the knives. Other discharges immediately reform at the initial spots. The high-voltage (10kV, 0.4A) self-maintained discharges strike directly across the propane, air and steam flow. The electrodes are not cooled so that all the electrical energy is directly and totally transferred to the processed gas. The syngas produced was immediately flared. The GlidArc has a double mantle structure. The inner ceramic cylinder contains a special Ni-based catalyst surrounded by the outer mantel. The liquid water at room temperature has been injected into the space between the two mantles. The water is then evaporated by absorbing the internal heat produced from the exothermic reactions in the reformer. The experimental results show the syngas quality depending on temperature, mass flow of propane and steam. Detailed mass and energy balance has been performed. The temperature and the input electrical power have been kept constant during the experiment. The effect of steam injection on the optimal air/propane vs. energy power input and the amount and selectivity of syngas produced has been calculated.
HIGH TEMPERATURE GAS TREATMENT FOR THE OPERATION OF A SOLID OXIDE FUEL CELL (SOFC)

Martini S, Kleinhappl M, Hofbauer H

Bioenergy 2020+ GmbH, Area II Biomass Gasification Inffeldgasse 21b; A-8010 GRAZ

Steam gasification of biomass delivers product gas of high hydrogen content and high volumetric energy density because of low nitrogen fraction. Together with carbon monoxide and methane this gas is expected to be an almost perfect fuel for high-temperature-fuel cells, such as SOFC (Solid Oxide Fuel Cell). By the conversion of these fuel components the fuel cell technology can be a future perspective technology for energetic conversion of product gas. High overall efficiencies combined with extremely low emissions can be expected. In a running project Bioenergy 2020+ (former Austrian Bioenergy Centre) is doing R&D since 2004. The fundamentals of high temperature gas cleaning and micro scale operation of SOFC-Reactor units are investigated under real conditions.

For successful operation of SOFC-units the characteristics of the (fuel-) product gas and the operational behaviour of the fuel cell unit should be brought together. In detail this means, that the quality of the product gas after clean up and the handling of the fuel cell application are in focus. This paper shows the high temperature gas treatment, including hot gas filtration and desulphurisation including quality analytics, demonstrated at the Güssing Biomass Gasification Plant with a side stream (5 m³/h, usc). The most relevant impurities of the gas, such as dust, tars and sulphur derivates, can reduce the capacity of the fuel cells or even damage the cells (=clean gas consumer technology). To remove these impurities from the gas the cleaning unit consists of two process units, the hot gas filtration and the adsorption.

The filtration is realised with filter candles, which can be cleaned alternately during the operation. By the filtration particulate matter (containing coarse ash, fractions of fly coke and soot) are precipitated out of the reductive acting product gas at temperatures of 300 to 800 °C. Successful operation was demonstrated under test conditions of 15 to 30 g/m³ dust load from the crude gas (usual conditions of fluidised bed gasification). The residual dust load after one continuous operating filtration stage was reduced below 5 mg/m³. Back flushing with nitrogen shows successful operation of the GST-filter candles, in the tests different operational parameters are investigated. The separation of the initial dust load and also the final clean up before the cell unit is important for successful long term operation (see below attrition from adsorption materials).

Without additional cooling in the adsorption column hydrogen sulphide and organic sulphur compounds are treated at temperatures up to 600 °C. Actually running test series are showing the behaviour (capacity, ability of regeneration) of different adsorbent materials, such as different modifications of zinc oxide, under real conditions.
In the column also combinations of adsorbent materials and staged precipitation are optional. The quality and effectiveness of this treatment is shown in concentration levels of the different sulphur components and the absolute capacity of the adsorbent used. Therefore suitable detection technology is necessary, see below. Depending on the operational temperature a residual content of hydrogen sulphur between 0,3 and 35 mg/m³ was achieved. The lowest value is held at 400°C and increased values at 550°C, when zinc oxide is used as adsorbent. These results are effected from reactive kinetics and reduced capacity at elevated temperatures. The initial load of sulphur contains about 200 mg/m³ hydrogen sulphide and 10-30 mg/m³ of different organic sulphur components. Suitable technology for sampling the quality is necessary to monitor non energetic parameter. Bioenergy 2020+ has developed appropriate equipment for sampling of standard parameter in biomass gasification product gas. The sampling and treatment procedure are done according to the Sampling guideline for particle and tars. Additional to these procedures long term experience does exist for chemical defined parameter like hydrogen sulphide. During the last year of R&D-work a semi continuous working detection method for total sulphur content has been developed. At high concentration levels the organic sulphur components are enriched in a special solvent or at activated carbon and then detected with oxygen combustion under lab conditions. At lower concentrations levels the total sulphur content is converted at the sampling location via combustion directly. The detection is operated via IC or conductivity.

Summary of current results: The side stream test rig - located at the Güssing Biomass gasification power plant - shows successful operation of the hot gas filtration and the desulphurisation of product gas to operate a SOFC-unit. The back flushing of the filter unit is tested under different conditions. Different adsorbents for desulphurisation are tested. Proper technology for detection of the sulphur content have been developed and can be concerned as crucial for the further development of clean gas consumer technologies. After the raw product gas is conditioned, a share of it (about 10 to 20 %) is used in the SOFC-reactor for operation. See for the operational results of the SOFC-technology in a detailed paper.
FLEXIBLE DRY HIGH TEMPERATURE SYNGAS CLEANING


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The properties of syngas from biogenic feedstocks are strongly influenced by the gasifier’s type and the gasification parameters. Besides the main syngas components and the H2 to CO ratio the content of particulates, tar, S- and Cl-species, alkali and heavy metals can vary strongly. The target levels of these trace contaminants with respect to syngas utilization technologies differ within magnitudes. The lowest levels have to be achieved for synthesis applications. At present syngas cleaning in atmospheric and pressurized systems is mostly performed by scrubbing preferably with physical sorbents, where the sorption capacity is proportional to the system pressure. The most important state-of-the-art gas cleaning technologies are the RECTISOL® process, a cryogenic scrubbing process with methanol and the SELEXOL® process, which uses dimethylethers of polyethylene glycol slightly above room temperature. In any case quenching/cooling before syngas cleaning and reheating afterwards to synthesis temperature is mandatory. Exergetic efficiency is poor and total gas conditioning is expensive. Thus High-Temperature (HT) or High-Temperature-High-Pressure (HTHP) gas cleaning will be optimum, either at gasifier outlet conditions or slightly above the temperature of the syngas utilization.

An innovative dry HT/HP syngas cleaning which combines HT/HP particle filtration, dry HT/HP sorption with mineral sorbents and a catalyst for the relevant trace contaminants is being developed at Forschungszentrum Karlsruhe. Operating at a uniform process temperature up to 800 °C the process line for a dry HTHP gas cleaning is based on a recleanable ceramic filter, which is combined with the dry sorption of sulfur and chlorine components. Minor contaminants, mainly NH3 and tar are to be treated in a catalyst bed afterwards. Syngas quality required for synthesis catalysts in only 2 combined stages is achieved.

The basic design and the adaptation to different gasification and syngas utilization processes will be outlined and the setup of a dry HT gas cleaning line, which is run in pilot scale at the outlet of a 60 kW entrained flow gasifier will be presented. Major investigations focus on the HT sorption of HCl and H2S in biogenic syngas by sodium and calcium carbonates and the conversion of tar at temperatures below 600 °C in lab-scale and in pilot scale. Results from sorption tests at 600 and 800 °C will be presented. The influence of the sorption material, the temperature and the raw gas concentration on the trace contaminant level achievable in the syngas are addressed. The data measured for the sorption of HCl and H2S on the minerals Trona and chalk reveal clean gas levels much below 1 mg/m³ levels even at 800 °C which confirmed equilibria calculations for typical syngas compositions. Based on SEM analysis of spent sorption materials the reaction type and process options are discussed.

Concerning tar catalysis the development and performance of a Pt based catalysts for the tar conversion at temperatures below 600 °C is presented. The conversion of Naphthalene as model tar is evaluated with the parameters catalyst support, preparation procedure, pellet size and desactivation by carbon formation. The influence of temperature and space velocity are addressed. Finally preliminary results from the transfer to a honey comb support are presented.
NOVEL BIO-SYNGAS CLEANUP PROCESS

Leppin D, Basu A, Wangerow J, Slimane R B

GTI

Syngas from gasification of woody biomass contains tars, sulfur compounds, alkali metals and ammonia. When it is desired to use this gas for chemicals synthesis such as Fischer Tropsch, methanol, DME and similar, quite severe restrictions are imposed in order to prevent the necessary catalysts in such processes from being poisoned. As this can add significantly to the cost of producing BTL, it is important to devise cleanup processes that are efficient and effective. Minimizing steps requiring cooling and then subsequent heating of the main stream are critical to this objective, and this process succeeds in that regard.

GTI has developed a novel approach using monolith tar reforming catalysts, sour shift, sulfur and trace metal removal via novel filter reactors, and acid gas cleanup, in this case CO2 removal only (optionally using a new solvent formulation developed by Uhde GmbH and GTI).

The approach will be described in detail and mechanical design of a slipstream test system for approx. 1500 SCFH (42 Nm3 per hour) will be presented. Approx. cost of a scaled up system for 100 and 500 tons of biomass gasification per day will be presented.
CATALYTIC CERAMIC FILTER CANDLES INTEGRATED IN A FLUIDIZED BED BIOMASS GASIFIER

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Keywords. Biomass Gasification, Ni catalyst, Ceramic Filter Candles, Fluidized Bed, Tar Analysis

Biomass could be successfully used in gasification considering the great potential as a renewable and CO2 neutral feedstock for producing modern energy carriers. Gasification is a thermal conversion process in where solid fuels are converted into combustible gases. The synthesis gas conditioned and upgraded may be used either to produce electricity by means of internal combustion engines and fuel cells, or to develop synthetic biofuels. However, process simplification could play a very important role to a real breakthrough in the use of biomass in general and specifically of gasification plants. Gas cleaning is normally done by filtration and scrubbing of the producer gas to drastically reduce particulate and tar content. For a better exploitation of the thermal and chemical energy of the produced gas, hot gas cleaning and conditioning systems (abatement of particulate content and tar conversion at a temperature close to the gasification temperature) should be developed and implemented. A bench-scale plant operating at atmospheric pressure is utilized in this work to check innovative, catalytic gas cleaning processes and plant arrangements. It is mainly composed of a fluidized bed gasifier with an internal diameter of 0.1 m. Olivine bed inventory is used. As it is extensively reported in the literature, this naturally occurring mineral has demonstrated tar conversion activity similar to that of calcined dolomite. Moreover, olivine is a much more robust material and has been applied as a primary catalyst to reduce the tar levels in the syngas. In order to increase the tar abatement efficiency, a catalytic filter candle consisting of a commercial hot gas filter candle with an integrated Ni catalyst was inserted into the freeboard of the gasifier. Some studies have also shown that nickel catalyzes the reverse reaction of the ammonia synthesis reaction from the elements thus reducing the amount of NH3 in the gasification product gas. Housing the whole gas conditioning system in the gasifier reduces thermal losses and allows for a very compact unit.

The continuous catalytic gasification runs have been performed in a temperature range of 800 – 900°C and the volume composition of the product gas is analyzed by means of IR, UV and TCD facilities for the online detection of CO, CO2, CH4, H2, NH3 and H2S.

Results of gasification tests performed at different operating conditions will be presented and discussed in this conference presentation.
III

Gas Utilization
Biomass is heading for a great future as renewable energy source. It not only is available in large quantities but it also is the only renewable energy source that is suitable for the sustainable production of (generally carbon containing) transportation fuels and chemicals. Due to the very wide application framework for biomass, the biomass demand in the future is expected to be enormous, which will result in increased raw biomass costs. The biomass available, therefore, has to be converted with high efficiency into a variety of products, maximizing overall process economics, and minimizing the overall negative ecological side effects.

A promising option to achieve this is to convert it on a large-scale via gasification and subsequently to co-produce a variety of marketable products from biomass. The main objective of the work described in this paper is to determine the feasibility of a system which targets to an efficient co-generation of chemicals, transportation fuels and secondary energy carriers from biomass via allothermal gasification. After clean-up, conditioning, and CO2-removal, the allothermal gasifier product gas can be used to synthesize a variety of marketable biomass based products:

- Chemicals (methanol, BTX, olefins, phenols, naphthalene, cresylic acid, fertilizers, …)
- Transportation fuels (FT-diesel, mixed alcohols, H2, …)
- Gaseous energy carriers (SNG, H2)
- Power and/or heat

Several of these products can also already be obtained as intermediate co-products during the clean-up stages, for example in the tar removal step. In this paper the benefits of a biorefinery concept are described by comparing a base case production process of Substitute Natural Gas (SNG) to different co-production process options. As the base case of SNG production on which the development of a variety of process alternatives will rely, allothermal gasification step (850°C) of the biomass is chosen. For SNG production the product gas is subjected to a series of cleaning steps for impurities removal and as a result the clean gas rich in CO and H2 is routed to a methanation step for the catalytic production of SNG.

Taking into consideration the base case, two process routes are further developed. One including the separation of value-added chemicals, such as ethylene, acetylene, benzene, toluene, xylene, tars, incorporated in the product gas and subsequent catalytic production of SNG from the rich in CO and H2 product gas. The second option differentiates from the former one on two aspects.
The first aspect concerns the production of SNG, which can be achieved either through catalytic production or by separation of CH4 from the product gas. The second aspect refers to the additional catalytic step towards production of transportation fuels or chemicals from CO and H2.

The process options developed are compared on an economic basis. More specifically, economic margins are determined for the different process options. This economic margin should enable compensation for additional capital expenditure as well as operation and maintenance of the process. The main conclusions that can be drawn is that the separation of chemicals seems to be an economically more attractive option compared to the base case production of SNG.

During the conference this economic advantage will be clarified, however will also be emphasised which developments in this thermochemical biorefinery production concept of SNG will still have to be made.
FROM SYNGAS TO FUELS – MICROREACTOR TECHNOLOGY IN FISCHER-TROPSCH (FT) SYNTHESIS

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Micro-engineering FT-reaction technology as a pretty new strategy for the generation of fuels from SynGas (gasified wood), also suitable for small and medium sized plants.

A microreactor based FT-process was developed for the optimization of fuel production from SynGas to provide a future tool, also for the local generation of FT-fuels.

The FT-synthesis provides huge exothermal heat, which makes the process difficult to control within conventional plant equipment. One promising advantage of the micro-technology is that some of the common problems in FT-synthesis, such as hot spots and heat transfer, are circumvented by the implication of a microstructured reactor. Second one is small size of the microstructured equipment which makes it easy to handle, compared to conventional equipment being used for the same throughput.

The used research-plant set up allows high flexibility in changing different important reaction parameters like temperature, pressure, gas composition, residence times and catalyst. The reactor, which is about 13x7x4.5 cm in size, consists of a stack of catalyst-coated plates. The flow rate of the research-plant is adjustable from 200 ml to 2000 ml / hr. The catalyst is adjusted on the plates by using a modified wash coat technique. Analysis of the achieved liquid products and the gas phase is done by GC/MS and micro GC.

Results demonstrate the suitability of the research-plant setup to generate a wide range of fuel fractions (kerosene 20%, diesel 80% to lightpetrol 60%, kerosene 40%), according to the adjusted reaction-parameters.

We would like to thank the Austrian Research Promotion Agency (FFG) for funding this project.
The energy demand - especially in industrialized countries - is determined by a steady increase. As fossil fuels are running out, we have to face a leak in energy supply. Moreover, fuels are even nowadays reasons for several crises like war in the Middle East. Furthermore it is misused for political strategies as it could be seen when some well known president capped the supply of Russian natural gas.

This reasons show the high importance of independence of energy supply. Austria owns a lot of energy, captured in a biological storage named wood. While every year more wood grows than can be used, this is an ideal resource for power generation and gives the possibility to get independent of fossil fuels. Besides, fuels produced from wood are carbon dioxide neutral and therefore a measure to keep money, which would have to be paid for “green certificates” that are obligate, when using fossil fuels for energy production. Using a resource that is situated all over Austria offers several advantages. On the one hand it strengthens regions economically by keeping money in the region and on the other hand socially by creating new jobs.

To convert wood in a transportable form of energy - in this case in a gaseous form - the methanisation process is the ideal option.

Gasification in an allothermal biomass power plant represents the first step of the process of thermal conversion of biomass into a synthetic natural gas. The result of this process is a nearly nitrogen-free and therefore high calorific product gas. To convert this product gas into Bio-SNG, sudden purification steps are necessary. The following methanisation process is based on a catalytic reaction. The result of this reaction is a “raw-SNG” with a methane content of about fourtysix percent. After purifying the “raw-SNG” further the gas quality is nearly similar to natural gas and can be fed into the natural gas grid or delivered to a fuel station.

A demonstration plant for the methanisation process has been built up in Güssing in the years 2007 – 2008. The first Bio-SNG was produced in December 2008. Referring to the quality of gas composition, similar results compared to these of laboratory scale could be reached with the demonstration plant. The plant has been operated successfully at a size of 1 MW power from methane. The Bio-SNG was delivered to a fuel station and tests with cars driven by Bio-SNG have been done.

The high quality of Bio-SNG enables the injection of the synthetic natural gas into the natural gas grid. The natural gas grid is well structured and reaches nearly every edge of Austria. Therefore it’s a logical step to convert wood to a synthetic natural gas – Bio-SNG.

Promising results led to interest of other countries and further projects are planed. On the basis of modelling work options for optimization of the process could be found, which will be taken into account when building up the next methanisation plant at a size of 20 MW.
The production of Second Generation Fuel out of woody biomass is one of the key technologies for the future energy supply. Concerning polygeneration, in addition to Second Generation Fuel, heat, e.g. for district heating systems and electricity can be produced. Particularly interesting is substitute natural gas (SNG). Producing SNG from woody biomass, requires conversion of biomass into a so-called syngas. Therefore allothermal gasification systems are necessary.

For the investigation of the influence the gasifier’s gas quality has on the production of second generation fuels, a lab-scale gasifier for continuous operation with a thermal input of 5kW was developed, which produces syngas with a gas composition comparable the syngas of existing allothermal gasification systems. Compared to common lab-test, where a syngas mixed together out of bottled gas is used, the gas from the small-scale gasifier contains sulphur components, condensable alkalis, nano-particles and condensable higher hydrocarbons (tars). Furthermore this device allows to vary the syngas composition in order to meet published gas compositions of operating allothermal gasifiers. This is possible due to the use of electrically operated tube furnace, which provides the heat for the reforming of the biomass and a electrically heated steam generator. The heat, transferred from the electric furnace to the reformer, regulates the gasification temperature; the applied steam massflow determines the stoichiometric steam ratio. Both parameters, because of Le Chateliers principle, influence the product gas composition and therodynamical equilibrium. Higher gasification temperatures are shifting the product gas composition to the educts, e.g. lead to higher hydrogen and carbon monoxide concentrations. An increased stoichometric steam ratio will, if the vapour-content in the productgas is fully condensed, cause high hydrogen concentrations. The reactor vessel is carried out as a stationary fluidised bed; due to the good heat and material transfer in such systems a very compact gasifier design is reached. For particle removal a two-stage system that works on a temperature level of 500°C is installed. In the first stage coarse particles are removed by means of a cyclone separator, the second stage filters fine-particles by means of a sinter-metal filter cartridge. Due to the pressurized operation, there are no additional compressors necessary for gas transportation. Overcoming the pressure drop of aggregates eventually used downstream is easily possible. Furthermore the lab-scale gasifier is equipped with intelligent systems for measurement and control, so the remote access to the plant can be reached with standard cell phones. One of the main challenges dealing with SNG production out of biogenous syngases is the field of gas conditioning. Tars, generated while gasification as well as sulphur compounds resulting from the used biomass, lead to a deactivation of the catalyst used to convert the productgas into a methane-rich gas. This step of conversion is called methanation.
Present allothermal gasification systems are using a gas cleaning system, based on a pre-coated filter cartridge combined with a rapeseed oil methyl ester (RME) scrubber. In the EU-project “BioCellus” a hot gas cleaning system was developed which is used to absorb sulphur compounds as well as to reform tars catalytically. Both concepts have the disadvantage, that for the gas cleaning high a technical effort is necessary, that results in high specific investment costs. How far the methanation of an uncleaned, particlefree productgas influences the catalyst’s lifetime e.g. the methane yield is unknown.

Due to the reduced specific investment costs, there is, with expectable catalyst lifetime, an economic plant operation, even with a periodic catalyst change, achievable. To study the effect of the catalyst poisons mentioned above, a methanation test rig, with a plant capacity adapted, to the gasifier was designed. The catalyst used for methanation is hereby arranged in a horizontal fixed bed reactor, whereas the direction of the flow is bottom up. To get better comparable measurements, is has to be assured that there are isothermal conditions in the reactor. Because of the fact that the process of methanation is strongly exothermic, it is a challenge to heat on the one hand the zones of the reactor where no methanation occurs and, on the other hand, to cool zones where heat has to be removed. To get rid of this effect, the test rig is equipped with an electric tube furnace that is separated in two independent heating zones and, for cooling, with a gap between the outer wall of the reactor and the inner wall of the furnace that is rinsed with air.

The paper proposed will show measurement data of the various operation modes of the TU-Graz lab-scale gasifier. It will further present results of the methanation tests with tar, and sulphur containing productgas.
Studies have indicated that producing fuel from lignocellulosic biomass offers the best opportunity for reducing life cycle greenhouse emissions. Furthermore, the most efficient route today to convert biomass is gasification and Fischer-Tropsch (FT) synthesis; resulting in approximately 90% less life cycle greenhouse gas emissions than petroleum derived fuel. Producing synthetic fuels from biomass presents a number of new challenges, including the need to economically reduce the size of facilities to match the quantity of biomass that can logistically gathered in one location. The concept of producing synthetic fuels in compact units hinges on the ability to scale-down reaction hardware while maintaining sufficient capacity. Systems based on microchannel process technology have been shown to greatly reduce the size of chemical hardware.

In 2007, Toyota commissioned a life cycle analysis of alternative fuels. This well-to-wheel study compared petroleum derived fuels with a wide range of alternatives ranging from traditional biodiesel (FAME) to ethanol to FT synthetics derived from biomass, coal and natural gas. The two fuels that performed best in this study were ethanol from sugarcane and FT synthetic diesel from biomass. Both of these fuels were shown to result in a 90% reduction in greenhouse gas emissions compared to gasoline derived from oil.

The core technology for synthetic fuel production, FT synthesis, has been practiced for decades; however, this has occurred in world-scale gas-to-liquids (GTL) or coal-to-liquid (CTL) plants. In these facilities, the slurry and fixed bed reactors are much larger than the sizes needed for biofuel facilities and are limited by heat or mass transport performance. Microchannel reactors, which have thousands of parallel arrays of process channels in the 0.25 mm to 5 mm range, overcome these limitations and increase reactor productivity by 10 to 15 fold over commercialized FT reactor technologies. Capital costs, operating costs and size are all reduced.

A pilot scale microchannel FT reactor, utilizing an advanced catalyst supplied by Oxford Catalyst of Abingdon, UK, recently passed 4,000 hours time on stream. Single pass conversion of carbon monoxide (CO) at commercial conditions was over 70%, and selectivity to methane was well under 10%. The pilot reactor produced over 8 liters per day of high quality distillate and waxes from a pressurized stream of synthesis gas, with a CO to H\textsubscript{2} ratio of at 2:1. These results provide a high level of confidence as final preparations are made for a small commercial scale demonstration that is to be conducted in conjunction with the U.S. Air Force, which has a goal of replacing half of its petroleum based fuel with synthetic fuels by 2016.
Biomass-derived Dimethyl Ether is a promising second-generation biofuel. However, the complete process chain for the production of DME from synthesis gas obtained by wood gasification has not been investigated sufficiently, especially at a large scale. To evaluate possibilities of DME in the future biofuels market, it is necessary to tackle this knowledge gap. This is the aim of our present modelling work.

Two different large-scale production concepts were developed. These concepts are based around wood gasifiers and single-pass DME synthesis reactor. For efficiency purposes, a gas turbine is incorporated to produce electricity from unconverted synthesis gas. The main differences between the two concepts are the two gasifiers adopted. Specifically one uses a steam blown atmospheric circulating fluidised bed (CFB) gasifier in comparison to a pressurised (CFB) gasifier utilising a mixture of steam and oxygen as gasifying agents used in the other. The atmospheric gasifier (concept 1) has been developed by Taylor Biomass Energy, the pressurised (concept 2) is the so called Värnamo-Gasifier, but already incorporating all modifications planned by the Chrisgas-Project. These gasifiers were chosen to look at the influence of different H2/CO-Ratios. For comparability purposes a capacity of 60 MW fuel input was defined for both gasifier concepts.

The process chain for synthesis gas cleaning comprises of a catalytic tar reformer, followed by a metallic filter, a sulphur guard bed with ZnO as adsorbent and an amine scrubber for CO2-Separation. The synthesis gas then needs to be compressed to meet the synthesis pressure of approximately 50 bar.

The H2/CO-Ratio of the syngas fed to the DME slurry reactor was about 2.5 for concept 1 and nearly 1 for concept 2. However, the specific quantity of gas produced was seen for the Värnamo-Gasifier as being greater due to the different gasification technique employed.

The results of our simulation showed, that 600 kg/h (equivalent to 4.9 MW) or 1 040 kg/h (equivalent to 8.6 MW) DME could be produced from concept 1 and concept 2 respectively from 16 260 kg/h of Woodchips (25% moisture content), which is equal to 60 MW. Concept 1 requires additional input of 7.3 MW of electric energy, while concept 2 only requires 5.6 MW electricity. However, the reduced DME output is compensated in terms of efficiency by the production of additional electricity (23.5 MW for concept 1 and 21.4 MW for concept 2). Overall, this results in a high efficiency of biomass utilisation (42 % and 46 %, resp.) without trying to maximise DME yield.

Finally, economics of these two concepts were investigated. The investment costs for concept 2 were considerably higher than for concept 1, which can be accounted to higher costs of pressurised gasification. This disadvantage of concept 2 ultimately leads to better overall profitability of concept 1.

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IV

Life Cycle Analysis, Simulation and Techno Economic Studies
The main aims of energy politics are the reduction of greenhouse gas emissions, the reduction of local pollutants (e.g. PM10), the reduction of fossil energy use and the increase of energy efficiency and the use of renewable energy. The polygeneration of transportation fuels (e.g. FT-fuels, SNG) in combination with electricity and heat via the gasification of wood offers the possibility to meet these goals at the same time. High energy efficiencies of more than 80% from biomass to useful energy can only be reached by polygeneration.

Based on the detailed techno-economic layout of polygeneration plants integrated in existing infrastructure in Austria life cycle assessments were made to identify the environmental benefits and impacts from polygeneration plants compared to conventional fossil energy systems and gasification systems for transportation fuels only (“single product systems”). The life cycle assessment (LCA) includes all processes, which influence emissions and energy consumption from cradle to grave. It starts with the raw material production (e.g. collection of forest residues, cultivation of energy crops) and ends with the supply of useful energy at the consumer site (e.g. transportation service, space heating, electricity) including all transportation and conversion processes.

The biomass fuel input of the investigated plants ranges between 20 MW (mini), 50 MW (small), 100 MW (medium) and 500 MW (large). Different raw materials (feedstocks) were considered e.g. forest residues, straw, short rotation forestry. In total 30 different polygeneration systems were analysed, which were compared to fossil and biomass based energy systems e.g. natural gas, gasoline, biodiesel, biogas, bioethanol. The following five environmental impacts were quantified: fossil primary energy consumption, greenhouse effect (CO2, CH4, N2O), acidification (SO2, NOx), eutrophication, ozone formation (NOx, NMVOC, CH4, CO) and particle emissions.

As an example the results for the FT-fuel production of 200,000 t/a in two different plant types: a central plant with 500 MW thermal capacity fuel input (“single product system”) and five decentralised plants with 100 MW thermal capacity fuel input per plant (“polygeneration system”) in comparison to gasoline and diesel.

For this case the LCA results show, that FT-fuels, a mixture of gasoline and diesel, compared to fossil transportation systems reduce greenhouse gas emissions and primary energy consumption.

The contribution to acidification, to ozone formation at ground level, to particle emissions and
to the material consumption is higher for FT-fuels than for fossil fuels. FT-fuels have smaller green house gas emissions and smaller fossil primary energy consumption compared to the biofuels (e.g. biodiesel, bioethanol, biogas).

The results in detail for greenhouse gas emissions per passenger car km for systems with EURO 6 passenger car with internal combustion engine are: Diesel 196 g CO2-eq/ km, FT-diesel 60 - 66 g CO2-eq/km, biodiesel from rape seed 125 g CO2-eq/ km, petrol 242 g CO2-eq/ km, FT-gasoline 63 - 71 g CO2-eq/km, bioethanol from wheat 203 g CO2-eq/ km, biogas from corn silage 132 g CO2-eq/km.

The basic work for this paper was done in projects funded by the State of Styria, Ministry of Transport, Innovation and Technology (BMVIT), OMV and Österreichische Bundesforste. The project partners were JOANNEUM RESEARCH, Graz University of Technology, Vienna University of Technology and the Austrian Bioenergy Centre.
GASIFICATION AND GREEN GAS DEVELOPMENT IN THE NETHERLANDS

van Asselt W A

SenterNovem, agency of the Dutch Ministry of Economical Affairs

Overview of development of the production of greengas in The Netherlands and the status of gasification.

Contents

1. Dutch ambitions on renewable energy
2. The Dutch energy system
3. Approach Green Gas discussion
4. Stimulation programms and actual situation on Green Gas including gassification of biomass
5. The future?

1. Dutch ambitions on renewable energy:

policy target up to 2020
20% renewable energy
30% emission reduction of green house gases
(reference 1990)
2% energy saving yearly
Total GHG emission in 2020:
150 Mton CO2-eq
Governemental plan: “Schoon en Zuinig” published sept. 18th; 2007

2. The Dutch energy system

Natural gas since 1965
Yearly Energy consumption Natural Gas 1500 PJ
Qualities:
-- Groningen gas (L-gas)
-- H gas
Transport: HTL- 67 bar
Regional: RTL- 40 bar
Local : 8 bar
135,000 km pipe line, 94% of houses connected to gas grid and International grid connections
3. **Approach Green Gas discussion**

Short term target: Replacement of natural gas by upgraded biogas 1-3%
Midterm target: 8-12% replacement of natural gas in 2020
(4 billion Nm3/y), inclusive SNG production from biomass
Long term: Upscaling to 50% replacement of natural gas by green gas in het gasgrid

4. **Stimulation programs - Actual situation on Green Gas including gassification of biomass**

20 years of experience with upgrading landfill gas production with grid injection
Two new upgradings plants as pilot plant since 2006-2008
- Beverwijk (sewage sludge; 80 Nm3/h natural gas quality)
- De Marke
(pilot 15 Nm3/h)
About 10 plants in direct preparation and in planning (2009): capacity range: 40 Nm3/h-700 Nm3/h
20-30 in capacity range:
200 Nm3/h – 3000 Nm3/h
Research and results on gas quality and injection in local (8 bar) and regional (40 bar) gasgrid
Development of certification system for greengas (greencertificates)

5. **The future?**

Big potential for SNG production
Import of biomass will be necessary with increasing number of natural gas replacement
(harbors locations preferend locations)
Focus on SNG as a flexible fuel (power generation / storage in old gasfields)
Not only need for SNG but partly Syngas quality is required for industrial purposes
Many claims and possibilities have been promoted for Biomass To Liquids BTL concepts. Conventional thinking is that BTL plants need to be very large to be economic with a minimum economic size of 25000 bbls per day or 1.1 million t/y hydrocarbon fuels. This would require between 5 and 7 million t/y biomass on a dry basis. The logistics of financing, building and operating such a biomass based plant are very considerable.

In order to address these concerns, a number of alternatives are being considered including downscaling, de-severitising process conditions, higher energy density gasification feedstocks, and integration into a conventional refinery.

This paper focusses on the pretreatment of biomass by fast pyrolysis to give a higher energy density liquid that can be transported, handled and gasified more easily than solid biomass, but with a performance and cost penalty associated with the fast pyrolysis pretreatment step.

The advantages and disadvantages of solid and liquefied biomass for gasification feedstock for BTL are discussed and overall process performance and cost analyses presented.
SMALL-SCALE GENERATION OF SUBSTITUTE NATURAL GAS

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Dezentralized Generation of Substitute Natural Gas allows an exceptionally efficient conversion of biogenous feedstock. In particular local use of the processes waste heat increases the total efficiency of the polygeneration. Exceptionally favourable is the combination of pressurized steam gasification in combination with hot gas conditioning and methanation. Pressurized gasification enables condensation of the syngas' steam content at high temperatures. Similar to condensing boilers the heat-of-condensation increases the total process efficiency significantly.

The paper will present the Agnion Methanation and Polygeneration concept. The concept bases on the Agnion Heatpipe Reformer Technology and comprises pressurized steam gasification at 5 bars in combination with an integrated gas conditioning and methanation. The paper will present the Agnion technology and operational results of Agnions the first 500kW pilot plant in Pfaffenhofen, Germany. It will present applications, efficiencies and economics of the technology for decentralized applications in the thermal range below 1 MW.
BIO-SNG CONCEPT DEVELOPMENT WITH FOCUS ON ENVIRONMENTAL ASPECTS

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Worldwide many countries are motivated to explore alternative energy sources due to strongly varying prices for fossil fuel energy, energy supply security and environmental consciousness (especially related to climate change). Against this background the interest in biofuels has increased significantly over the past years in industrialised as well as in developing countries. Due to high overall efficiencies, especially the thermo-chemical conversion of solid biofuels into the natural gas substitute Bio-SNG (Synthetic Natural Gas) seems to be a promising way for the energetic use of solid biofuels. However, this conversion process consisting of i.) biomass pretreatment, ii.) biomass gasification, iii.) raw gas cleaning, iv.) methanation and v.) raw Bio-SNG upgrading is currently at pilot/demonstration stage and therewith still characterised by optimisation potential regarding the choice of process components. Within this context especially the specific greenhouse gas emissions related to different plant components are of particular interest.

To give advises for a reasonable Bio-SNG plant design (assuring high overall efficiencies as well as low greenhouse gas emissions), different Bio-SNG plant components have been analysed and compared from a technical and environmental point of view under uniform frame conditions. Calculations concerning the CO2-equivalent emissions based on process modelling with regard to mass- and energy-balances form the main part of the analysis. Thereby, influencing factors as methane losses, heat consumption as well as electrical power consumption are included and specific CO2-equivalent emissions are assigned.

Against this background especially the gas cleaning components have been identified to be of major influence on the CO2-equivalent emissions released throughout the overall Bio-SNG provision life cycle: Depending on the gas cleaning system the specific greenhouse gas emissions of Bio-SNG provision vary in a range of approximately 33 - 39 kg CO2-Eq per GJ Bio-SNG.
BIOMASS GASIFICATION FOR AMMONIA PRODUCTION

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109 million tonnes of ammonia is produced globally each year, 85% of this is synthesised from combining H₂, produced from steam reforming of natural gas, and nitrogen separated from air. The process is very energy intensive and releases 208 million tonnes of CO₂. Production of ammonia from renewable resources, such as biomass, could substantially reduce this. One option is to gasify biomass to produce a hydrogen rich syngas for ammonia production. This paper reviews currently available gasification technologies to assess the viability of ammonia production using this method, and identifies those most suitable for further analysis. The gasifier selection is based on the following criteria: syngas composition, efficiency, operating conditions, scale and biomass track record. Potential process schemes are presented with preliminary mass/energy and greenhouse gas balances to estimate the potential value of developing such a system. Critical issues in the overall system from biomass cultivation to ammonia production, which need to be evaluated further via economic and life cycle assessment techniques, are identified.
V

Small and middle scale Gasifiers
- from experiment to Practice
EXPERIENCES AND RESULTS DERIVED FROM THE GASIFIER AT THE TUV

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Gasification is an upgrading process for solid biomass to produce a valuable gas which can be used for a large variety of applications. Steam gasification leads to a nitrogen free producer gas with a low tar content and a high hydrogen content. Fluidized bed technology is well known for high fuel flexibility and can therefore used for a lot of different biogenous fuels. By choosing a dual fluidized bed configuration an air separation unit could be avoided which is normally necessary for a nitrogen free gas. This leads to an interesting technology also for medium sized gasification plants and therefore most suitable for biomass.

The steam blown dual fluidized bed gasification process has been developed during the last fifteen years using cold flow models, laboratory units, and mathematical modelling and simulation. A lot of knowledge could be obtained from these research and development tools in order to be able to scale up this gasification process. This led to a demonstration plant with a fuel capacity of 8 MW located at the city of Guessing, Austria. This plant is dedicated for combined heat and power production using a gas engine with an electricity generator. However, the steam blown gasification process offers a wide variety of applications which are currently investigated at Vienna University of Technology. Besides heat and power production via gas engines, gas turbines or fuel cells also gaseous and liquid fuels can be produced. Biofuels are worldwide of increasing importance as certain amounts are politically required. Such biofuels can be produced by generating a synthesis gas via biomass steam gasification and further synthesis to biofuels. Biomass to liquids can be obtained by Fischer-Tropsch synthesis (BioFiT) and gaseous biofuels (BioSNG) by methanation reaction. Finally, the production of a hydrogen rich gas and even of pure hydrogen from biomass is a future option.

Such future applications need increased fuel flexibility. Thus, different methods for increasing the feedstock basis and to improve the gasifier performance were studied using a 100kWth process development unit. Several fuels (wood chips and pellets, straw, sewage sludge, lignite, coal etc.) have been tested and the influence on tar content, tar composition as well as gas composition was measured and compared among themselves. Moreover, different bed materials (olivine, calcite, silica sand etc.) have been applied and their influences on the gas quality have been determined. As further development the bed material is replaced by a reactive CO2 absorbent material (lime) and the gasification temperature is reduced to temperatures below 700 °C in order to enable CO2 chemisorption. By this in situ measure, the product gas quality is improved and its composition can be adjusted according to subsequent product gas applications (combustion, synthesis gas, H2 production, etc.).

Summarizing, the dual fluidized bed system offers an excellent fuel flexibility to be used in advanced power cycles as well as in future liquid/gaseous fuels production systems.
DESIGN, CONSTRUCTION AND OPERATIONAL EXPERIENCES WITH A 3 MW TORBED WOOD GASIFIER IN THE NETHERLANDS

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Polow Energy Systems

A Dutch SME company dries residues from the food industry (e.g. production waste from bakeries, out of date products) for fodder applications and was facing difficulties in answering to the regulations concerning smell and emissions of hydrocarbons from their natural gas-fired dryer.

Polow Energy Systems designed, constructed and tested a wood-fuelled gasifier integrated into the existing drying process and the newly installed incinerator. By using the wood gasifier as a substitute for the existing natural gas burner the client did solve his regulation problems with the authorities and achieved a considerable reduction on the use of natural gas. Natural gas is now only used as back-up system.

The fuel gas from the wood gasifier is used to fire the incinerator, to abate the smell of the clients drying operation, and produces at the same time the heat for the drying process, using an air-to-air heat exchanger to transfer the energy from the exhaust of the incinerator to the drying air.

The gasifier is based on the Torbed technology, which consists basically of a cylindrical reactor in which the process air with recirculation gases are thoroughly mixed together with the wood fuel, thus producing a syngas which than is used as fuel in the incinerator. The turbulent, rotating movement created by air respectively recirculated syngas inside the reaction chamber creates a very intense contact between process air, syngas and the feed material, which yields a highly efficient and quick heat and mass transfer. This feature allows for the system to handle a wide variety of biomass products (e.g. forest- and agricultural waste) and to efficiently and expeditiously transition to a variety of renewable products. The following are the advantages of the technology:

- Rapid combustion and gasification capabilities
- No residential bed necessary, the biomass forms the bed
- High controllability, turn down ratio’s virtual infinite
- No moving parts inside the reactor and therefore very low maintenance cost
- Simple up scaling
- Compact installation
- Relatively low investment needed
Table with design and operational data on the gasification process:

Drying capacity of rotary killn in kg/h water evaporation: 3.500 kg/h
Operational hours: 4.000 h.p.a.
Fuel quantity (wood chips): ~ 800 kg/h
Moisture content fuel average: ~ 12 wt %
Dimensions for fuel (desired): max. 70 x 10 mm
Drying temperature at begin of killn: max. 500 °C
Fuel gas composition: CO, H2, CxHy, CO2 balance N2: 14/6/3,5/14 vol %
Total tar content according to measurements ECN: < 3 g/m3
Stack temperature: ca. 180 °C
Investment in wood gasifier, excl. wood preparation: 1,2 Mio €
Savings on natural gas: 300 m3/h

The gasification plant was taken into operation late in 2007 and after a number of modifications is now operating satisfactorily. An overview of the operational data and experiences will be described.

Several new gasification projects are in preparation.
PRELIMINARY RESULTS WITH A 450 KWTH BUBBLING FLUIDISED BED GASIFIER

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A pilot scale biomass gasifier to produce heat and electrical energy has been designed and operated within the frame of a nationally funded project led by TUBITAK Energy Institute and supported by Turkish universities.

The system consists of two bubbling bed reactors; the bigger one for gasification, the smaller one for combustion. The latter is necessary to supply the heat needed for endothermic gasification reactions to achieve allothermal operation conditions. The gasifier can be run with or without the combustor. In the latter case, the necessary reaction heat is supplied by gas burners. The gasification is capable to be run on air, oxygen and steam. Allothermal operation is chosen for steam gasification.

The capacity of the gasifier is 450 kWthermal. Bubbling fluidised bed gasification regime is chosen. The bed diameter is 450 mm and the bed height above the distributor plate is 6000 mm. The combustor height is 5500 mm and has a square cross section (260 mm). The design feeding capacities are 120 kg/h and 50 kg/h for gasifier and combustor, respectively. The bubbling fluidised bed gasifier has three feeding ports above the distributor plate. Hence, it can be fed with different feedstocks such as biomass, coal, additives, etc. Feedstocks are carried pneumatically. Each feeding point consists of one silo and two interconnected screws, the first one to adjust the flow rate, and the second one to achieve homogeneous feeding to the gasifier. The average particulate size is 1-2 mm; the design allows runs with particulate sizes up to 5 mm. The gas cleaning system consists of a cyclone for particulate removal, a heat exchanger for cooling of the product gas, a scrubber for tar removal and a wet electrostatic precipitator and fabric filter for final clean-up. Different scrubbing solvents will be tested. The clean product gas is to be fed to a gas motor at 50 kWe capacity.

This study presents the preliminary gasification results with hazelnut shells. In this study, the product gas is not fed to the gas motor; it has been analysed with on-line gas analyser and GC, and burnt in a flare. Preliminary test have been done at different equivalence ratios and bed temperatures. Temperature has been monitored along the whole gasifier height along with pressure. It can be concluded that the designed bubbling fluidised bed gasifier system can be run with hazelnut shells without any problems, and produced a gas of acceptable composition. The next step will be to connect it with the gas clean-up unit.

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Vo4

‘ANKUR’ BIOMASS GASIFICATION TECHNOLOGY - FIELD EXPERIENCES

Dr. B.C. Jain – Managing Director

Ankur Scientific Energy Technologies Pvt. Ltd.

Ankur Scientific from India has been in the business of Biomass Gasification for almost two decades now. Over the years, the company has been developing and fine tuning the technology of Biomass Gasification for a variety of applications, using a wide range of feedstock. The company has also installed the largest number of small and medium rating Biomass Gasifier Systems in the world with total number of installations adding up to over 900 systems. The applications have included thermal energy as well as electricity generation - in both dual-fuel and 100% gas mode. The systems currently on offer commercially cover the range of 5 kg / hr to 2,000 kg / hr of biomass being processed in a single gasifier unit with power outputs of 5 kW to 2,000 kW and oil replacement capability of upto 600 ltrs / hr.

The paper describes the basic technology developed at Ankur Scientific which is driven by the guiding principles of simplicity and cost-effectiveness. A variety of applications as well as specific system installations are covered including the following:

- Rural / Island Electrification through dual-fuel and 100% gas systems with output ratings of 4 kW to 1,000 kW.
- Captive power for industry, again in both dual-fuel mode as well as in 100% gas mode with the company having over 250 installations using rice husk as feedstocks.
- Biomass Gasification Systems in grid-fed mode, including those in Europe.
- A wide range of thermal applications with institutions and industry.

The paper goes on to describe the active and sustained R&D culture of the company including substantial efforts to ensure use of a wide range of feedstocks in a given gasifier design. An effort is made to bring out experiences from the field, both positive and negative, with a view to plan strategies that could lead to wider acceptance of the technology. Potential major growth areas are then identified along with the barriers in achieving the vast potential that this technology promises.
VI

Poster Session
A PRELIMINARY STUDY OF SINGLE TUBE FISCHER-TROPSCH REACTOR

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A very effective method of utilizing landfill biogas is to convert its methane to a second generation biofuel via Fischer-Tropsch synthesis. Air reforming is a cheap way to produce syngas but it may lead to formation of syngas diluted with a large amount of CO2 and N2. However, the stability of the Fischer-Tropsch reactor run by such a diluted syngas can be questioned. Literature studies conducted on the Fischer-Tropsch synthesis with N2 and/or CO2 diluted syngas are scarce.

Laboratory Fischer-Tropsch synthesis with different syngas compositions and/or catalysts is normally performed in relatively small electrically heated fixed bed reactors. A drawback with these reactors is that the heat produced in the tube may not be effectively removed. Limited studies on relatively larger oil-cooled tube reactors have also been performed with the aim of modeling the chemical reactions.

The aim of this work is to study the Fischer-Tropsch synthesis of a N2/CO2 diluted syngas supposed to be produced by reforming of landfill biogas in a GlidArc-assisted POX reformer using air as oxidant over a commercial Co-based catalyst on Al2O3. The laboratory Fischer-Tropsch reactor is a double-mantled single-tube reactor where the temperature is regulated by high-pressure saturated water/steam. Besides the thermal stability, the advantage of this reactor is that it is possible to develop commercial catalysts in an environment which resembles a real FT-reactor in future. In this way, the catalyst and the reactor can be optimized in a combined fashion. The special emphasis was put on the stability of the reactor, continuous conversion of CO and production of liquid hydrocarbons.

The cobalt catalyst was activated in-situ using pure H2 at 2 bars. The linear gas velocity was relatively high to remove the H2O produced during the process. H2O has been regarded as an important factor which sinters the cobalt catalyst in a Fischer-Tropsch reactor.

Thermodynamic parameters such as temperature, volume flow rate of syngas (but not the pressure), were kept constant. The temperatures in the bulk of the cooling medium and on the outer part of the reactor wall were measured accurately. The reactor was also tested at low pressures because a plasma-assisted GlidArc reformer produces syngas at max 6 bars.

In spite of the fact that the current thermodynamic parameters are not optimal for the reactor, the results clearly show that it is possible to convert a CO2 and N2 diluted syngas to liquid hydrocarbons. The GC/MS chromatograms indicate the production of a wide range of hydrocarbons (C5-C23) that encompasses diesel fuel fractions. The high CO conversion in the Fischer-Tropsch reactor indicates that the feedstock recycle can be avoided.

In order to scale up this single tube research reactor to a multitubular reactor, future works should be focused on the detailed measurement of heat transferred from the reactor tube into the cooling media.
Three commercially-available biomass fuels, made of natural and waste wood, were fed in a pilot plant bubbling fluidized bed gasifier, having an internal diameter of 0.381m and a maximum feeding capacity of 100kg/h. The experimental runs were carried out at about 850°C and under values of the equivalence ratio between 0.20 and 0.30. The fluidized bed was generally made of natural olivine even though some runs utilized beds of dolomite or quartz sand. The results indicate that the air gasification process is technically feasible with all the biomass tested. The role of olivine as tar removal bed catalyst provides different results with waste and natural biomass fuels.
BIOMASS GASIFICATION IN ATMOSPHERIC FLUIDISED BED: IRON CATALYST FOR TAR REMOVAL AND SUBSTITUTE NATURAL GAS (SNG) PRODUCTION

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Introduction

Green “methane gas”, also called Substitute Natural Gas (SNG), can be used for all applications that are already known for natural gas. The producer gas contains tars, which cause serious problems downstream the gasification process, e.g. corrosion in equipment and blockage of pipes. The double aim of the study is to reform tar without breakdown of existing methane and to produce as much methane as possible.

Several gasification experiments have been performed in the KTH atmospheric fluidised bed gasifier. The aim was to explore the performance of different kinds of metallic iron catalysts. In previous works at KTH it has been established that metallic iron has a pronounced ability to decompose tars that originates from the gasification process. The decomposed tars normally enhance the gas yield and the concentration of permanent gases as CO, CO2, H2 are increased. The reason why metallic iron is of interest in this study is because it has been observed that the methane concentration is more or less unaffected during the passage throw the catalyst bed. Consequently it may be possible to employ a metallic iron catalyst to increase the permanent gas yield and at the same time keep or perhaps increase the methane concentration.

The results from this study confirm the trend as for keeping the methane concentration unaffected and to some extent the tar decomposition result in an increased gas evolution. Three different commercial iron-based catalysts were tested for tar removal in a produce gas from an atmospheric fluidized bed biomass gasifier. The catalysts were provided by Höganäs AB. All catalysts provide a similar activity.

Materials and Methods

The gasification experiment was performed in a fluidised bed gasification system. Its major components are: a fluidized bed reactor, a biomass feeder, a ceramic filter and a catalytic bed reactor. The cool, dry, clean gas product was measured with a gas chromatograph (Model Shimadzu, Japan), equipped with a flame ionization detector (FID) and a thermal conductivity detector (TCD). The tar sampling and analysis was accomplished using the solid phase adsorption (SPA) method. The fuel, Swedish birch with a particle size of 1-2,5 mm, was fed into the hot bed with a screw feeder that operates continuously at 0,22 kg/hour. The bed, consisted of silica, was heated to a temperature of 850 °C in all experiments.
The temperature in the catalytic bed reactor was varied between 700 and 850 °C.

Free types of iron (A, B, C, D and E) from Höganäs AB (right now the information is confidential) were introduced as catalysts for tar cracking. The catalysts used have been described and characterized (BET surface area and concentration of C, N, O and S).

Results and Discussion

Several gasification experiments have been performed. The tar content and the gas composition have been monitored. The results confirm to some extent the expectations. The most effective catalysts under prevailing conditions is the A and C type. This is also in accordance with theory since these two types has the largest surface area. Although the differences between the five types of catalysts tested are in the region of 10 %.
BIOMASS SELECTION FOR THE TEST CAMPAIGN AT THE UNIQUE PILOT PLANT

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A 1 MWth pilot plant for efficient CHP and power production via biomass steam gasification is under development within the European project “UNIQUE”. The project is funded under the 7th Framework Programme and is intended to the production of a high purity syngas by integrating the gasification fluidised bed and the hot gas cleaning & conditioning system in a single reactor vessel.

To the aim of identify the more interesting biomass to be used during the test campaign, feedstocks of different origin were taken into account. A preliminary selection was made on the base of the potential availability of biomass on a large scale. A total of 18 samples, some of which provided by partners, were then considered for their further characterisation with respect to: ultimate and proximate analysis, heating value, major and minor elements. On the basis of the experimental data collected, all samples were compared and a reduced number of materials were delimited.

As regards this aspect, particularly useful were found the data on sulphur, chlorine and heavy metals. Biomass such as: poplar, oak, almond shells and pine seed shells were finally identified as the feedstock more interesting to be used at the pilot plat.

An overview of the overall data and procedure adopted for the biomass selection is reported in this paper.
In an updraft gasifier the feedstock is fed from the top, while the gasification agent is introduced from the bottom, so that the gaseous stream flowing upward, in the counter-current direction. The biomass particles travels downwards progressively trough zones of drying, pyrolysis, reduction and combustion. Thanks to the excellent energy exchange within the fixed bed which allows the gaseous stream to exit the gasifier at a low temperature, the gasification process is characterised by a high thermal efficiencies.

The product gas mainly consist of gaseous fuels such as: carbon monoxide, hydrogen, methane and light hydrocarbons, but also gases such as: carbon dioxide and nitrogen are typically present in significant amount. Because of the counter-current configuration, the product gas is also characterised by a high tar content, char and fly ash particles. All components (gas, tar and particles) are together present in the stream at the exit of the gasifier; their relative abundance depend on the gasification agent and the operating conditions.

The objective of the present work has been the development of a complete model, as simplified, useful to design and implement a small scale pilot plant, and able to describe the overall updraft gasification process. The plant to which the model is intended, is based on an updraft gasifier and is supposed to be fed with 50 kg/h of a biomass/RDF mix.

To the construction of the most useful model, both literature and experimental data have been considered. A flexible model have been set up by using the commercial software ChemCad (Chemstations, Inc). The expected performance of the updraft gasifier have then been simulated and evaluated with respect to gas composition and thermal efficiency.

By a sensitivity study it has been possible to evaluate how the gas composition changes by varying the operating conditions. Effect of the changing on biomass/RDF and Air/steam ratios on the gas composition has been simulated. It has been calculated that, at the highest biomass/RDF ratio by using air as a gasification medium, the composition of CO and H2 at the exit of the gasifier is expected to be 25 and 15 % vol, respectively. However, by using a steam/air mix, the expected composition of CO and H2 is 20 and 21 % vol, respectively.

The gas cleaning section of the plant is a biodiesel scrubber and two coalescer filters in series, therefore concerning the evaluation on the thermal efficiency of the plant, by including the performance of the two equipments into the model, a thermal efficiency of 80% and a thermal output of 150 – 200 kW have been calculated.
CATALYTIC CONVERSION OF VEGETABLE OILS TO HYDROCARBONS IN A CONTINUOUS FCC-PILOT PLANT

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Fluid Catalytic Cracking (FCC) is one of the most important processes to produce gasoline. The main objective of the presented investigation was to add vegetable oils to vacuum gas oil (VGO, the standard FCC feed) in order to contribute to a reduction of CO2 production from fossil fuels.

The experimental test program was conducted in a fully continuously operated FCC pilot plant with internal CFB-design at Vienna University of Technology. Vegetable oils with the highest global production (rapeseed oil, soy bean oil and palm oil) were mixed in steps of 20 percent (m/m) with the common feedstock. Its influence on the cracking process as well as the obtained products was investigated. During the experimental work it was accomplished to conduct test runs with pure vegetable oil as feedstock.

Vegetable oils are composed of triglycerides (esters) with oxygen in the oxycarbonyl-group between the glycerine-molecule and the fatty acid, while VGO is a mixture of different hydrocarbons like paraffins, naphthenes and aromatic hydrocarbons. It could be shown, that the addition of vegetable oil to the feedstock has no significant influence on the routine operation of the FCC-plant but it does result in a slightly modified product spectrum: The oxygen embedded in the ester group was mainly converted into water, and no oxygen compounds were detected in the liquid products. Higher ratios of vegetable oils in the feedstock lead to a decrease of the main product gasoline while the amount of gaseous hydrocarbons stays constant. For the by-products coke and heavy residues (light cycle oil) a small increase was observed. Using vegetable oils as a feedstock for fluid catalytic cracking an overall conversion into gasoline and gaseous hydrocarbons of about 65 percent mass can be achieved. The gasoline fraction of the product contains high amounts of aromatics at octane numbers of approximately 99 RON and 86 MON.

Fluid catalytic cracking of vegetable oils is a new way which is hardly known today for producing high quality gasoline, gaseous hydrocarbons (e.g. propene, ethene) and consequently plastics out of biological sources. Future work will concentrate on testing new feedstocks like pure fatty acids, pyrolysis-oils and FT-waxes as well as on optimizing the FCC technology for renewable sources.
CO2 CAPTURE BY DOLOMITE PARTICLES IN A GAS FLUIDIZED BED

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Carbon dioxide capture is widely studied with a view to its implementation in energy generation systems as a means of reducing greenhouse gas emissions; solid sorbents, capable of being regenerated, provide a promising means for effecting this operation. When CO2 capture is combined with steam gasification of biomass or coal, and/or steam reforming of methane or higher molecular weight hydrocarbons, the resulting fuel-gas quality is markedly improved, hydrogen yield being substantially increased and reduced operating temperatures become permissible.

Cyclic CO2 capture and CaCO3 regeneration characteristics were investigated experimentally in a laboratory-scale fluidized-bed reactor containing dolomite sorbents. Dynamic, step-response tests were carried out to determine CaO conversion rates as a function of time for dolomite particles of various sizes included in the bed - the total dolomite content being a small fraction of the overall bed inventory, so that the behaviour could be related to that of a single particle exposed to the CO2 containing gas stream. On-line measurement of CO2 concentration in the outlet stream provided the response curves from which the take-up rate of CO2 on the dolomite could be calculated as a function of time, and the kinetic parameter k of a simple flow and reaction model for the process could be evaluated. Five dolomite particle sizes were investigated in the range 0.10 – 1.55 mm, CO2 capture at a temperature of 650°C revealing a clear dependence on particle size of the CO2 take-up rate. This is attributable to intra-particle diffusional resistance phenomena, quantifiable in terms of the model parameter k, which was found to decrease progressively with increasing dolomite particle size.

The effect of cyclic, sorption/regeneration, operation was also studied. Following a sorption run, the bed temperature was increased to 850°C and the CO2 content of the flow stream reduced to zero, thereby initiating the recalcination of the dolomite, liberating the reacted CO2. This enabled any deactivation of the dolomite to be identified and measured in terms of its reduction in sorption capacity with progressive cycles - twelve of which were carried out for selected dolomite particle sizes. Deactivation effects were found in general to be small and to increase somewhat with increasing particle size.
COMPARISON BETWEEN OLIVINE AND M/OLIVINE (M=FE, NI) FOR TAR REMOVAL AND ADDITIONAL HYDROGEN PRODUCTION BY WATER GAS SHIFT REACTION.

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Biomass gasification is a thermochemical process carried out at high temperatures in order to optimize the gas production. In presence of steam, a quite clean synthesis gas is formed: syngas (H2 and CO) along with CO2 and CH4. However the main drawback in gasification technologies is the formation of solid residues consisting of char, ash, volatile alkali metals and organics vapours known as “tar” which is necessary to remove from the syngas before further applications. Tar contains significant amount of energy and can be converted by steam reforming in H2, CO and CO2 gases that improve gas production.

Previous works have revealed that olivine (which is an iron and magnesium orthosilicate mineral available in nature) has a good performance in terms of tar reduction [1]. It has been shown that the iron state into the mineral is essential for its reaction efficiency [2]. Moreover a Ni/olivine catalyst has been developed for the methane [3] and tar [4] steam reforming presenting high activity for both reactions. However nickel compounds are toxic and the utilisation of such catalysts is a potential environmental problem. That why we developed a Fe/olivine catalyst. Iron is cheap, largely available, less toxic, well known to break C-C bonds and to have a real efficiency in water gas shift reaction (WGS). In the gasifier, the Fe/olivine catalyst, in presence of H2O and CO will be of great interest for additional hydrogen production through WGS and is expected to be efficient in tar steam reforming. Toluene was selected as a tar model compound [4, 5].

We have compared performances of olivine, Ni/olivine and Fe/olivine (with different percentage of iron) in toluene steam reforming and in water gas shift reaction. The operating conditions have been studied to optimize the catalysts activity (reaction temperature between 750°C and 850°C; oxidant-reductive conditions: H2/steam ratio). The concentration of H2 in the gas flow was found to be the key of the Fe/olivine efficiency and stability in toluene steam reforming. After 30 hours of reactivity, the Fe/olivine and the Ni/olivine revealed the same stable activity (about 90% of conversion and 60% of hydrogen yield at 825°C). Both metals favoured the water gas shift reaction (CO/CO2 = 1.6 for Ni/olivine and CO/CO2 = 1.4 for Fe/olivine at 825°C) and exhibited similar hydrogen production (7.4%vol for Ni/olivine, 6.8%vol for Fe/olivine in the gas flow). Olivine alone showed less activity. However, a part of the hydrogen produced with the Fe/olivine and olivine alone is mobilized in order to form a small quantity of methane. Reactivity results will be explained through several characterization techniques (XRD, Mössbauer, TPR, XPS) performed before and after reaction.
Finally, we concluded that the Fe/olivine catalyst reveals to be of interest for tar reforming and WGS reaction, moreover it is a better choice than Ni/olivine catalyst taking account environmental and economical reasons.


CONVERSION OF LOW GRADE BIO-OILS TO BIOSYNGAS USING GLIDARC-ASSISTED POX REFORMER

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Low grade bio-oils such as deep-frying fat have been regarded as an alternative fuel for diesel engines. These oils are normally very low in cost and therefore attractive for diesel engines. However, due to their low quality properties, they can cause serious engine problems such as formation of combustion chamber deposits and/or injector deposits. An alternative method is converting these oils to biosyngas. The biosyngas can be used as fuel itself or it can be converted to biodiesel via Fischer-Tropsch synthesis.

An economical way to produce syngas from low grade bio-oils is the low cost gliding arc plasma reforming. In a gliding arc reformer, the reforming is driven by high-voltage discharges that catalytically assist the exothermic partial oxidation process. The unique oxidant source is air.

An important question is the injection method of oil into the GlidArc, which is also very important for the stability of the reformer. Direct injection of preheated oil in the reaction zone of the GlidArc can affect the stability of the electrical discharge, disturb the temperature and produce soot. A better method is to use a small amount of propane to maintain a stable temperature in the reformer. In this way, the chemical reactions do not only depend on the injected oil and the oil can be injected directly into the reaction zone of the reformer without any pre-heating procedure.

A 60 kW GlidArc containing Ni-based catalyst on Al2O3 support was used to produce syngas from liquid oil. Propane was used as the stabilizing fuel and the working pressure was atmospheric. In order to change the H2/CO ratio in the syngas, water blended with oil was injected directly into the reformer chamber without any pre-heating procedure and without use of any vaporizer or nozzle.

The working temperature inside the catalyst bed was about 1000 °C. Detailed mass and energy balance with and without water has been performed. The exhaust syngas was cooled to almost room temperature. No organic deposits were observed on the surface of the catalyst.

Because, the syngas will be compressed to at least 20 bars in a Fischer-Tropsch reactor, special emphasis have been put on monitoring the amount of oxygen in the syngas.

The energy used for production of suitable syngas (suitable for production of liquid hydrocarbons via FT synthesis) from different bio-oils using the reformer has been further evaluated. The future work should focus on the detailed chemical analysis of the catalyst material and high temperature corrosion analysis of the steel material after a long run.
DEMONSTRATION OF THE PRODUCTION AND UTILIZATION OF SYNTHETIC NATURAL GAS FROM SOLID BIOFUELS - PRESENTATION OF THE EUROPEAN PROJECT “BIO-SNG”

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The thermo-chemical gasification and the complete conversion from ligno-cellulosic biomass to methane that can be distributed through the existing gas grid and utilised in the stationary and mobile sector is an interesting and promising alternative. In comparison to e.g. liquid synthetic biofuels is synthetic natural gas (SNG) characterised through several advantages especially with regard to the high technical potential and the high overall efficiency. Despite these advantages, the methane production is still under development although many efforts have been carried out in the field of gas production and subsequent methanation. Against that background, the research project “Bio-SNG” started in the year 2006, which demonstrates the production of biomethane via thermo-chemical gasification and utilization within the energy system.

The objective of the “Bio-SNG” project is it to demonstrate the SNG production from woody biomass in the 1 MW-range using steam gasification, advanced gas cleaning, methanation and gas upgrading as a part of an innovative 8 MW biomass CHP gasification plant, and to integrate this Bio-SNG into the existing energy infrastructure (i.e. fuel station for vehicles). To meet the specifications required for the gas-utilization in vehicles or the gas-feed-in into an existing natural gas grid, the produced SNG has to be upgraded. With this upgraded renewable gaseous fuel cars will be operated to demonstrate the application within the transportation sector.

The entire provision chain of SNG was assessed on (i) technical (e.g. overall efficiencies), (ii) economic (e.g. cost efficiency) and (iii) environmental (e.g. overall primary energy demand, GHG emissions) parameters. Out of these conclusions it can be drawn, whether the SNG production is competitive to other synthetic biofuel pathways and when a market mature technology will be available. The assessment of the overall Bio-SNG provision chain shows, that the production of biomethane via thermo-chemical conversion, is characterised in comparison to other synthetic biofuels (e.g. FT-diesel) by outstanding energy efficiency and lower production costs. With regard to the environmental criteria, Bio-SNG contributes to the CO2-mitigation.
As a next generation hydrogen production technology from coal with inherent CO2 capture, SEWGS (Sorption Enhanced Water Gas Shift) process has been developed. In this study, conceptual design and sensitivity analysis of operating variables have been investigated based on a design program of two-interconnected fluidized bed and reactivity data for WGS catalyst and CO2 absorbent. Based on the conceptual design results, the optimum configuration for SEWGS was considered. Among three configurations (transport-bubbling, transport-bubbling-bubbling, bubbling-bubbling) the bubbling-bubbling system was selected as the best configuration. Process design results indicate that the SEWGS system is compact and feasible. Based on the selected operating conditions, the effects of variables such as pressure, CO2 capture capacity, solid inventory, and CO2 capture efficiency have been investigated as well.
EFFECTS OF HYDROGEN AND LEVOGLUCOSAN ON THE CHAR REACTIVITY IN THE BIOMASS GASIFICATION

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It is known that in coal gasification when volatiles produced in pyrolysis contact with char, steam gasification of char is inhibited by volatiles. Thus, there is a possibility that similar inhibition occurs in biomass gasification.

In this study, the inhibition of the gasification rate of biomass char by volatiles was investigated. The effects of H2 and levoglucosan, which is a major pyrolysate derived from cellulose, on char reactivity were measured. At first, the reaction rate of char in steam gasification was measured using a thermobalance fixed bed reactor by changing H2 concentrations. It was found that the presence of H2 in the gas phase decelerated the steam gasification rate. The inhibition of reaction rate of char by levoglucosan was measured with a newly developed drop-tube/fixed bed thermobalance reactor. In the result, it was found that levoglucosan and its pyrolysates also inhibit the gasification of char substantially. When the feed rate of levoglucosan is 250 mg/min, the gasification reaction is terminated by levoglucosan and/or its derivatives.
EXPERIMENTAL RESULTS ON HYDROGEN PRODUCTION FROM BIOMASS APPLYING THE ABSORPTION ENHANCED REFORMING (AER) PROCESS IN A 20KWTH DUAL FLUIDIZED BED

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The European Project AER-II focuses on the development of a low cost-gasification process with integrated in situ gas cleaning for conversion of biomass into a product gas with high hydrogen concentration, high heating value and low tar concentration in one process step.

This paper presents the results obtained from an experimental investigation on the hydrogen production using the Absorption Enhanced Reforming (AER) of biomass in a 20 kWth Dual Fluidised Bed (DFB) system.

The AER process involves two coupled fluidized beds: a gasifier and a regenerator (calciner). The in-situ absorption of carbon dioxide by a sorbent (i.e. CaO) during steam gasification in the gasifier provides the heat necessary for the endothermic gasification reactions. Due to CO2 absorption, the equilibrium of the water-gas-shift reaction is shifted to the hydrogen product. As a result of the in-situ CO2 capture the hydrogen concentration is higher than 70%vol,db in the AER product gas. The carbonated sorbent is then transferred to the regeneration reactor where the CaCO3 is calcined and recycled back to the gasifier.

The experiments were carried out with wood and straw pellets and two different limestones in a 20 kWth DFB system. A special feature of the DFB facility is the possibility of circulation rate control between the gasifier and the regenerator. In the regenerator, the CaCO3 will be regenerated to CaO and returned to the gasifier thereby allowing continuous operation of the AER-reforming process. In this paper the influence of different process parameters, e.g. gasifier temperature and circulation rate on the gas composition, especially the hydrogen concentration, during the absorption enhanced reforming is shown.

To get information about the influence of different process parameters on the gas composition an online gas analyzer is installed. An additional online tar measurement system was used to get more information about tar concentration and product gas quality. Hereby, the hydrocarbon levels are measured by a flame ionization detector.
FAST PYROLYSIS FOR BIOSYNCRUDRE PREPARATION AS A VERSATILE INTERMEDIATE FOR BIOMASS GASIFICATION

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The biosyncrude gasification concept bioliq has been developed to use biomass as a renewable carbon resource for the co-production of synthetic biofuels, organic chemicals, heat and electricity. Potential feedstocks comprise residual wood, straw or even organic residues with higher ash content. The solid biomass is first converted by fast pyrolysis in a number of regionally distributed pre-treatment plants to yield pyrolysis oils and char. From the condensed pyrolysis products, the liquid like biosyncrude is produced, exhibiting a volumetric energy density considerably higher than that of the original biomass. Therefore, this biosyncrude can be transported economically to a large central plant for the generation and use of synthesis gas as required by economy of scale considerations.

Within this biosyncrude gasification concept the suitability of the twin screw mixer reactor for fast pyrolysis (FP) of lignocellulosic biomass has been proved for pre-treatment of biomass prior to gasification. In lab scale and process development units (PDU) a broad variety of biomass feed stocks have been tested successfully. Yields for the solid, liquid and gaseous FP products have been determined and compare to results of the bubbling or circulating fluidised bed reactors and other FP reactor types. The main twin screw reactor features are mechanical fluidization by transport along the screw axis and efficient radial mixing of dry biomass particles with a surplus of hot heat carrier particles. Sand as well as other small sized heat carriers have been used as heat transfer media and assessed for use in large scale facilities. The twin-screw concept has finally been chosen because of the technical experience from earlier applications e.g. for town gas production from coal in the 1970ies. This experience is activated to accelerating the scale-up of biomass FP reactors to commercial scale. At present, a 0.5 t/h FP-pilot facility has being build-up in cooperation with Lurgi AG on site of the Forschungszentrum. It is part of a complete bioliq-process pilot line “from straw bale to fuel station” and consists of biomass pre-treatment (cutting, milling), the fast pyrolysis plant with pneumatically driven heat carrier loop, and a section for bio-syncrude preparation. Lab and PDU scale results are presented and the first results of the pilot plant operation will be reported in the contribution.
FEASIBILITY ANALYSIS OF A GASIFICATION PLANT FOR POWER PRODUCTION FROM PAPER INDUSTRY REJECTS

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The management of rejects from the pulping of waste paper and cardboard is a central issue for industries using recovered paper as raw material. These rejects are usually burned in large scale centralised incineration plants with low energy efficiency and high disposal and transportation costs. These problems along with the high energy requirements by paper industries encourage the research and development of advanced cost-effective solutions. The main objective of the present paper is to provide a preliminary assessment of the feasibility of pulping rejects gasification and its potential advantages in comparison with conventional technologies for its conversion into electricity. The work is based upon the experimental data obtained at the ENEA Trisaia Research Centre laboratories on rejects samples provided by a local paper industry, which is assumed as case study. According to the results of the characterisation tests, this fuel is mainly composed of plastics and, in a lesser extent, paper and has a valuable lower heating value (LHV) of almost 28 MJ/kg on dry basis. Furthermore both ashes and pollutants content is comparable to that of an untreated biomass, with the exception of chlorine which is significantly higher (more than 1 wt.% dry). On the other hand the presence of heavy metals and solvents must be carefully considered. On the whole the pulping waste appears to be a potential fuel for the gasification process. Preliminary pyrolysis and gasification tests, using either air or steam as gasification agent, were performed on an appositely designed and constructed laboratory scale reactor having a fuel capacity of around 1.5 kW. The producer gas quality appears to be suitable, since its LHV ranges from more than 6 MJ/Nm³ for air gasification to nearly 40 MJ/Nm³ for pyrolysis, mainly due to the high propane concentration in the gas. Basing upon these preliminary results, the feasibility of a medium scale gasification plant was analysed. The system size was chosen according to the case study annual production of pulping rejects. Similarly both energy needs and waste disposal charges of the case study were considered in order to achieve a preliminary cost analysis. In conclusion gasification of rejects from the pulping of waste paper and cardboard appears to be a suitable, cost-effective and environmentally sustainable solution for medium to large capacity paper industries using recycled paper as raw material. However a pilot scale investigation is necessary in order to identify the most appropriate gasification technology for this application and to optimise the main operational parameters. Furthermore specific solutions could be required for the fuel feeding system and the producer gas cleaning.
FEASIBILITY ANALYSIS OF A TRIGENERATION PLANT USING MOLTEN CARBONATE FUEL CELLS (MCFCs)

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In recent years the energy market is rapidly changing because of important and decisive technical, ecological, and political actions such as the liberalization of the energy market, the imperative need to reduce environmental pollution, and the security of energy supply. In this picture, the development of innovative systems, with high performance and low environmental impact, opens an attractive upcoming scenario. Hence, a new approach to the electricity and thermal energy production is proposed in this work with the aim to meet the new target of the energy market beyond the traditional concepts of combustion and dynamic machines. Precisely, the technical feasibility of a trigeneration plant fueled with syngas product of the biomass gasification and using Molten Carbonate Fuel Cells (MCFCs) for the combined production of electricity, heat and cooling is assessed.

The plant joins fuel cells with gas turbines giving out a very powerful and promising technology. Fuel cells have already reached a R&S leading position in the field of production of electric energy as well as gas turbines and adsorption heat pumps for electricity and thermal energy production. The obtained technology allows to recover a share of thermal energy, otherwise lost in conventional power plants, almost equal to 2/3 of the total. Moreover, it allows to get yields higher of the 4/5 of primary energy associated with syngas and convert it into usable energy with enormous financial and economic benefits. Finally, through trigeneration it is also possible to use the waste heat (1/5 of the total) to produce cooling through absorption cycles resulting in the so-called final process CHCP (Cogeneration of Heat, Cooling and Power) or generate heat for winter heating. Main advantages regarding trigeneration are the reliability and flexibility related to the energy production because of the proportions in which the three different types of energy can be varied to suit the needs of the final users. Furthermore, from a socio-economic point of view, trigeneration is excellent for promoting the decentralization of the energy production and, consequently, the liberalization of the energy market. An additional advantage is represented by the low environmental impact, as the emissions are strictly reduced compared to traditional systems. On this basis, the use of hydrogen(syngas) as fuel for trigeneration can provide energy for many applications with low environmental impact.
FIXED BED GASIFICATION OF WOOD CHAR: THERMAL, CHEMICAL AND MECHANICAL CHARACTERISATION

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CIRAD
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Fixed bed gasification is one of the most promising technologies in the area of biomass gasification to be introduced into the market of low and medium power ranges due to the higher electricity output expected compared to combustion. Moreover, downdraft or two-stage gasifiers are known to produce low tar content in fuel gas.

Objectives

In this work, we focused on the step of the char bed gasification in fixed bed or two-stage gasification processes.

We propose here a fine characterisation of the char bed during its gasification by H2O and CO2.

The global objective is to provide key information to improve both the char conversion in char bed reactor and the control of fixed bed gasifiers, which remain today a brake to industrial development.

Approach

The characterisation of char bed gasification has been carried out thanks to the Continuous Fixed Bed reactor (CFiB) at Cirad. This reactor replicates the gasification zone apart from the rest of the fixed bed process. It is specifically instrumented to allow the measurement of thermal and chemical profiles all along the bed. Indeed, measurements of temperature, pressure and gas composition each 10 cm in the bed are performed.

The non condensable gases are on-line analysed by gas-chromatography analysis. The condensable products (water + residual tar) are collected to be analysed in the lab by Karl Fisher, gas- and liquid- chromatography analyses.

At the reactor outlet, ash removed is continuously weighed and gases are quantified to establish a precise mass balance of each experiment.

Scientific innovation and relevance

This CFiB reactor is an innovative tool to study wood char gasification in continuous fixed beds.
The accuracy of the measurements carried out inside the bed is a step forward in the understanding of fixed bed gasification processes.

Such profiles of temperature, gas composition, char conversion, and bed morphology provide original and relevant data to localise the zones where char oxidation by O2 and char gasification by H2O and CO2 effectively occur.

**Results**

In this paper, full characterisation of the fixed bed is presented, including axial and radial profiles inside the 700 mm height bed.

Influence of steam partial pressure (from 0,1 to 0,4 atm) and initial oxygen content (2 to 5 %) on char gasification has also been investigated with the proposed methodology.
Due to concerns over the spread of Bovine Spongiform Encephalitis (BSE), feeding animals with the meat and bone meal powder (MBM) left over from the cattle rendering process will be severely restricted or even banned entirely. Large stockpiles of MBM will be created unless alternative disposal methods can be developed. One option is to exploit the MBM for its fuel value (approximately 20 MJ/kg) through the use of high-temperature gasification. This process will allow the energy value of the fuel to be recovered while the elevated temperature treatment will destroy the proteins responsible for BSE, thus eliminating them from the food chain. While the incineration, combustion, and pyrolysis of MBM have been studied, gasification of the MBM powder has received comparatively less attention.

The present paper will present results on the gasification of MBM in a pilot-scale fluidized gasifier at temperatures ranging from 650 to 850 °C, with both air and steam as the fluidizing medium. The gasifier is 20 cm ID by 7 m tall and is designed to process up to 100 kg/day.

Recovery of the MBM energy value through gasification presents an interesting opportunity for polygeneration. The product gas can be cleaned and used in a gas turbine to generate electricity or simply burned (with less gas cleanup) to generate steam for thermal energy. In either case, use of the producer gas will displace reliance on natural gas or electricity, thus reducing operating costs for the rendering plant. There is also the potential for higher value chemical production, which would open up the possibility of an additional revenue stream for the traditional cattle rendering businesses.
In order to find the better use of bio-oil produced from saw dust, an experimental set-up for gasification of bio-oil was set up at BTG, The Netherlands. It consists of 25 mm inner dia MS pipe placed in an electric oven of 1800 W capacity which can heat up to 1200 °C with thermostat control to maintain any desired temperature. The temperature of the experiment was varied from 1000, 1050 to 1150 °C. A liquid pump pumps the oil at different mass flow rates through a nozzle of dia 3 mm inside the MS pipe. The air flow meter was calibrated at 1 bar and 2 bars for different positions from 0 to 150 using a wet type gas flow meter. The pressure of the air can be varied using the air pressure valve arrangement and the volume flow rate of air can be varied using the air flow meter. The mass of the oil at definite time interval was observed to calculate the mass flow rate of oil during the gasification experiments. The outlet of the gasification pipe was connected to the gas outlet pipe. The gas from the outlet pipe was drawn periodically and analysed for its composition in a Gas-Chromatograph. The results indicate that the air pressure of 2 bars give better results than 1 bar with respect to better heat content of the gas. As the air flow rate increases, the quality of gas increases up to 568 L/h and then it decreases. Hence the air flow rate of 568 L/h is found to yield the best results at the air pressure of 2 bars. The temperature of 1050 °C is optimized to give the best results for the air pressure of 2 bars. It is observed that use of catalyst increases the gas quality. The heat content of the gas is in the range of 4 to 5 MJ/Nm3. It is suggested that a large scale/pilot plant can be constructed for gasification of bio-oil and tested for its performance.
Gasification is one of the most promising conversion processes for the use of biomass. This thermochemical process biomass leads to the production of a low-heating-value fuel gas (10-18MJ/m³) mainly composed of CO and H₂. The biosyngas produced offers a wide range of applications for energetic purposes: boilers, engines, gas turbines or fuel cells among others.

Nevertheless, the industrial development of such a process is slowed down by technical problems. Indeed, some unwanted compounds like particulates and tars are the results of complex chemical reaction occurring inside the gasifier. These can cause operating problems, especially condensation in transfer lines as heat exchanger surfaces, fouling of pipes, plugging of valves, deactivation of catalyst and may also present environmental problems. Tar reduction is thus a key point for the development of such processes.

Different methods have been developed involving catalytic and thermal system but economic feasibility of these alternatives are not demonstrated. An innovative concept has been developed and patented (n°0602840-2006) in EIFER to answer the problematic of tars formation. The method proposed in this work consists in sparging gasification products into a bath of molten salts at temperature in range of 700°C to 1000°C. From the point of view of energy utilization and heat transfer enhancement, inorganic molten salts present a promising option as a medium for destruction, conversion, and/or reduction of tars for the gas clean-up process.

Experiments have been performed at a lab-scale device. In order to distinguish and to understand mechanisms of tar reduction, tests have been performed on a gas model produced by mixing heated nitrogen (300°C) with benzene. Benzene has been chosen as tar model since it is one of the major and more stable aromatic compounds in gasification products.

The produced gas model containing 1 g/Nm³ of benzene is continuously injected in an inox bubble chamber filled with a mix of sodium and potassium carbonate (50/50 in mass) which temperature varies between 700°C and 1000°C. Resulting gases are then analysed at the outlet of the reactor by FTIR spectrometry for permanent gases (CO, CO₂, CH₄) and by the SPA method for tars. The method developed in this laboratory allows a qualitative and quantitative analysis of about twenty aromatic compounds. The efficiency of the molten salts bath system is given by comparison of the tar content before and after the system. Tests are also performed without salts to distinguish the thermal effect of the molten salts bath effect.
First results show the feasibility of the reduction of the tar content into gasification products by sparging in a molten salts bath. Indeed, higher benzene conversion rate are observed with molten salts in the range of 750°C to 950°C. Conversion rates at 700°C (around 0 %) and at 1000°C (around 95 %) are quite similar with and without molten salts. The temperature where the shift between the two experiments is the most important is around 900°C; the conversion rate is, in these conditions, 25 % without molten salts against 85 % with molten salts. It has been shown that conversion of benzene into aromatic compounds of higher molar weight is limited and that the major part of benzene is converted to gases participating in the increase of the heating value of the resulting gas.
For the production of liquid synfuels from biomass feedstocks, a water gas shift reaction step carried out at high pressure and temperature may be advantageous in terms of minimizing energy losses. Since biomass gasification yields insufficient H2/C0 ratio for fuel synthesis and high pressure may be applied, subsequent gas cleaning and water gas shift should be carried out at elevated pressure and above the temperature level of synthesis.

Due to their excellent heat and mass transfer conditions, microstructured reactors potentially offer advantages for process design and control. For example, variations in synthesis feed gas composition may be compensated by temperature adjustment, thus ensuring constant outlet gas composition. In addition, temperature profiles along the catalytic reactor may be set to achieve optimum conditions with respect to chemical equilibrium and reaction kinetics. Thus, by a decreasing temperature profile with increasing conversion, local reaction rates can be maximized and catalyst demand minimized.

However, catalyst preparation for microstructured reactors, reaction kinetics, catalyst stability against biomass-specific poisoning and potential byproduct formation at high pressure conditions have to be investigated. In the present contribution, these issues will be discussed in more detail. Moreover, first experimental results obtained with a new, lab-scale microstructured reactor will be presented. Microstructured foils coated with Pt/CeO2/Al2O3 and a commercial iron-chromium catalyst in a micro fixed bed foil design will be tested with variation in reaction pressure up to 50 bars and temperature between 300 and 500°C.
HIGH-TEMPERATURE PYROLYSIS OF LOW-GRADE AGRICULTURAL WASTES

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This research project is aimed at developing a waste-to-energy technology suitable for power generation from various low-grade agricultural by-products, e.g. rice husk, cereal straw, corncob, olive husk, etc. The research is currently focused on rice husk, which is possibly the most under-utilized biomass feedstock in many countries cultivating rice. Due to its high mineral content (mainly silica), the efficiency of husk utilization as fuel in the conventional high-temperature combustion and gasification systems is low, around 50%, and results in large amounts of ash and unconverted carbon.

The present study on energy recovery from rice husk is based on conducting the simultaneous pyrolysis-gasification reactions of biomass in a molten carbonate salts medium under high temperature. This concept of thermochemical conversion of biomass to syngas was developed at the Weizmann Institute of Science and demonstrated using cellulose particles. It was shown that the thermal and reacting conditions in a molten salt reactor are favorable for the production of syngas with minimal tar and solid residue. Syngas is a clean, energy-valuable fuel to be utilized in high efficient conversion systems such as gas turbines or fuel cells for electricity production.

The investigation of rice husk pyrolysis in a molten medium of Na-K carbonate salts has been conducted at temperatures of 800-900°C using a lab-scale, electrically heated reactor. The rice husk feed is made in the form of 1 g tablets produced by compression of the pre-milled stuff.

As follows from the experimental results, about 82-90% wt of the initial biomass could be converted to syngas at 900°C versus about 46-55% wt obtained at the same temperature in the reactor without molten salt. The syngas was primarily comprised of H2, CO, CO2 and CH4, about 98% vol. in total, with a fraction of hydrogen 13-16% vol. It is suggested, based on chemical thermodynamics that silica contained in rice husk could be reacting with the molten salt of sodium carbonate. Therefore, the completion of rice husk gasification obtained is much higher than that observed in conventional gas-oxidizing processes.
Driven by growing concerns about global warming and resource depletion, the setting of the political frame conditions led to a significant increase in the use of biofuels within Germany as well as within the European Union throughout the recent years. However, the expected positive environmental impact of this strategy – especially concerning the reduction of greenhouse gas (GHG) emissions – is strongly and very controversial discussed nowadays. Looking for alternative fuels with an advantageous environmental performance, especially the production of so-called Bio-Synthetic Natural Gas (Bio-SNG) from ligno-cellulose biomass could be a promising option.

Within the European research project “Bio-SNG” the production and utilization of synthetic natural gas is analysed. Practical data and operational experiences are derived from a demonstration plant in Güssing (Austria). The project also included the environmental assessment of different Bio-SNG concepts for different time horizons and under uniform frame conditions. For this assessment, the methodology of Life Cycle Analysis (LCA) was used to calculate the overall greenhouse gas (GHG) emissions and the consumption of finite energy resources for the considered Bio-SNG pathways. Furthermore, the GHG mitigation potential in comparison to fossil fuel was calculated according to the methodology of the European Renewable Energy Directive proposal. The system boundaries of the environmental assessment covered all basic elements of the Bio-SNG production and utilisation, i.e. biomass provision, the conversion process, the Bio-SNG distribution and the use of the Bio-SNG in the transportation sector.

The results of this assessment will be presented including a comprehensive comparison to the potential environmental aspects of other promising first and second generation biofuel pathways (e.g. Bioethanol from sugar cane, BtL, etc.). Furthermore, the conclusions can be used to identify areas for a further process optimization regarding environmental aspects as well as areas requiring further research.
LOW TEMPERATURE PYROLYSIS OF AGRICULTURAL RESIDUES IS USED TO SUBSTITUTE FOSSIL FUELS IN A THERMAL POWER PLANT

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A. PURPOSE OF WORK

Pyrolysis is a process to convert biomass directly into solid, liquid and gaseous products by thermal decomposition in absence of oxygen. Pyrolysis is a very complex process; many different reactions take place and can be influenced by numerous factors. Aim of this work is to obtain fundamentals for an advanced pyrolysis model approach by the results of the pilot plant.

B. APPROACH

A 3 MW pyrolysis pilot plant is presently being investigated using agricultural residues (straw as the primary feedstock). This externally heated rotary kiln pyrolysis reactor is used as a new process technology for the conversion of biomass into useful primary energy products. Several analytical methods are applied to provide an insight into the complex process of pyrolysis (e.g. gravimetric determination, GC-MS determination, IC determination and fuel analysis).

C. SCIENTIFIC INNOVATION AND RELEVANCE

The design fuel power is about 3 MW; the pyrolysis gas capacity is about 1.5 MW. Approximately 0.6 t/h straw can be processed in the rotary kiln. The externally heated rotary kiln pyrolysis reactor in Dürnrohr is an innovative process technology which can also be used for high capacities. The process is operated at low temperatures (350 to 630 °C) to prevent an entry of corrosive ash elements (K, Cl, S, etc.) and additional emissions in the steam boiler of the coal fired power plant. An energetic use of the pyrolysis-charcoal (approximately 40-50% of the original heating value) occurs separately in a fluidized bed reactor. Several analytical methods are used to get more insight about the behavior during pyrolysis. First test runs were carried out at pyrolysis gas temperatures ranging from 560 to 630 °C.

D. RESULTS

Organic liquids can be classified due to the viscosity. Thereby liquids differ in low viscous pyrolysis oils and high viscous tar. The components are a mixture of alcohols, furans, aldehydes, esters, phenols, organic acids and oligomer carbohydrate and lignin products. The composition depends on the raw material and the pyrolysis process.
The pyrolysis gas mainly contains H2, CO2, CO, CH4, trace amounts of larger gaseous organics compounds and water vapor. The water content results from the biomass humidity, about 10 %, and from the reaction water. To control the water content, the water content of the used biomass should be lower than 10 wt. %. The charcoal consists of carbon, volatile components, ash and partly tar. The content of carbon is one of the most important parameter for the quality of the charcoal, as well as the water content, ash content, elemental analysis, particle size, and energy density. All of the quality characteristics depend on the used biomass and the pyrolysis process as well as the purpose of use. The paper will show the enrichment of potassium, chlorine, sulphur, sodium and nitrogen in the pyrolysis char, the relationship between pyrolysis gas temperature and tar content, and the results of different feed stock variations. Furthermore an advanced pyrolysis model will be introduced.

E. CONCLUSION

The findings of the pilot plant will deliver fundamentals for the development of an advanced pyrolysis model. Furthermore, the results will be the basis for a scale up to a 30 MW capacity. For an improved description of this highly complex process further test runs are in progress.
MODEL VALIDATION AND SIMULATION OF A BIOMASS GASIFIER INTEGRATED IN A 6 MWE ENGINE COGENERATION PLANT OF AN ALCOHOL DISTILLERY

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The potential for biomass to supply much larger amounts of useful energy with reduced environmental impacts compared to fossil fuels has stimulated substantial research and development. The increasing dependence on imported oil as well as the urgency to reduce greenhouse emissions abounds in justifying an energy policy that carefully considers the role of renewable sources as energy carrier. Among the renewable energies, biomass is expected to be one of the most important in the near future. Gasification is one of the most efficient ways to convert the energy embedded in the biomass and it is becoming one of the best alternatives for waste solids reuse.

This paper presents a modelling of the biomass gasification process and more particularly the wood gasification. The proposed gasification model can be used as a predictive tool at the optimisation stage. The model, based on the minimisation of the Gibbs free energy, is developed for an atmospheric fluidised bed gasifier using the ASPEN PLUS simulator. The ASPEN PLUS software simulator has been used successfully by different investigators to simulate biomass gasification and it is chosen as a simulation tool because of its capability on the solids handling. This model aims to be able to predict gasification output mixture composition when changing the type or the characteristics of the biomass used.

Validation of this model will be carried out using the commercial gasification plant located in Campo de Criptana (Spain), built by EQTEC Iberia at the alcohol distillery of the company “Mostos, Vinos y Alcoholes S.A. (Movialsa)”. This plant has an electrical output of 5.9 MW and produces 5600kg/h of saturated steam at 6 bar(g) and 159 m3/h of hot water at 90°C, which are used by the alcohol factory. The plant gasifies 4000 kg/h of waste bagasse from the alcohol factory and allows total elimination of the bagasse liquid and effluent of the factory. Three Jenbacher 620 synthesis gas engines are used for electricity generation. Different sets of operating conditions for the gasifier will be used to validate the developed gasifier model. In a near future, the model will also be applied to a commercial gasification plant to be built in Cerdanyola del Vallès (Spain) in the framework of the European project Polycity. This plant will have an electrical output of about 1MWe and will gasify 1000 kg/h of wood waste. The heat recovery system will be coupled with an absorption chiller to produce chilled water at 7°C.
MODELLING OF AN ABSORPTION TOWER FOR THE REMOVAL OF SULPHUR IN PRODUCER GAS FROM BIOMASS GASIFICATION

BLASI A 1,2, MOLINO A 1,2, FIORENZA G 1, BRACCIO G 1, GIORDANO G 2

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Gas cleaning is the key step in biomass gasification in order to exploit the producer gas for power generation, especially if advanced conversion devices, such like gas turbines or fuel cells, are used. Actually these machines are extremely sensitive to pollutants concentration. On the other hand gas cleaning becomes even more critical if producer gas is used as feed stream for either Fischer-Tropsch or methanol synthesis in order to produce liquid bio-fuels.

Sulphur components are amongst the main contaminants to be removed from producer gas. In effect, H2S must be limited to 0.1 ppm for a trouble-free use of producer gas in gas turbines or molten carbonate fuel cells. Furthermore this compound reacts with oxygen, at hot temperature, and forms SO2 and SO3, which are the main factors of acid rain, thus requiring an accurate cleaning of flue gas downstream of the conversion device.

In addition, it must be observed that the current world energy scenario is characterised by a growing interest in the use of coal, in particular in biomass/coal cofiring power plants. Being this primary energy source rich in sulphur, it can be deduced how sulphur removal systems optimisation is going to be a core target of scientific research in the field of polygeneration technologies.

Two biomass gasification plants are currently operating at the ENEA Research Centre Trisaia in Rotondella (Italy), based upon different gasification concepts: a dual fluidised bed steam gasifier and a downdraft fixed bed air gasifier. Two more pilot plants, which are now under construction, will be started soon: a bubbling fluidised bed oxygen/steam gasifier and an updraft fixed bed air/steam gasifier. All of these plants are going to be combined with different producer gas conversion devices, such like, an internal combustion gas engine (already working), a molten carbonate fuel cell, a methanol synthesis reactor.

The aim of this work is to compare the sulphur reduction by means of an ammine scrubber for the different producer gases from these gasification pilot plants. Both experimental and simulated data are used to define the design producer gas composition for the different gasifiers. Furthermore an apposite model is developed by the authors in order to evaluate the performance of an ammine absorption tower in the various cases under investigation. Literature data are then used in order to validate the model and finally the results obtained with the proposed technology are compared to those relevant to a hot sulphur removal technology, such like metallic oxide adsorption.
OPERATION OF A SOLID OXIDE FUEL CELL (SOFC) WITH PRODUCT GAS (THERMAL GASIFICATION)

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Bioenergy 2020+ GmbH, Area II Biomass Gasification Inffeldgasse 21b; A-8010 GRAZ

Steam gasification of biomass delivers product gas of high hydrogen content and high volumetric energy density because of low nitrogen fraction. Together with carbon monoxide and methane this gas is expected to be an almost perfect fuel for high-temperature-fuel cells, such as SOFC (Solid Oxide Fuel Cell). By the conversion of these fuel components the fuel cell technology can be a future perspective technology for energetic conversion of product gas. High overall efficiencies combined with extremely low emissions can be expected. In a running project Bioenergy 2020+ (former Austrian Bioenergy Centre) is doing R&D since 2004. Prior work focused on the high temperature gas cleaning. Now Bioenergy 2020+ can also present operational test of micro scale SOFC-reactor units.

For successful operation of SOFC- units the characteristics of the (fuel-) product gas and the operational behaviour of the fuel cell unit should be brought together. In detail this means, that the quality of the product gas after clean up and the handling of the fuel cell application are in focus. This paper shows the coupling of a micro scale SOFC-unit with the gas treatment and the operational results, demonstrated at the Güssing Biomass Gasification Plant. In the first task – gas treatment - the most relevant impurities of the gas, such as dust, tars and sulphur derivates are detailed, because they can reduce the capacity of the fuel cells or even damage the cells (=clean gas consumer technology). In the second task the technology of the test rig and operational setting of the FC unit is shown.

The test set up is designed to be coupled on the gas treatment unit. The tubular unit of the SOFC consist of cell arrangements of 3 to 9 single cells. Until now the majority of tests were performed with 3-cell units. The nominal power of such settings is in the range of 700 to 1,000 mW. The cells are single contacted and no voltage pump via serial junction is made. The gas treatment can process about 5 m³/h (standard state) product gas. A used side stream of 10 to 500 l/h can be extracted, measured in flow and supplied to the test SOFC-unit. For variation of the test conditions the gas can be treated additionally with solid reactants and reheated at freely controllable temperature. The stack unit can be operated directly or via a prereformer unit. The stack unit is enclosed into a heated casing, with free adjustable temperature, by means of the surrounding surface and the applied flow of air conducted at the cathode section. The flow of cathode air is directed in defined way to the stack unit. The electrical conditions are defined with fixed resistive load, switchable with discrete steps. During the operational start a special procedure of temperature-gas-load-conditions must be conducted, as well in cool down procedure. All the reported conditions are relevant to document the test conditions during the field tests.
Additional all relevant quality parameter of the applied product gas sampled and analysed. The first operational tests with single cells units have been performed 2005 and have shown deactivation of early cell generations after a few hours. A shift in performance compared to pure hydrogen and the deactivation from low sulphur concentrations was detected.

The evolution to better cell concepts, improved ceramic structure and coatings has delivered the cell generation 2.0. The actual tests with product gas have shown successful operation with product gas during 22 and more hours. Actually all operational data from the process conditions of the product gas and the operational condition of the cell unit are available. Compared to expected values (proposed) the specific performance of the cell units is lower than single-cell-tests at pure hydrogen, the long time operation shows more stable trend.

Based on the overview of technological approach of FC-units the further demand in development must be declared in stack design and material upscale, because a number of different defects is located there. The operation with the product gas itself is showing successful performance at stable conditions. A long time performance test under field-lab-conditions has been started, and will be performed within the next six months at the Güssing Biomass Gasification Plant.

Summary of current results: Starting in 2005 with single cell tests Bioenergy 2020+ has performed the first test series at the Güssing Biomass Gasification Plant. A special test rig combined with the existing gas treatment unit has been developed. Successful operation of a micro scale FC unit has been performed until now. Further demand in development of stack design & technology has been evaluated. A long term test run of micro and midi scale FC-units has been started. In six months actual new results will be presented.
Biomass gasification is a possibility to produce from a solid fuel a synthesis gas, which can be used for many different applications as production of chemicals like ammonia, production of heat and electricity, production of 2nd generation biofuels like FT diesel. In this project the upgrading of the raw product gas to synthesis gas is investigated.

The biomass CHP Güssing uses the allothermal steam dual fluidised bed gasifier and produces a high grade product gas, which is used at the moment for the CHP in a gas engine. As there is no nitrogen in the product gas and high hydrogen content, this gas can be also used as synthesis gas. At the biomass CHP Güssing there are about 10vol% of methane in the product gas, which means, that about 1/3 of the chemical energy is bound in the methane and cannot be utilised in synthesis gas reactions, like Fischer Tropsch. The aim is to convert this methane over a steam reforming step to hydrogen and carbon monoxide to increase the conversion efficiency from biomass to FT fuels in this way.

The product gas from the biomass CHP Güssing has normally a H2:CO ratio of 1.8:1. By reforming of the hydrocarbons a H2:CO ratio of 2.1:1 is adjusted.

The steam reformer is integrated into the existing FT synthesis and is used as first upgrading step without previous sulphur removal.

In the first experiment it was shown, that the reactor itself has no catalytic effects and the gas composition does not change over the reactor. It was also recognised, that there is soot formation, if the steam carbon ratio is too low.

In the first experiments a methane steam reforming catalyst was used. It was shown, that the higher hydrocarbons are reformed almost completely, but the methane conversion was not as high as expected. Also a deactivation of the catalyst by carbon formation occurred.

A catalyst for reforming aromatics was used in further experiments. It showed higher methane conversion rates than the previous catalyst due to the suppression of soot formation by the catalyst itself.

At the moment the parameter variation is going on, to optimise the steam reformer. First different catalysts are used and afterwards a parameter variation (temperature, steam carbon ratio) is done to find the optimal operation conditions for the steam reformer.
Increase of the greenhouse effects, climate warming, decrease of the fossil resources and perpetual increase of the population on the surface of the planet and thus of the energy needs … how to deal with this problem? Gasification undoubtedly constitutes a considerable brief reply in the near future. This field has obviously been studied in the past but it is nowadays braked by the high costs of wood and biomass. The idea is currently to substitute this natural feedstock by wastes from wood such as wood laminated floorings. This kind of waste is relatively interesting in so far as it appears in the 80’s (in the Scandinavian countries) and it has known a very large development and success due to their easy fabrication and conditioning (for the transport), their easy and fast installation (without the need of a professional) and above all, their very attractive costs. A lot of these wood laminated floorings are today at the end of their life and are waiting for a treatment or are simply burning without any consideration of the pollutants inside.

This pool is very interesting for the development of the gasification process because of the so low or even negative costs they present. Nevertheless, this type of waste contains huge amount of nitrogen coming from urea–formaldehyde and melamine–formaldehyde resins associated with wood and which are responsible for the production of nitrogen species (ammonia, isocyanic acid, hydrogen cyanide, NOx) during classical thermo–chemical conversion (combustion, pyrolysis, gasification).

A two steps process of thermo–chemical conversion has been setting up: a first low temperature pyrolysis step which aims to remove nitrogen and a second step to produce combustible gases for different applications (combustion, cogeneration, bio–oil). The aim of this work is to study the first stage of this multi-steps process (removing nitrogen) with several parameters combinations in saving the maximum of energy in the combustible.

Experiments are achieved in a quartz tubular furnace and the gases produced are analysed by FTIR spectrometry. The quantities of removed nitrogen are obtained by comparison of the ultimate analysis of initial and treated samples whereas the quantity of recovered energy is determined by tests in calorimetric bomb. Results show that high quantity of nitrogen can be removed by this low temperature pyrolysis step. It has been shown that treatments temperature has an influence on the necessary time to eliminate nitrogen and on the available quantity of energy.
PRODUCTION OF HYDROGEN BY CATALYTIC STEAM REFORMING OF THE AQUEOUS FRACTION OF BIOMASS FAST-PYROLYSIS OIL (BIO-OIL)

Feifei C

Catalytic steam reforming of the aqueous fraction of biomass fast-pyrolysis oil (bio-oil) was studied as a strategy for producing hydrogen. The process combines the merits of renewable feedstock and convenient transportation. In this paper, a fixed-bed reactor was employed to investigate the performance of Ni/CeO2-ZrO2 catalysts for hydrogen production from bio-oil. Effects of steam to bio-oil ratios, reaction temperatures, and Ni and CeO2 content on the catalytic performance of Ni/CeO2-ZrO2 catalysts were examined and the catalysts were characterized by means of XRD and BET. Obtained results were compared with commercial nickel-based catalysts(Z417).
A newly experimental set-up was developed for gasification of biomass shown in Figure 1. This experimental set-up can control temperature up to 1300 K and gasify sample under vacuum or up to 300 kPa. Generated gases are analyzed the composition by using a gas chromatography.

In this study, woody biomass and waste plastics were gasified under no oxygen and analyzed its generated gas. It is clearly that the different temperature region makes different generated gases. That is, low temperature under 350 °C make carbon oxide mainly. Hydrogen or gases containing hydrogen atom like methane are generated over 400 °C. Hydrogen gas is generated around 700 °C mainly and 1000 °C too.

Thermogravimetry/differential thermal analysis (TG/DTA) under nitrogen gas has done too. About 10 mg of sample was analyzed by pyrolysis mass-spectrometry. In case of woody biomass, about 6 % mass was decreased under 200 °C and this is almost moisture. About 70 % mass was decreased up to 400 °C, and almost generated gases are carbon oxides. Around 700 °C, rapid decreasing of mass is confirmed, and generated gases are gases containing hydrogen atom mainly.
Biomassekraftwerk Guessing (the Guessing Group) and the University of Redlands and ESRI, Inc., both of Redlands, California (the Redlands Group), are working together to site the first mixed waste stream polygeneration demonstration project in Southern California. The site criteria for the project will be analyzed using a geographic information system (GIS) model. Input data to the model include waste stream component analysis, transportation and delivery, parcel size, land use compatibility, etc. The GIS model has broad application for evaluation of optimum site locations for polygeneration facilities with a variety of biomass resources.
STEAM/OXYGEN GASIFICATION IN A FLUIDIZED BED GASIFIER AND BIO-DIESEL/WATER SCRUBBER ANALYSES FOR POWER GENERATION

Fanelli E, Freda C, Nanna F, Villone A, Canneto G, Barisano D

Heat and power can be produced from biomass via thermochemical technology such as combustion, gasification or pyrolysis. Biomass gasification allows the conversion of different biomass to a more convenient energy gaseous carrier. Compared to the direct combustion of biomass, the production of fuel gas can be exploited more efficiently in various application such as: internal combustion engine (efficiency of 30-35%), and advanced systems gas turbine based (BIG/GT or IGCC, efficiency of 40-45%). In the latter use, the syngas from the gasification section, after cleaning is fed and burned into a gas turbine (GT). Since the exhaust gas from the GT is generated at about 580°C, by recovering heat from the flue gas additional power can be produced via a steam turbine unit (electrical efficiency up to 45-50%). Higher efficiency can be obtained with a DHP configuration, where the residual heat of the gaseous stream is further recovered for district heating.

Despite the great potential of BIG/GT or IGCC systems, because of some technical problems these system are still at the experimental stage. To the full technology development of the power production from biomass gasification via atmospheric GT based systems, two kinds of drawbacks can be identify as the major obstacles. The first one concern the need to cool and pressurise the syngas before injecting it in the gas turbine. This need can cause tars condensation upstream the gas combustion section and consequently give rise to problems of system operation. The second one is correlated to the presence in the syngas of alkali halides, which can damage the turbine blades by hot corrosion phenomena. Therefore before being fed to the GT system, the syngas has to be deeply cleaned.

At the research centre of Enea Trisaia (Italy) is under development an innovative gasification plant which main objective is the production of a high purity, hydrogen rich, syngas to be used in advanced applications such as gas turbine and fuel cell. The plant is based on a 1 MWth fluidized bed gasifier and uses steam/oxygen mixture as gasification medium. For alkali halide vapour and tars removal the cleaning section is equipped with an hot ceramic filtering system and a bio-oil scrubber. In the present study results from the experimental activity curried out at a 10 KWth bench-scale facility are presented.

The plant was operated to assess the overall performance. To this aim a tests campaign was performed in autothermal mode, at temperature of 850 °C and pressure of 1 atm. Different steam/biomass ratio (0.5-2) were explored. Gas composition and cleaning efficiency at different operating condition were evaluated. The syngas yield was found to be of about 1 Nm3/kg(daf biomass). The hydrogen and carbon monoxide content was of about 26-30%v and 37-26%v, respectively. A low heating value (LHV) of about 11-13 MJ/Nm3 was calculated.
SYNGAS UTILIZISATION IN A 100KW MICROGASTURBINE WITH MODIFIED COMBUSTION CHAMBER

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Utilization of syngas in a gas turbine instead of a gasengine leads to several advantages: In order to achieve sufficient power input with a gasengine, the gas has to be cooled down, which subsequently leads to condensation of the tars.

With utilization of a gasturbine, the gas can be supplied above condensation temperature of the tars. Sensible heat and tars remain in the syngas resulting in an efficiency increase of the process.

Furthermore, pressurized gasification allows the elimination of the fuel gas compressor but requires fuel input against pressure into the gasifier on the other hand.

The poster presentation will explain the process scheme of allothermal steam gasification with Heatpipe-Reformer® technology and the utilization of a modified Microgasturbine Turbec T100.

Main topic will be the results of research and development regarding modification of the combustion chamber and the fuel distribution system (FDS):

1. Implementation of syngas-piping with reference to higher mass flow, higher temperatures up to 400°C and new control system of pilot- and premix gas.

2. Replacement of original Turbec burner with an hse premix burner (using ALSTOM-technology). The design of the burner considers the influence of the flame velocity, mainly triggered by the hydrogen content up to 40%vol.

Furthermore, the chosen design reduces risk against flash-back, since syngas and air will not be mixed before they are injected into the combustor.

3. The standard natural gas compressor has been eliminated, which leads to an increase of power output of about 10%.
TAR COMPOSITION IN THERMO-CHEMICAL BIOMASS CONVERSION PROCESSES

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The global warming, the increasing CO2 emission, the combustion of and dependency on fossil fuels, as well as the high-energy price have resulted in an increasing demand in renewable energy source. Biomass, as a renewable energy source, has the potential to contribute to the future energy mix in various ways.

In thermo-chemical biomass conversion processes, especially gasification and pyrolysis, the tar content and composition is a major subject. Due to the various processes examined at TUV, this work picks up the opportunity to compare the different tar amounts and its composition at different temperatures and process parameters. The steam gasification tar contents of straw and wood producer gas as well as slow straw pyrolysis tar yields are compared in the following work.

Pyrolysis experiments were conducted in a rotary kiln reactor at a temperature range from 600°C to 630°C. Gasification experiments were carried out in a 100 kW dual fluidized bed gasifier at a temperature variety of 800°C to 870°C.

For better understanding of the tar transformation during thermo-chemical conversion of biomass the tar was analyzed with a gas chromatography/mass spectrometer to gain its composition.

Main observation was at higher temperatures the tar composition is shifted to higher molecular tars as poly aromatic hydrocarbons (PAH). Key tar components at lower temperatures (pyrolysis) are phenols. A comparison of these two thermo-chemical processes, in particular because of the separate performance of pyrolysis and gasification, leads to a better understanding of tar transformation during biomass conversion. Therefore for the future an optimization of both processes should be easier to accomplish. For gasification that means lower tar content in the producer gas and for pyrolysis achievement of required pyrolysis oil yield.
THE EFFECTS OF INLET POSITION ON THE FLOW DISTRIBUTION DURING THE PULSE-JET CLEANING OF A CERAMIC FILTER VESSEL

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Particulates of high concentration in the gas stream are accumulated on the surface of the filter element as the gas passes through it and forms a dust cake. The dust cake should be removed periodically to reduce the pressure drop. Pulse-jet injection is one of the effective methods to clean the filter element by applying the high pressure into the filter cavity. An instance momentum of the over pressure is formed in the filter cavity during the injection of the pulse gas. The over pressure is the main driving force to overcome the binding force between cakes and filter medium and remove the dust accumulates on the surface of the candle filter. So it is better as high as possible.

The particles detached after the pulse cleaning should be well removed by the settling force of themselves into the bottom area connected to the dust outlet facility. It is sure that the flow dynamics should be influenced by the inlet position of the dust gas into the filter vessel. We are roughly understood that the inlet at upper position will help for the settling of the detached-dust owing to the development of under gas flow in the filter vessel. Otherwise, the inlet at bottom position will inhibit the settling moment of the dust cake. Several studies on the gas flow and dispersion and particle deposition in a filter vessel are reported by several authors. Especially, Park and Park [1] recently reported in their computational work that the middle position inlet shows uniform distribution of particle deposition on the filter surface as well as the lowest particle concentration among the upper, middle, and bottom positions. However, their results are not proven in an actual operation unit.

The gas flow patterns and the particle attainments in the filter vessel are investigated in this study. The profiles of the transient pressure and temperature in the filter cavity as well as the outside of filter element during the pulse cleaning were carefully measured to estimate the effect of the inlet positions.

REFERENCES

In recent years, the importance of alternative energy sources using renewable raw materials has increased. Biomass gasification is one of the most efficient technologies for biomass energy conversion. It offers the advantage of product flexibility, e.g. heat, power or synthesis gas for production of synthetic fuels. The “UNIQUE” project aims at the development of a compact version of a gasifier for syngas production with specifications required for the use in fuel cells. Thereby, several technical processes like the fluidized bed gasification, the hot gas cleaning and the gas conditioning system are all integrated (unified) into one reactor vessel. The bed material consists of a catalytically active mineral substance to reach a primary tar reforming and is mixed with sorbent material to reduce the detrimental trace elements. Further, a bundle of ceramic candle filters is placed in the freeboard of the gasifier. The operation temperature of the gasifier and the filter is 800-850°C. With this gasifier design the thermal efficiency is kept high, as no cooling step is included. Further particle entrainment in the product gas is avoided. The hub of this project is the Güssing Gasifier in Austria and the use of the biomass-fuelled IGCC as pilot plant.

Aim of the present work was to proof the feasibility of chemical hot gas cleaning in the “UNIQUE” gasifier in a first step via thermo chemical modeling using the software package SimuSage (GTT-Technologies). As syngas derived from biomass treated in a fluidized-bed gasifier suffers from contaminants released during thermal conversion, which can harm downstream equipment, e.g. by fouling, filter plugging and poisoning of catalysts, the modeling is focused on detrimental inorganic contaminants. The most important detrimental inorganic contaminants are alkalis, with other contaminants including HCl, sulphur compounds and particulates. By using the design of the thermo chemical model shown in figure 1 the release of detrimental inorganic contaminants during gasification of biomass used in the “UNIQUE” project and the retention potential of sorbents can be calculated.

Metal oxides like CaO and CuO were chosen as sulphur sorbents and alumino silicates as alkali sorbents. The paper will present the results of the thermo chemical calculations. The results clearly indicate that sorbents like alumino silicates are suitable to sufficiently remove alkali species for woody biomasses. In addition, sulphur can be limited to values compatible with reforming catalysts.

Keywords: synthesis gas, biomass gasification, chemical hot gas cleaning, thermo chemical modeling
Build-up and experimental plant tested pilot equipment on gasification sorted waste and biomass for combination production electric equipment and heat energy by the help of turbine-generator unit powered by hot air Solving project presents proposal and production pilot conceptual quite new combined heat and power unit. Consists in utilization single shaft turbine-generator unit, where’s compressor pressure air in exchanger, constitutive combustor energy gas heated beyond temperature 900 °C and subsequently expanded graphite in two stage expansionary turbine. From turbine way out air

with temperature c. 450 °C is used for gasification and burning. Energy gas in this case doesn’t need to in face of combustor cool down nor purify from tar dust. Supposed electric output in this system will 75 kWe or 2 x 75 kWe.
VII

Gasification Guide
GUIDELINE FOR SAFE AND ECO-FRIENDLY BIOMASS GASIFICATION

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ABSTRACT: Biomass gasification is considered a promising technology that can contribute significantly to renewable energy generation. The technology is close to commercialisation but large-scale implementation is hampered by the poor awareness and lack of understanding of Health, Safety and Environment issues; authorities tend to impose unrealistic and costly requirements on gasification plants. A broadly accepted HSE guideline would effectively tackle this barrier. The main objective is to accelerate the market uptake of biomass gasification technology by developing a guideline that is accepted by relevant target groups and key market actors. The HSE project will result in a Guideline and a Software Tool for easy and systematic assessment of HSE hazards in biomass gasification plants. This can be used in designing more safe and eco-friendly equipment, in the construction of plants, and in the operation and maintenance procedures. The Guideline and Software Tool will be developed in close co-operation with existing thermal biomass conversion networks to gain optimal benefit and feedback of these platforms into the HSE project. The draft Guideline and software tool are available through the website www.gasification-guide.eu. This paper describes the status of the Guideline and software tool.

Keywords: biomass, conversion, gasification, barriers, legal aspects

1 BACKGROUND

Pilot and prototype biomass gasifiers often operate under temporary (trial) environmental licenses for which emission limits are usually somewhat ‘relaxed’. For gasifiers intended for commercial operation permitting authorities have a tendency to impose unreasonably strict emission limits and safety measures due to their lack of familiarity with and understanding of the technology. For permitting authorities and other key market actors it appears difficult to properly appreciate Health, Safety and Environmental (HSE) risks.

This lack of knowledge and poor appreciation of HSE hazards was identified by leading experts from the gasification networks GasNet (later: ThermalNet) and IEA Bioenergy Agreement Task 33 as an important barrier for the implementation of gasification technology. It has been on their agenda since the early 2000’s. Non-technical barriers as identified in these networks include:

- Lack of knowledge and awareness on potential HSE risks associated with the construction, operation and maintenance of gasification plants;
- Lack of separate emission legislation (in most cases the Waste Incineration Directive has to be fulfilled);
- The general negative public perception on bio-energy as a clean energy source;
- Lack of knowledge at permitting authorities;
- Lack of standards and certification.

Lacking the financial resources the mentioned gasification networks were not able to actively tackle the problem. Stimulated by both networks a separate project was formulated and approved by the European IEE programme. Funding for a three-year project was secured in 2006, and the project started in January 2007.

The development of a practical biomass gasification guideline in close consultation with a leading HSE authority and based on realised and planned biomass gasification plants will help to ensure that in future permitting authorities draw up reasonable and fair HSE requirements, and that the identified barriers to the market uptake of the technology will be removed.
2 OBJECTIVES

The aim of the project is to accelerate the process of market introduction and commercialisation of gasification by developing an accepted guideline and associated software tool for relevant target groups and market actors on potential HSE hazards of biomass gasifiers up to about 5 MWe. In this context, accepted means acknowledged and used by manufacturers and authorities. Specific objectives include:

• To remove an important non-technical barrier for wide-spread market introduction of biomass gasifiers, i.e. awareness on HSE hazards, by:
  • Identifying all possible HSE hazards associated with construction and operation and maintenance of biomass gasifier plants (BGPs), and of recommendations to reduce these hazards;
  • Raising awareness of communities, (potential) customers and public authorities on the HSE hazards in such way that fewer objections are raised and procedures are shortened and simplified;
  • Guiding manufacturers and technology developers in the development of safe designs and safe operation & maintenance of the plants;
  • Disseminating the guideline and spin-off results to the target groups; and
  • Simplifying and shortening of procedures, in particular for permitting;
• To decrease financial risks of investors to stimulate the market implementation;
• To remove associated non-technical problems like the negative public perception of biomass gasification;
• To benchmark the legal frame for plant permission and operation;
• To recommend a better fit of the EU legal framework to biomass gasification, in particularly regarding emission levels;
• To create a framework for the further development of the guideline to an international accepted technical standard, which can be used for commissioning, guarantee, acceptance testing and certification.

3 PROJECT PARTNERS AND CONTRIBUTORS

Seven full partners and two sub-contractors are directly involved in the preparation of the guideline (see Table 1).

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<tr>
<th>Participant name</th>
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<td>BTG biomass technology group</td>
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<td>Technical University Graz</td>
<td>Austria</td>
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<td>Fördergesellschaft Erneuerbare Energien e.V (FEE)</td>
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Various other groups indirectly contribute(d) to development of the guideline, including:

• A project Advisory Board, consisting of some 20 experts, manufacturers, authorities and other stakeholders from around the world;
• The biomass gasification expert networks ThermalNet and IEA Bioenergy Agreement Task 33;
• Manufacturers and owners of gasifiers plants that were the subject of case studies, and helped with the validation of the guideline and the software tool;
• The FEE-led Arbeitsgruppe Biomassavergasung (Working Group Biomass Gasification).

4 WORKPLAN AND APPROACH

Preparation of the guideline is executed in the following systematic way:

• Benchmarking the legal framework for plant authorisation and operation. Gasification plants have to be planned, built and operated according to several European and national directives, guidelines, laws, standards etc. This means there is a need for a legal basis for manufacturers, operators, permitting authorities etc. for placing technologies on the market as well as the development of a guideline and a software tool to simplify and shorten procedures, in particularly for permitting;
- Systematic description and classification of gasification plants. The description includes main unit operations, typical process parameters, possible plant process configurations, critical process requirements, etc. An example of a process chain is presented in Figure 1.

- HSE risk assessment study covering the consequences of possible accidents, spills, emissions, toxicity, etc. A risk assessment study is the base for safe plant design and needed to obtain the necessary permits for plant construction and operation. The main potential hazards are illustrated in Figure 2.

- Determination of technical possibilities to avoid or minimise the HSE risks and their consequences, economic impact, Best Available Technology solutions;

The experience is presented systematically in case studies, which help guiding the preparation and validation of the Guideline and the Software Tool.

- Preparation of a Guideline for safe and eco-friendly biomass gasification;
- Collecting information from gasifier manufacturers and plant owners through site visits and interviews on practical experiences with the authorisation of existing and planned biomass gasification plants. Information is collected on e.g.

  - How HSE issues were taken into consideration during engineering, planning and construction,
  - How HSE issues were taken into consideration when formulating operating and maintenance procedures,
  - Which Standards and Directives were considered,
  - How legislation and permitting procedures influenced the plant design or concept,
  - Which procedures and safety measures need to be considered in future.

5 PROGRESS AND INITIAL RESULTS

The progress to date can be summarised as follows:

**Legal framework:** Planning, building, commissioning, and operation of biomass gasification plants are activities that are subject to European and national regulations. In order to determine the relevant legal framework for small and medium biomass gasification plants, it is useful to draw a rough distinction between those requirements applying to the design and manufacturing of BGP.s (as products that are to be placed on the European market) and those applying to ownership and operation – in simple terms, to distinguish between the manufacturer’s and the operator’s duties.

![Figure 1: Typical process chain (simplified) of a biomass gasification plant for combined heat & power generation](image1)

![Figure 2: Potential Heath & Safety aspects of a biomass gasification plant](image2)
The underlying legal background is different for the two parties. While the legal framework with regard to the safety of products placed on the market is rather homogeneous throughout Europe, the legal framework for plant operation displays many variations across the European Member States.

The project provided a general overview of the legal areas that apply to biomass gasification plants, both from the manufacturer’s and from the operator’s point of view. The focus is on legal requirements towards health, safety and environment (HSE). Hazard identification and risk assessment are among those legal HSE requirements that have to be met both by the manufacturer and by the operator.

Risk Assessment: The technology of biomass gasification differs from other energy conversion technologies based on renewable energy sources (e.g. biomass combustion) because it inherently involves the production, treatment and utilisation of flammable and toxic gas mixtures, plant media and utilities. Therefore an adequate risk assessment is strongly recommended and is often a legal requirement for placing the plant into the market and running it.

A risk assessment is aimed at protecting the workers and the plant itself. It consists of a careful examination of what could cause harm to the people and environment in the plant, and the adoption of reasonable control measures. The manufacturers/operators have to produce a complete and well-documented assessment of the risk relative to:

- **Health** – e.g. hazards to human health, dangers from toxic gases, etc;
- **Safety** – e.g. explosion hazards, fire hazards, etc;
- **Environment** – e.g. plant emissions, loss of containment relating to toxic substances, etc.

A risk assessment has to be carried out during the planning phase (for manufacturers) in order to improve the plant’s conceptual design. In existing plants, a risk assessment allows the reduction of the remaining risks by continual updating of the original risk assessment (for manufacturers and operators).

Different methods for risk assessment are available but procedures for risk assessment are not generally standardised for biomass gasification plants. The project recommends using a risk assessment methodology based on functional analysis of the plant.

It follows principally the Hazard and Operability Studies (HAZOP) and Failure Modes Effects and Criticality Analysis (FMEA) methods, as well as recommendations given by an expert commission. An example is illustrated in Figure 3.

**Figure 3**: Example of a Risk Assessment procedure

**Case Studies**: Practical information was collected as input for drafting the Guideline. An elaborate questionnaire, focusing on plant design and constructional aspects, was sent to plant owners and manufacturers. This was followed-up by a site visit. The collected information gave valuable input to drafting the Guideline.

In a second round of case studies the target groups – in particularly permitting authorities – are interviewed to give their feedback after using the draft guideline in order to validate the usefulness of the draft guideline and identify room for improvement.

**HSE Guideline**: A first draft Guideline was produced in early 2008 and a second draft in early 2009. The guideline is intended to be a training tool and a resource for workers and employers to safely design, fabricate, construct, operate and maintain small scale biomass gasification facilities (about up to 1 MWe). The use of contaminated biomass and/or the application by larger companies is beyond the scope of this Guideline. In the Guideline less emphasis is placed on gas engines, as these are commercially available and already come with a CE mark and Declaration of Conformity.
In the formulation of this HSE Guideline, the following process steps and system components have been considered:

- Fuel storage and handling on site
- Fuel conveyance and feeding
- Gasification reactor
- Gas conditioning (cleaning and cooling)
- Gas utilization (gas engine)
- Automation and control
- Auxiliaries and utilities

The Guideline contains the performance levels and measures that are generally considered to be achievable in new facilities by existing technology at reasonable costs. Application of the Guideline to existing facilities may involve the establishment of site-specific targets, with an appropriate timetable for achieving them. The applicability of the HSE Guideline should be tailored to the hazards and risks established for each project on the basis of the results of an environmental assessment in which site-specific variables are taken into account. The applicability of specific technical recommendations should be based on the professional opinion of qualified and experienced persons.

The HSE Guideline is intended to be a “living document” at its inception. Given the broad applicability and use of the Guideline as reference documents, it must continue to meet internationally-accepted standards on pollution prevention and control, as well as occupational and community health and safety.

Initial response to the draft Guideline, prepared in 2008 and distributed electronically to more than 300 stakeholders, is very positive. More than 80 interested companies and institutes from 30 countries actively requested a copy through the project website. Among the interested organisations are several authorities charged with a permit application for a biomass gasification plant.

Software Tool: A software tool (called RISK ANALYSER) was developed to facilitate the implementation of the risk assessment proposed in the HSE guideline. In the software, a recommended risk assessment procedure is implemented which is practicable and sufficient for the application in small-scale biomass gasification plants. The risk assessment procedure with the software follows eight steps:

1. Definition of plant basic data
2. Definition of process units
3. Definition of functions
4. Definition of the operation modes
5. Definition of parts
6. Risk assessment
7. Countermeasures
8. Summary

At the end of the full risk assessment a report can be generated that can be used as documentation.

Checklist: The Guideline includes a checklist, intended for use by the main target groups (manufacturers and permitting authorities), for easy assessment of the risks, the consequences and the countermeasures. The checklist follows the general layout of a gasification plant starting at the biomass storage facility up to the gas utilisation device, in most cases a gas engine. Manufacturers can use the checklist as a reference whether all risks have been considered and the permitting authorities can use the checklist to validate whether all countermeasures are in place.

Stakeholder Involvement: The project puts a lot of emphasis on outreach to stakeholders. The preferred method is the organisation of stakeholder workshops. To date, the following workshops have been organised:

The first European workshop was held on 23 April 2008 in Vienna. It was organised in cooperation with the ThermalNet project and the IEA Task 33 on biomass gasification. Almost 70 persons attended the workshop. The first draft of the HSE Guideline was presented, and a panel discussion was held in which attendees from Europe and North America discussed safety issues from their own practice.

German subcontractor FEE organised various meetings on the topic, including one that was formally part of the project. The first FEE event where the Guideline was discussed was a meeting of the (German) Biomass Gasification Working Group, held in Rosenheim (Germany) in August 2008. Many German and Swiss manufacturers of small and medium biomass gasifiers attended this meeting.

The second FEE event where the Guideline was discussed was a public workshop held in Stuttgart in January 2009 in conjunction with the 3rd International Conference on Application of Biomass Gasification (ICABG). The workshop aimed to an in-depth intensive exchange of knowledge and experiences between concerned parties. The organisers wanted to:

1. Provide a platform to technology and market pioneers to pave the path into the European market,
2. Discuss the draft Guideline, the software tool and checklists with experts, manufacturers, operators, experienced in permission planning engineers and
representatives from permitting authorities from several countries.

- Offer operators - who are ready to take the early risk - opportunities for exchange of know-how,
- Give potential investors security and to convince them, time to act has come, now,
- Stipulate authorities to improve permitting practice,
- Reach a consensus on all controversial items in the draft Guideline and the feedback from the audience on these aspects, which could be a useful tool to get those issues clarified.

Figure 4: Public Workshop in Stuttgart, January 2009

In the second half of 2009, the following additional workshops will be held:

- The second European workshop will be held on 3 September 2009 in Vienna, in conjunction with the International Conference on Poly-generation Strategies (www.icps09.org).
- A regional workshop for stakeholders from the new EU Member States will be held in the autumn of 2009, probably in Bulgaria.
- A regional workshop for stakeholders from Nordic Countries will also be held in the autumn of 2009, probably in Denmark.
- Finally, the Guideline will be a key topic at the next meeting of the German Biomass Gasification Working Group (Herstellertreffen für Biomasse-Vergasungs-BHKW), organised by FEE on 14 and 15 August 2009 in Berlin.

6 CONCLUSIONS

Preliminary conclusions include:

- In most European countries there are no specific regulations for biomass gasification plants (BGPs). Gasification is often treated similarly to other thermal processing technologies such as combustion or incineration, which hampers the market penetration of small to medium scale BGPs.
- Leading European BGP manufacturers that respect client demands for safe equipment, CE marking and risk assessment are close to full commercialisation of small to medium scale biomass gasification technology.
- Streamlining of BGP permitting procedures and harmonization of existing BGP regulations within the European Community is considered crucial for the accelerated deployment of biomass gasification plants.
- There is significant interest from the target groups in the Guideline. This is concluded from the fact that workshops organised to date are well attended and that more than 80 requests were received to obtain the Guideline.

7 INVITATION

The active involvement of stakeholders strengthens both the quality and relevance of the Guideline and the Software Tool. Manufacturers, owners, permitting authorities and other interested parties are warmly invited to share their views on, and experience with, biomass gasifiers permitting and the use of the Guideline and Software Tool. They are likewise invited to participate in and contribute to the project as object for a case study or for software testing. Information can be found on the website www.gasification-guide.eu or please contact the coordinator at knoef@btgworld.com.

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