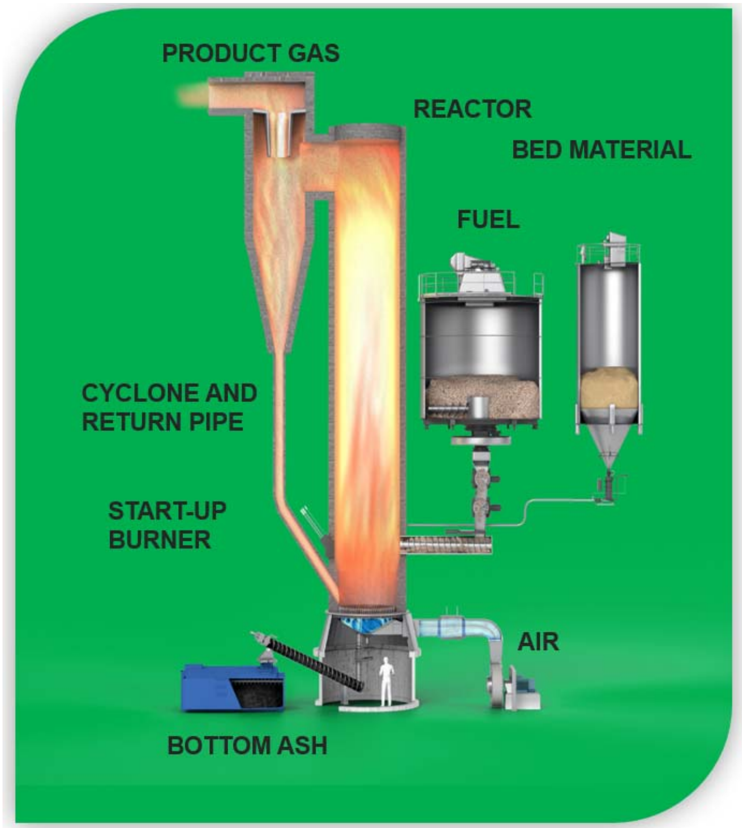
IEA Bioenergy, Task 33 – Gasification of Biomass and Waste



Workshop

Fluidized bed conversion of biomass and waste

24. October 2017, Skive, Denmark

Summary by Dr. Jitka Hrbek, Vienna University of Technology

and

Prof. Kevin Whitty, University of Utah

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Introduction

In fluidized bed conversion units (gasifiers and boilers) fluidizing gas is blown through a bed of solid particles at a sufficient velocity to keep these in a state of suspension. The bed is heated and the feedstock is fed into the reactor as soon as a sufficiently high temperature is reached.

The fuel particles are introduced at the bottom of the reactor or can be fed into the bed or over the bed as well. The particles are very quickly mixed with the bed material and almost instantaneously heated up to the bed temperature. As a result of this treatment the fuel is pyrolysed very fast, resulting in a component mix with a relatively large amount of gaseous materials.

Fluidized bed gasifiers and boilers can better process materials with higher ash content as typical for biomass and in general, this type of conversion unit is better suited for large-scale operations.

Fluidized bed reactors can be divided into stationary bubbling fluidized beds and circulating fluidized beds. Bubbling fluidised bed (BFB) is the classical approach where the gas at low velocities is used and fluidisation of the solids is relatively stationary with limited elutriation of material from the bed.

In circulating fluidized beds (CFB), gases are at a higher velocity sufficient to suspend and lift the particle bed, due to a larger kinetic energy of the fluid. As such the surface of the bed is less smooth and by design more particles can be entrained from the bed than for stationary beds. Entrained particles are recirculated via an external loop back into the reactor bed. Depending on the process, the particles in the external loop may be classified by a cyclone separator and separated from or returned to the bed, based upon particle cut size.

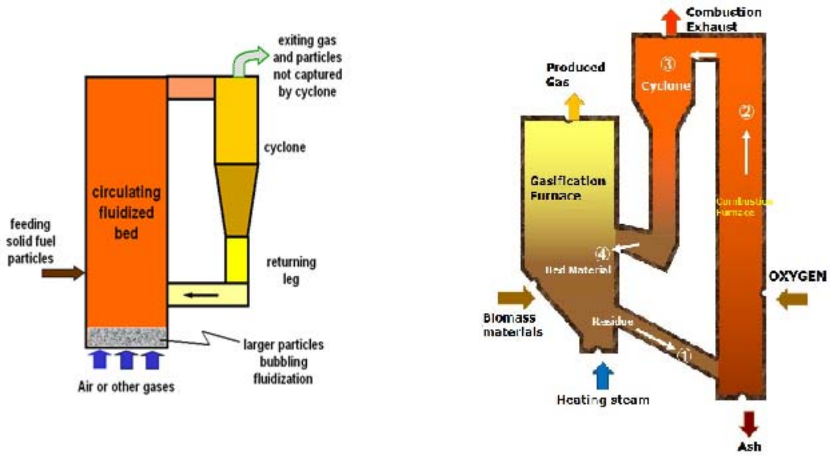

Figure 1: Examples of circulating fluidised bed units

Fluidized bed conversion of biomass and waste

Workshop presentations

Heat and mass transfer to fuel particles in fluidized bed combustors and gasifiers

B. Leckner, Chalmers University of Technology, Sweden

Heat and mass transfer between the gas and active particles in fluidized beds was the topic of the first workshop presentation. The following figure shows two large active particles surrounded by smaller inert particles in a bed with fluidization velocity u.

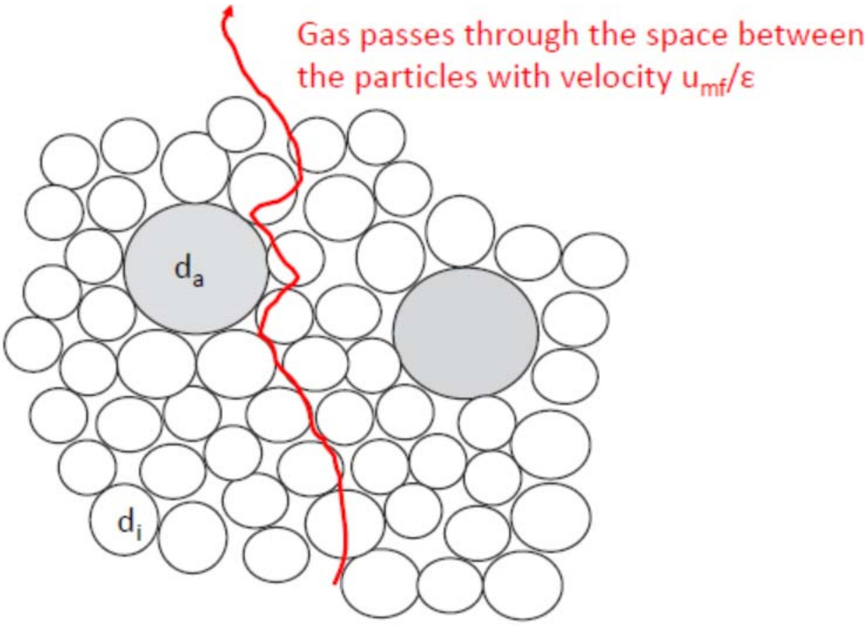

Figure 2: Heat and mass transfer between particles in fluidized bed

There are many correlations giving different results having a similar structure. An overview of the relevant published heat transfer data is shown in the following figure.

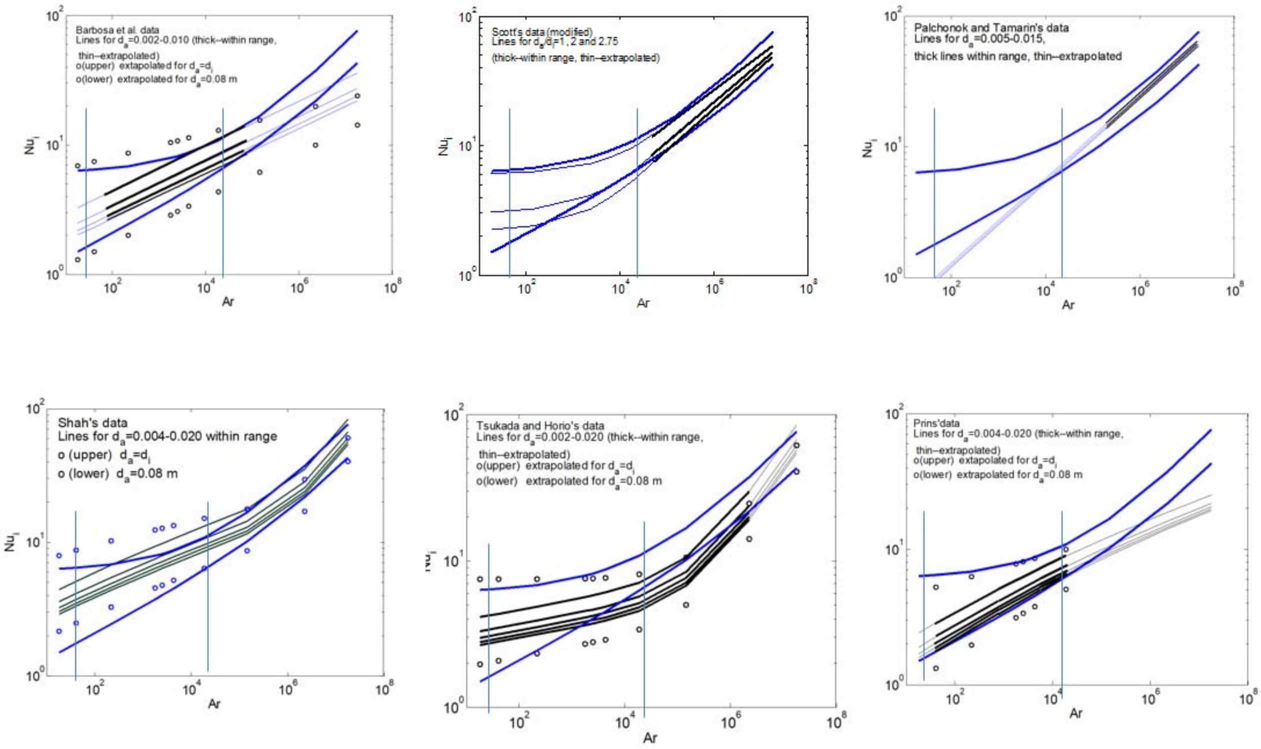

Figure 3: Overview of the published heat transfer data

The agreement between available correlations on heat and mass transfer to active particles in fluidized beds is not extremely high. However, the data in the measured ranges are at least within the limits of the Baskakov-Palchonok approach. A seemingly more accurate estimation would be given by the correlation of choice, applied within its measured range. Most correlations (exception Prins' for mass transfer) give erroneous values when extrapolated to large active particles. Despite the dimensionless representation, the correlations depend on the properties of the media, e.g. the Schmidt number in the case of mass transfer.

Co-firing of torrefied biomass and coal in oxy-FBC with Ilmenite bed material

R. Hughes, CanmetENERGY, Canada

In the R&D program introduced here, oxy-pressurized fluidized bed combustion (oxy-PFBC) uses biomass and fossil fuels to produce heat and power for industrial applications at high efficiency with near zero emissions.

Here, torrefied wood was selected due to its favorable transportation, storage and handling traits, reduced volatile plumes extent upon injection, blending with fossil fuels provides fuel flexibility, scalability, and relatively high energy density.

CFBC technology was considered because it reduces risk of bed material agglomeration compared to bubbling bed combustion due to particle velocity; it can incorporate an external heat exchanger, and allows control of the gas atmosphere around main heat exchanger using clean recycled flue gas. Furthermore, fouling, corrosion and erosion risk to boiler could be minimized.

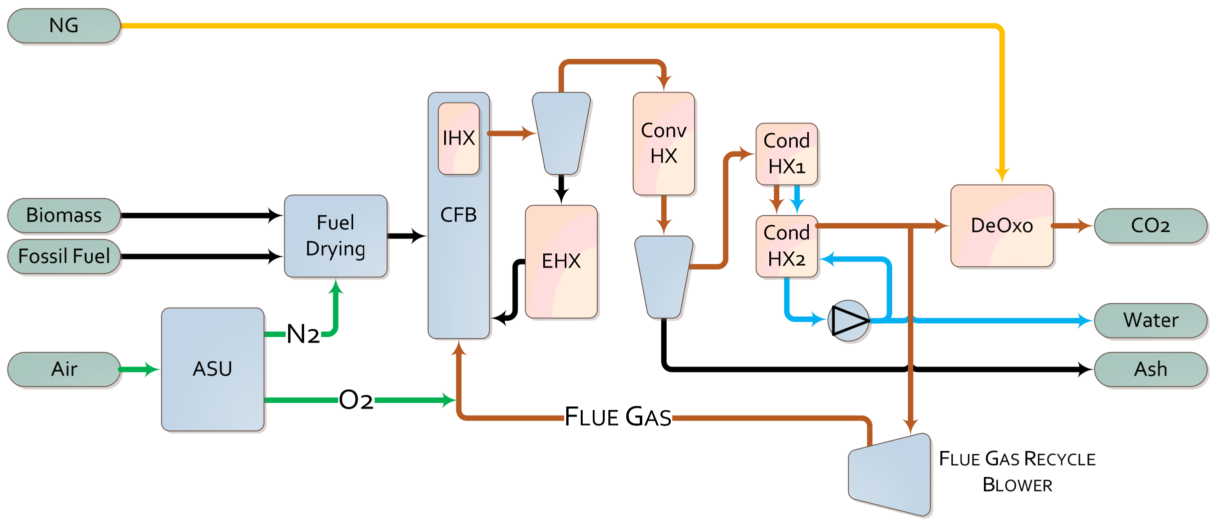

Figure 4: Process flow sheet oxy-PFBC

Process simulations have been completed to:

- Generate hot composite curves (enthalpy vs temperature) of the proposed configuration to select suitable operating conditions to match heating requirements of industrial heat and power applications
- Establish how much useful heat is available for process heating for various pressures, fuels, and fluidizing gas oxygen concentrations
- It was assumed that heat must be above 130°C to be useful for the purpose of this study – this is of course application specific
- Determine boiler efficiency (HHV): Heat input of all fuels / steam enthalpy
- Determine power requirements for ASU, recycle flue gas blower, condensate pump, and CO2 compressor

Range of conditions studied:

- Pressure 1 bar(g) to 40 bar(g) with base case of 15 bar(g)
- Airex torrefied wood (TW), Boundary Dam lignite, High value sub-bituminous coal
- Blends of torrefied wood and lignite with 25 wt%, 50 wt% and 75 wt% torrefied wood
- Oxygen concentration in fluidizing gas for riser of 21 vol%, 30 vol%, 40 vol%, and 50 vol% with base case of 40 vol%
- Heating input of solid fuels (wood + coal) maintained constant at 100 MW for all cases

Results presented:

- Effect of pressure on hot composite curve
- Preliminary parasitic power losses vs pressure
- Effect of fuel on hot composite curves
- Effect of oxygen concentration on availability of high temperature heat
- Approach to use biomass in oxy-PFBC

GoBiGas - 10 000 hours of gasification

A. Larsson, Gothenburg Energy, Sweden

GoBiGas is the world's first large-scale plant for production of bio-methane from biomass through gasification. The following table offers an overview on estimated production, consumption and performance goals of the project.

Table 1: GoBiGas – basic data

<table>
<tr><td colspan="2">Estimated Production</td><td>Estimated Consumption</td><td>Performance Goals</td></tr>
<tr><td>Biogas</td><td>160 GWh/y</td><td rowspan="5">Biomass 32 MW
Electricity 3 MW
RME (bio-oil) 0,5 MW</td><td rowspan="5">Biomass to Biogas > 65 %
Total efficiency > 90%
Operation 8000 h/y</td></tr>
<tr><td></td><td>20 MW</td></tr>
<tr><td>District heating</td><td>50 GWh/y</td></tr>
<tr><td></td><td>5 MW</td></tr>
<tr><td>Heat to heat pumps</td><td>6 MW</td></tr>
</table>

The GoBiGas gasifier can be operated with a wide variety of fuels with a stable gas quality, the temperature can be varied in the range of 790-870 °C with retained gas quality.

The following table shows the gas quality with different fuels.

Table 2: Gas quality with different fuels

	Typical operation wood pellets	Typical operation wood chips	Typical operation bark	Typical operation Return wood (A1)
Gasifier temp. (◦C)	870-830	790-830	850-820	830
H2 ($\%_{vol\ dry}$)	39-42	39-41	39-43	39-43
CO ($\%_{vol\ dry}$)	21-24	22-23	17-21	17-21
CO2 ($\%_{vol\ dry}$)	20-27	21-23	23-25	23-25
CH4 ($\%_{vol\ dry}$)	8.0-9.0	7.9-8.6	7.1-8.7	7.1-8.7
Tar (excluding BTX), (g/m_n^3 dry gas)	3.0-8.7	8.9-12.7	7.9-15.0	8.5-14
Tar (Including BTX), (g/m_n^3 dry gas)	9.7-23.3	22.1-29.5	21.7-33.4	22-26

The gas quality (tar level) is controlled by adding potassium to the process. Specifically K_2CO_3 dissolved in water (40%) is added to the combustion side.

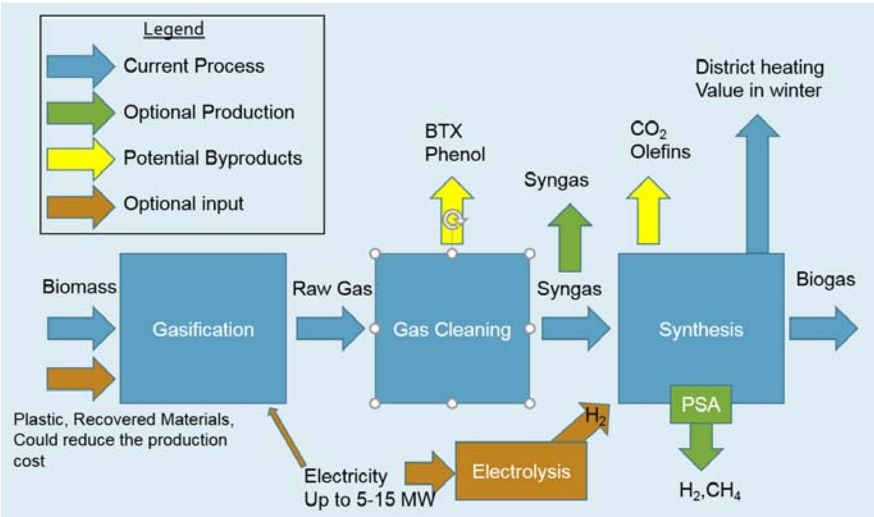

Figure 5: GoBiGas – plant potential

Conclusions:

- Good fuel-flexibility has been demonstrated
- High efficiency (up to about 70% biomass to product gas) can be reached with dry fuels
- With some modification on the fuel feed and product gas cooling the process is technically ready for commercialization
- Increased understanding of the function of potassium as well as the tar chemistry are required to optimize the gasification process and gas cleaning

Biomass utilization status and example in fluidized bed boilers in Korea

K. Park, KEPCO, South Korea

In 2012 a Renewable Portfolio Standard was introduced in Korea to promote the use and supply of renewable fuels and thus, selected suppliers must supply a certain amount of their total power generation capacity from renewable sources.

The following figure offers an overview on fuel application characteristics according to combustion type of existing facilities

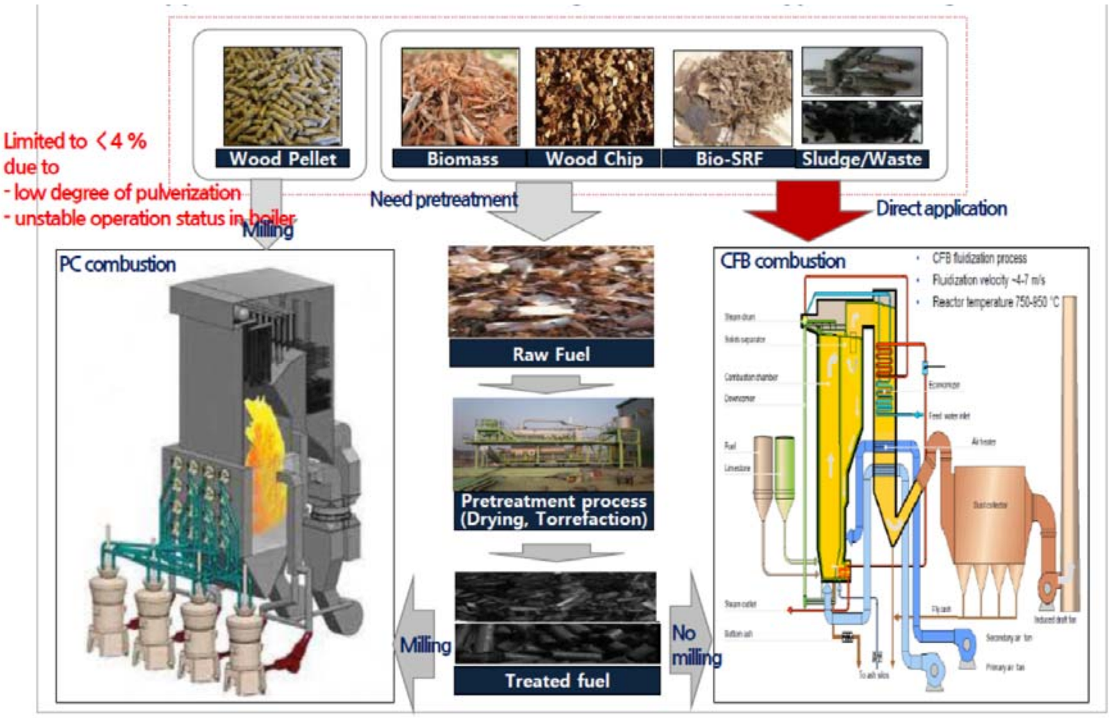

Figure 6: Biomass combustion in boiler – role of renewable fuel

The operation status of CFB boilers in Korea was presented. The shift from coal to waste streams and biomass is more obvious during the last years.

Commercial CFBC boilers were presented as well as KEPCO´s research experience (figure bellow).

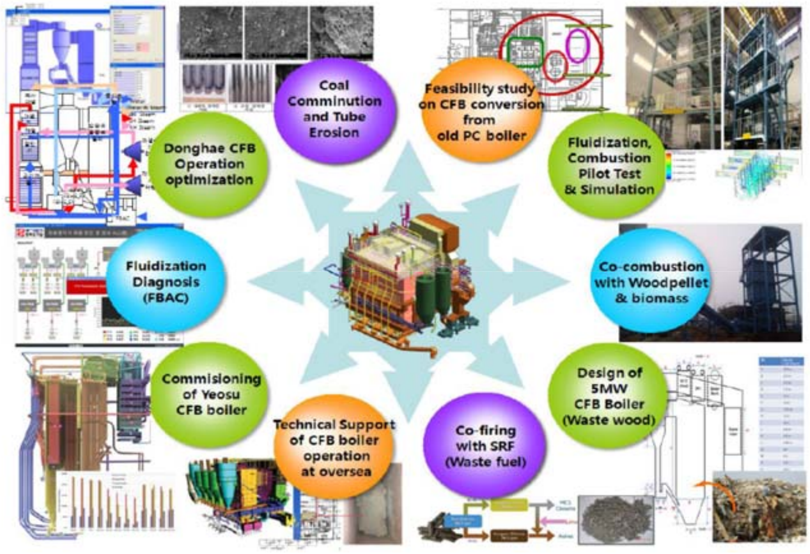

Figure 7: KEPCO´s research experience

Fluidized bed gasification and combustion of biomass

T. Kumagai, IHI Corp., Japan

IHI Corporation profile and business area were introduced at the beginning of the presentation.

IHI has developed technologies for reduction of CO_2 emissions. An effective approach is biomass utilization. 100% biomass fuel utilization has been realized by IHI Fluidized Bubbling Bed boiler (FBB) and Circulating Fluidized Bed boiler (CFB) technology.

Moreover, from the successful boiler technologies, the Twin IHI Gasifier (TIGAR®) has been developed for both coal and biomass gasification to be utilized for various applications – chemical production, power generation, methanation, etc. 100% biomass gasification and co-gasification of lignite and biomass has been achieved.

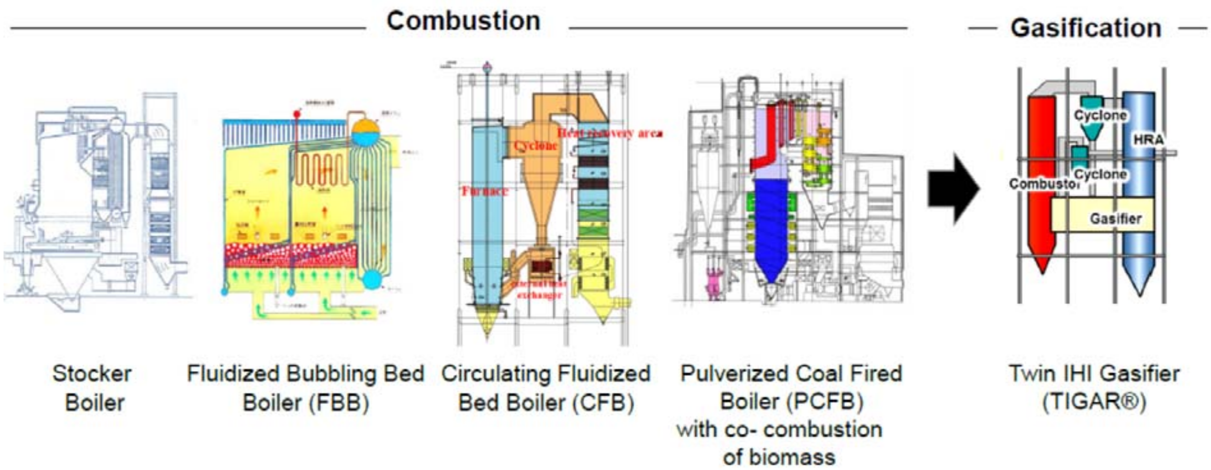

Figure 8: IHI´s product line-up on biomass utilization technologies

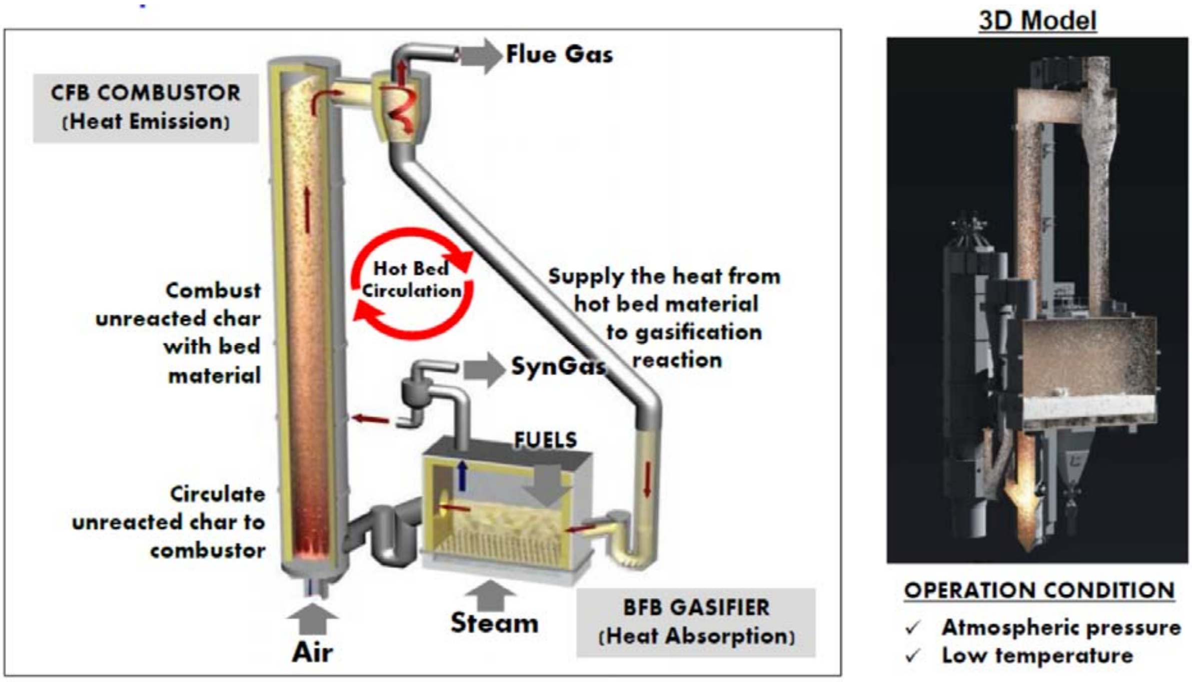

Figure 9: TIGAR gasifier

The syngas from the TIGAR gasifier could, after gas cleaning, be utilized for production of SNG by a methanation process and supplied to existing city gas infrastructure. In the 6t/d pilot plant in Yokohama, SNG production from biomass gasification has been successfully carried out.

At the moment a 50 t/d Twin IHI gasifier is being developed and will be constructed in Indonesia.

Conclusions:

- IHI has contributed to development of technologies for the reduction of CO_2 with biomass utilization.
- Various kinds of biomass can be utilized effectively by IHI's suitable combustion and gasification technologies at its economic and technical optimum.
- IHI is pursuing the realization of the further innovative and advanced technologies in the clean energy for the sustainable society future.

State of art CFB gasifiers and boilers for biomass and waste

J. Isaksson, Valmet, Finland

History as well as offering by business line of Valmet were presented.

- Biomass to Energy, Waste to Energy and Multifuel solutions
    - Fuel handling systems
    - Boiler islands, modularized power plants and heating plants
    - Air pollution control systems
- Products and Technologies

- Circulating fluidized bed boilers (CYMIC) and Bubbling fluidized bed boilers (HYBEX)
    - Biomass and waste gasification
    - Oil and gas boilers, waste heat recovery boilers
- Rebuilds and conversions
    - BFB conversions, capacity increases and lower emission levels
- Services

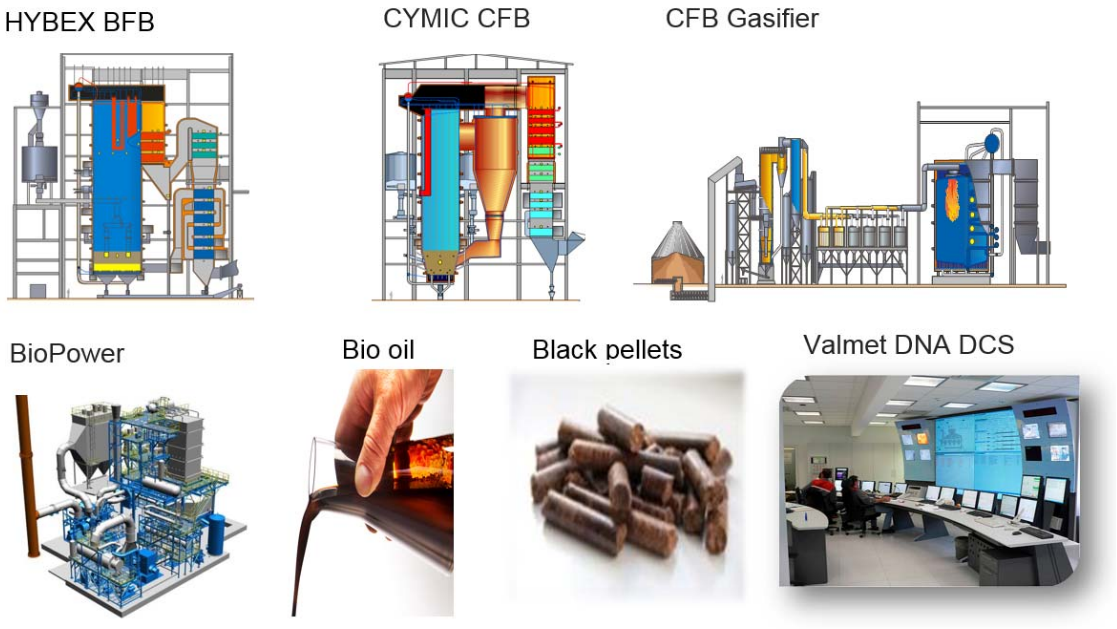

Figure 10: Valmet solutions for biomass and waste

Valmet CFB gasifier = large scale process equipment to turn biomass, waste and other reactive solid fuels into gas.

Features:

- Rugged steel frame
- Self- standing structure
- Prefabricated refractory
- Fuel feed with air lock
- 100 % redundant systems for fuel and ash handling

Applications:

- product gas for industrial kilns
- product gas for power boilers
- product gas from waste for power production

Valmet waste gasification - Kymijärvi II

- World's largest waste gasification power plant in operation
- Processes 250 ktpa of waste fuels (RDF & contaminated wood) to produce:
    - 50 MW of electricity
    - 90 MW of district heat
    - CHP efficiency of 87,5 %
    - Total investment ~ 160 M €
- 30,000+ operating hours since commissioning
- Over 1 million ton of processed waste (August 2016)

Experiences from waste gasification:

- Stable and easy to control
- Capacity achieved with a clear margin
- Tolerates fuel variation with a margin
- Compliance with WID (also with 2 s 850 °C)
  - No need for support fuel
- No corrosion detected (30 000 hrs)
- Availability challenges during the first year
  - Hot gas filtration was the major challenge
  - Operational routines required learning
  - Availability now improved up to the target level

Vaskiluodon Voima - Valmet gasification plant

- 560 MWf coal fired boiler
- Pulverized fuel firing
- Benson design
- 185 bar/540 °C +
  43 bar/ 570 °C
- Output capacity
  - 230 MWe
  - 175 MW CHP heat
- Commissioning of the unit
  - Boiler 1983
  - Turbine plant 1998
- Production
  - Electric power 0.9 – 1.7 TW_h/a
  - District heating to municipal net 450 GW_h/a

Ash and bed material research in fluidized bed gasification of biomass from lab- to industrial scale

M. Kuba, bioenergy 2020+, Austria

Ash chemistry, ash-bed material interaction, P-rich feedstock and P-recovery were the main topics of the presentation.

Ash interaction during gasification process can be seen in the following figures.

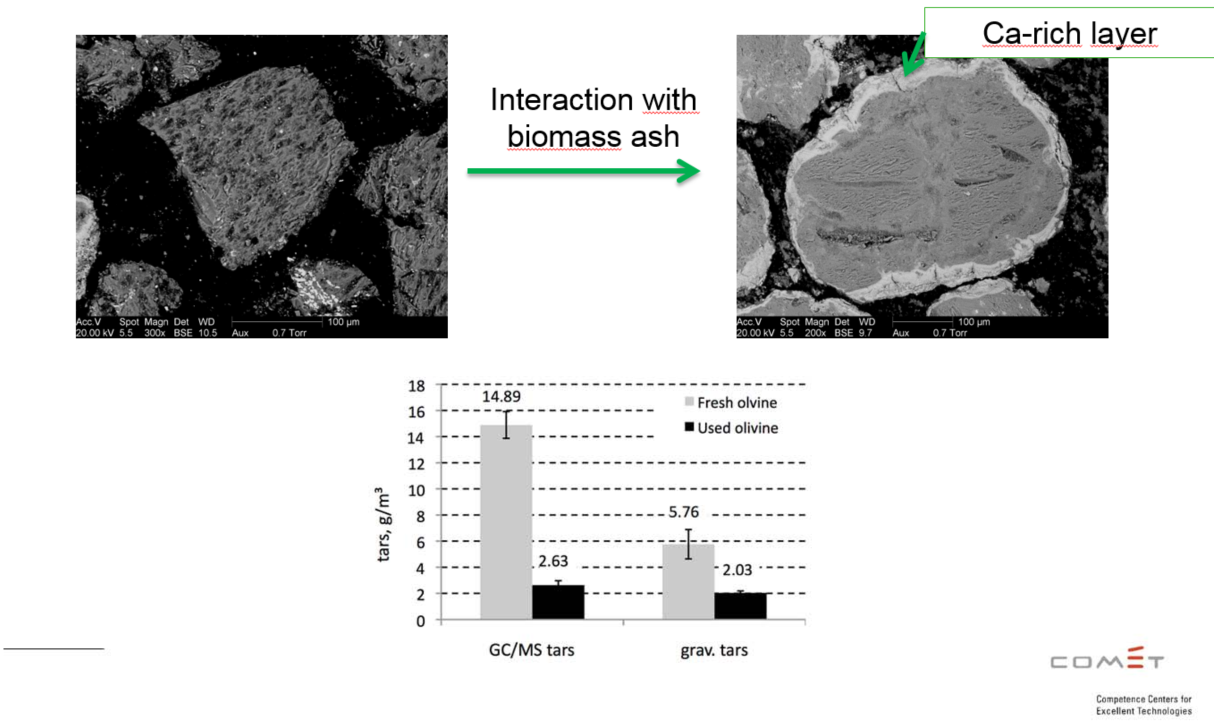

Figure 11: Interaction of bed material with biomass ash

As can be seen in the figures above, a Ca-rich layer forms on the olivine bed particles, which influence the tar amount in the product gas. The layer formation mechanism can be seen in the figure bellow.

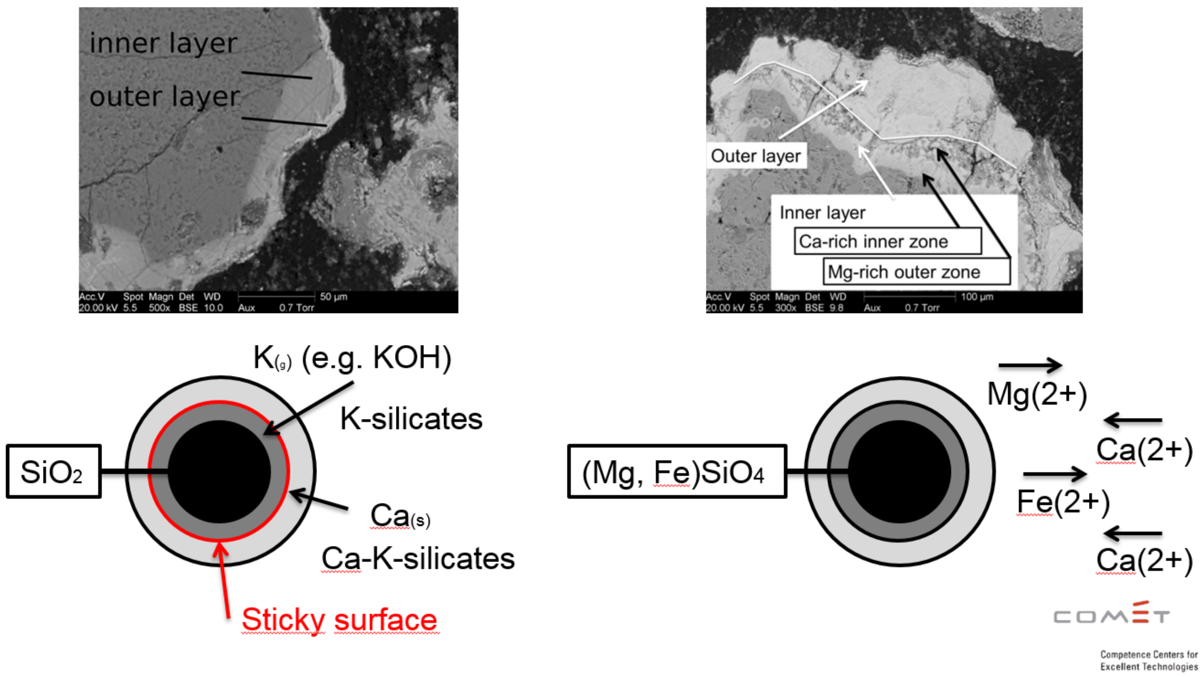

Figure 12: Layer formation mechanism (quartz vs. olivine)

In addition, phosphate formation was investigated. It is supposed that phosphate formation strongly influences ash chemistry and layer formation.

Outlook:

Selection of alternative bed materials

- Clarification of mechanism
- Prerequisites for catalytic activity

Broaden the feedstock spectrum

- P-rich residues (e.g. manures, sewage sludge)
- Agricultural residues (e.g. straw)
- Industrial residues (e.g. lignin)

Low-temperature corrosion in fluidised bed combustion of biomass

E. Vainio, Åbo Akademi, Finland

Low temperature corrosion of pre-heaters and the flue gas channel is a known problem in combustion. It was supposed that this problem is caused by sulphuric acid, but recent studies have shown that hygroscopic deposits cause corrosion in FBC of biomass and waste.

The following figure shows the salt method (KCl) to measure SO_3/H_2SO_4. Measurement range is 0,01 ppm_V – 20 000 ppm_V. This method is used by BFB, CFB, grate combustion, copper smelter, recovery boilers at pulp mills, IC engines, oxy-combustion, gas burners etc.

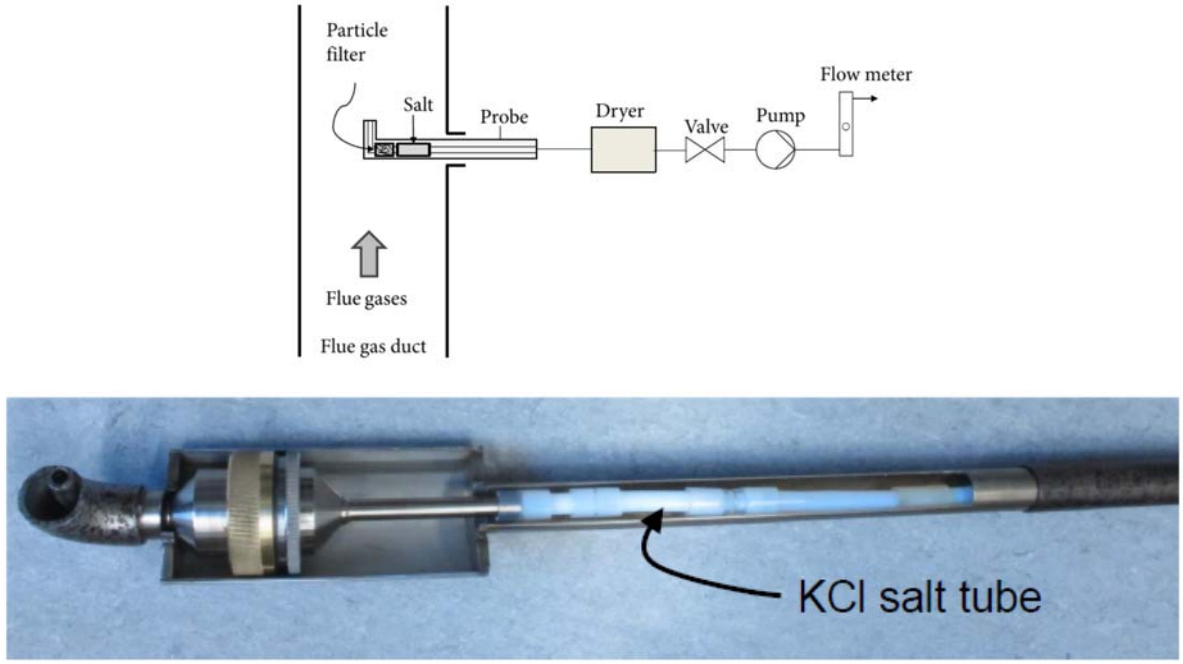

Figure 13: Salt method to measure SO_3/H_2SO_4

The measurement principle is based on equation:

$$H_2SO_4(g) + 2KCl(s) \rightarrow K_2SO_4(s) + 2HCl(g)$$

Deliquescence temperature is the temperature at which a salt or salt mixture at a fixed vol%. H_2O absorbs enough water to fully dissolve. Study of deliquescence at Åbo Akademi:

- Deliquescence temperature of $CaCl_2$ and other salts at various water vapor concentrations
- Corrosiveness of deliquescent salts on carbon steel
- Effect of varying water vapor concentration on the deliquescent behavior and corrosion

Conclusions:

- Hygroscopic deposit in FBC of biomass may cause low-temperature corrosion
- At high water vapor concentrations this may occur at temperatures well above 100°C
- If deliquescence occurs corrosion is usually severe
- Once $CaCl_2$ absorbs water, the water is released at a much higher temperature than the deliquescence temperature
- During down-time of a boiler, hygroscopic deposits may initiate and cause corrosion by absorbing moisture from the air

Hydrogen production from biomass feedstock utilizing a spout fluidized bed reactor

P. Clough, Cranfield University, UK

The world production of hydrogen is approx. 55 Mt/y (2015). The most common sources for hydrogen production are natural gas, oil or coal.

At Cranfield University, a fluidized bed reactor for hydrogen production was constructed; details of the reactor can be seen in the following figures.

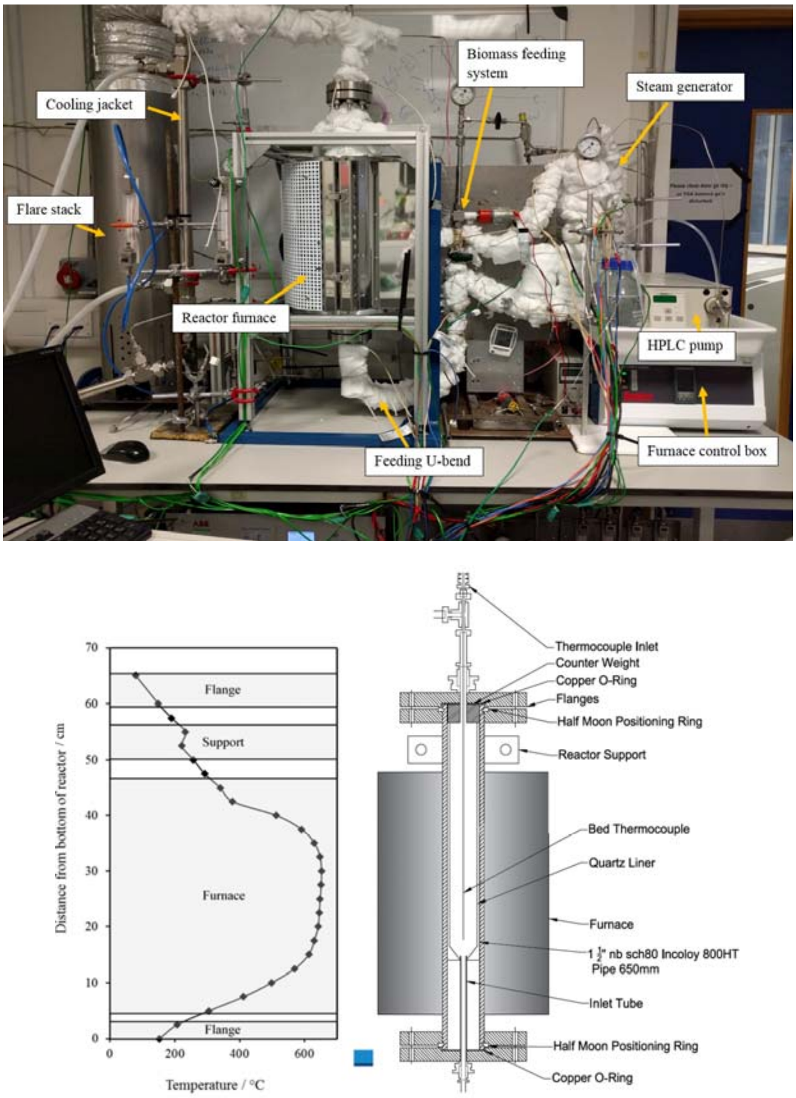

Figure 14: Reactor design and construction

Sorbent and catalyst materials were used to maximise:

- Particle porosity
- Similarity of reaction kinetics for carbonation and reforming
- Sorbent carrying capacity
- Particle and individual component lifetime
- Particle strength
- Resistance to attrition
- Ability to reuse/recycle spent material

and to minimise:

- Material sintering
- Pore blocking/product layer resistances
- Unintended inter-component interaction
- Expense, difficulty and time to manufacture
- The quantity of unreactive material

Conclusions:

- Combined NiO and CaO particles produced (some with C_2S support)
- Tested SER within a fluidised bed reactor with solid biomass feeding
- Stoichiometric steam to carbon ratios
- H_2 purity and yield did approach equilibrium
- Si-based support dramatically affected CH_4 production
- Demonstrated ability to balance SER reactions with gasification
- Coking limited reactions and operation

Opportunities of hybridization of CSP plants by biomass gasification

A.G.Barea, University of Seville, Spain

Concept of Solar-biomass hybridization was presented.

As advantages of such a concept can be seen:

- 100% Renewable Energy Plants
- Full dispatch ability
- Fuel Saving (vs Standalone Biomass Plant)
- Increased Capacity Factor (vs Standalone CSP Plant)
- Distributed power: CSP plants in regions with:
  (i) moderate DNI (≥1700 $kWh/m^2/y$)
  (ii) moderate biomass resources

There are also following disadvantages:

- Increased O&M costs
- Biomass availability
- Effect of Biomass on Solar Plant (dust, smoke etc.)

Hybridization strategies:

1. Biomass in parallel with solar field

2. Biomass in series with solar field

3. Biomass in parallel with solar steam generator, power block

4. Biomass in series with solar steam generator, power block

5. Combination of the 2 above

6. Hybridization at solar receiver (gasification only)

7. Combined cycle (a, b gasification only)

Following table offers an overview on feature of hybridization strategies.

Table 3: Features of hybridization strategies

FEATURES	C1	C2	C3	C4	C5	C6	C7	C8
Off-Sun Generation	X	-	X	-	X	X	X	X
Increase Power Block Efficiency	-	X	-	X	X	-/X	-	X
Decouple Solar and Biomass Resources	X	-	X	-	-	X/-	X	-
Easy Integration in Current STE Plants	X	-	X	-	-	X/-	-	-
Increase Biomass to Electric Efficiency	-	-	X	X	X	X/-	X	X
Low Technology Risk	X	X	X	X	X	-	-	-
Stable Solar receiver operation	-	-	-	-	-	X/-	-	-

Conclusions:

1. Solar-biomass hybridization is a promising concept (only one plant at commercial scale)
2. Storage or backup fuel is necessary to guarantee dispatchability. CSPbiomass hybrid is more competitive tan PV with batteries
3. Different alternatives of CSP hybridization with biomass, both based on combustion and gasification of biomass
4. Integration in current parabolic trough technology is straightforward and seems to be feasible
5. Challenges for advanced, more efficient concepts remain huge. Development of gasification seems to play a key role
6. Advanced design in development for both TES and hybrid integration

Bed material-alkali interactions during fuel conversion in fluidized bed

P. Knutsson, Chalmers University of Technology, Sweden

The role of bed material in fluidized bed during gasification and combustion is shown in the following figure.

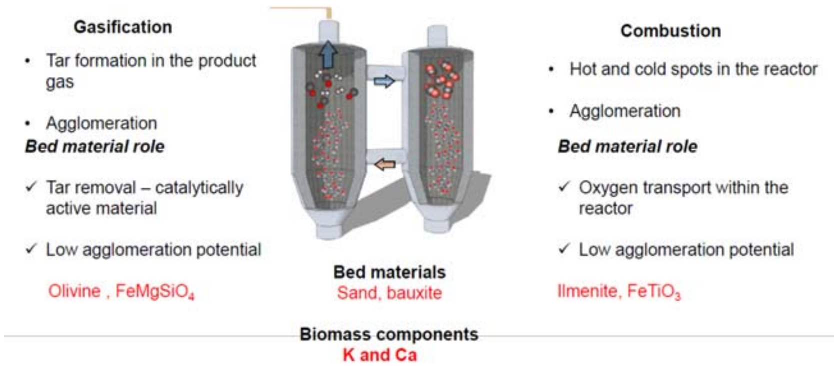

Figure 15: Role of bed material during combustion and gasification in fluidized bed

The interactions, which take place between bed materials in fluidized bed, are crucial for both agglomeration and activation of bed particles.

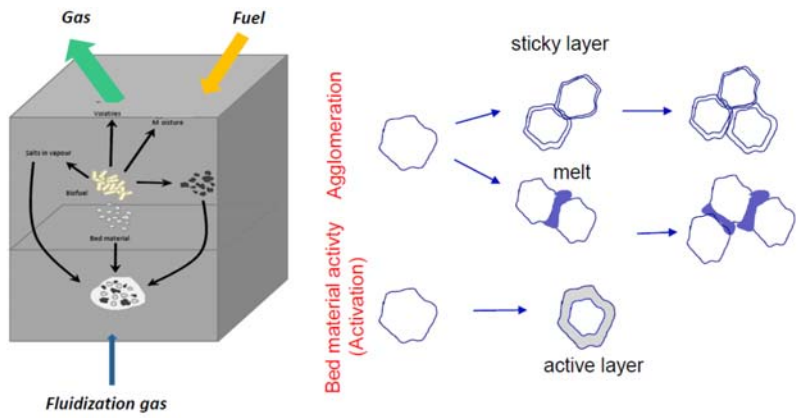

Figure 16: Bed material interaction and activation

An important role for agglomeration of fluidized bed play elements such as calcium and potassium. Potassium causes agglomeration in the fluidized bed and calcium seems to have an opposite effect. Both K and Ca were found on the surface of activated bed particles predominantly as oxides at the outermost layer.

It was found during experiments, that replacing two Ca^{2+} ion in the lattice by two K^{+} is able to activate O_2 by binding it to the vacancy. There are challenges to the mechanism. A border line between activation and agglomeration can be seen in the following figure.

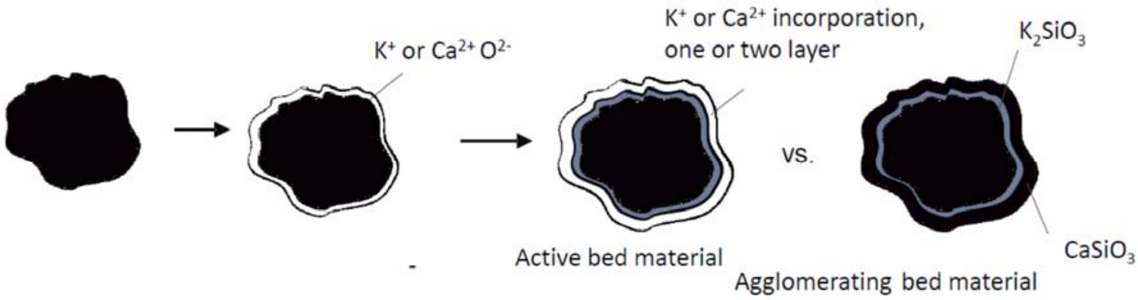

Figure 17: Active and agglomerated bed material particles

Assessing CFB combustors flexibility with respect to load changes and fuel type

A. **Nikolopoulos, CERTH, Greece**

General perspective of biomass co-firing:

- Main advantage of co-firing: potential to mitigate the CO2 emissions of coal sector at very low cost and short implementation time compared to other technologies.
- Over 100 successful field demonstrations in 16 countries that use every major type of biomass (herbaceous, woody, animal-wastes and wastes) combined with every rank of coal and combusted in every major type of boiler

Technology gap:

A combined sophisticated research on the operational flexibility enhancement of CFB boilers for retrofitting cases that are fuelled with Low Rank Coals and biomass/waste fuels blends, has not been conducted yet.

The development of new and innovative flexibility concepts for CFB technology, in terms of fuel and operation, seems to be of high necessity.

A RFCS European project, FLEX FLORES introduces new concepts that are intended mainly for low rank fuel (e.g. lignite) co-combusting power plants under high ramp-up rates. Project duration is 42 months, budget 2,8 mill. Euro. The project started on 01.07.2017. Partners: RINA CONSULTING - Centro Sviluppo Materiali S.p.A. , Foster Wheeler Energia Oy Finland, CERTH, TECHNISCHE UNIVERSITAT DARMSTADT Germany, Teknologian tutkimuskeskus VTT Oy Finland and PPC.

FLEX FLORES: FLEXible operation of FB plants co-Firing LOw rank coal with renewable fuels compensating vRES

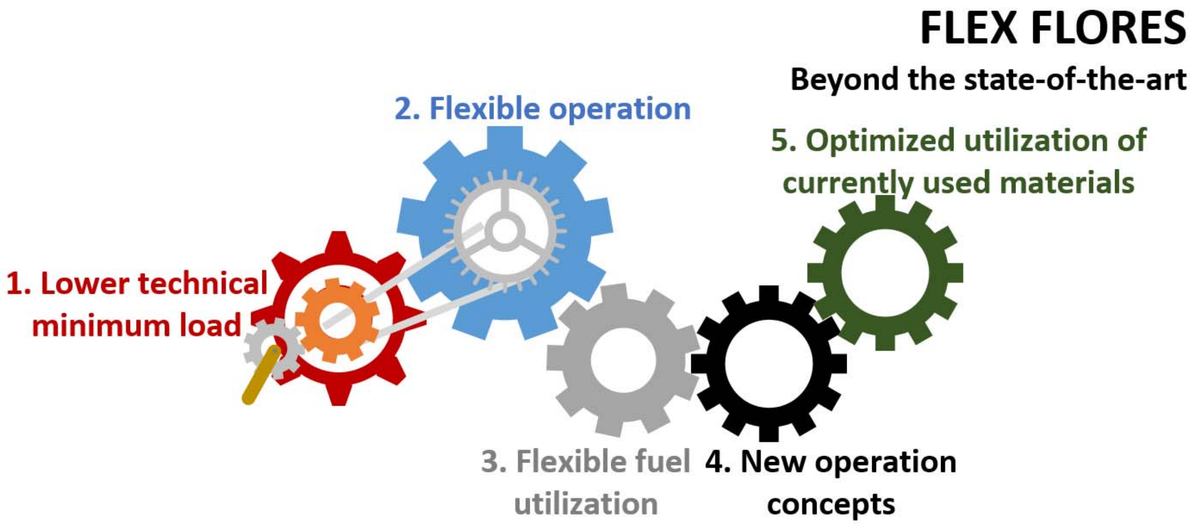

Figure 18: Main features and aims of the project

KEY RESULTS

- Higher availability factor for the plant (achieved with steady and reliable operational mode parameters)
- High ramp-up rates (up to 5%MCR/min) and faster start-up procedures of the plant
- The plant will operate under a wide range of different blends of LRC and biomass (increase of biomass share, operational strategies for a wide range of LRC substitution)
- New operation strategies implementation+ new devices assessment
- Increase of the components lifetime avoiding wastes of energy+ raw resources

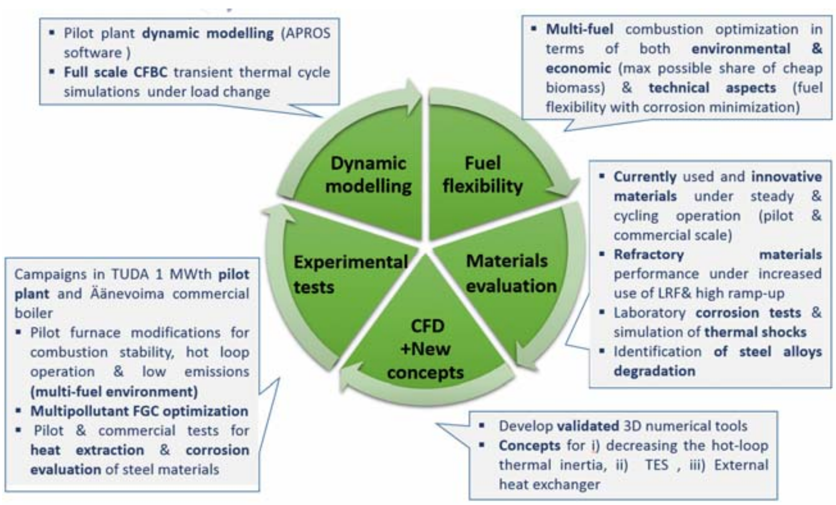

Figure 19: FlexFLores strategy and actions

The main target of the project is the search of two of the most promising biogenic fuels to be experimentally tested for their co-combustion with low rank fuels (LRF) under low thermal load conditions.

For this project the S2Biom platform is used. The user can select regional level, year and different types of potentials. The level entities can be in absolute levels (Kton dm or TJ), area weighted (Kton dm/km2 or GJ/km2) and weighted average road side cost (€/ton dm).

One of the project aims is operating flexibility in CFBs and energy storage concepts:

- Search of a new furnace flexible operating concept, aiming at optimizing hydrodynamics
- Aim: 1. Increase furnace operability at low load level through flue gas recirculation 2. Increase the furnace capability to ramp up/down
- Investigation of the bed material (inert material & fuel particles) intermediate storage during a rapid load ramp-down
- Aim: Enhance operation flexibility during start-up and quick load swings

Conclusions:

- Flex Flores project aims at flexible and environmental friendly CFB technologies under high ramp-up rates (up to 5% MCR/min) and the adoption of LRFs co-combustion with biogenic fuels as a retrofitting option in FB power plants
- Different research activities will be undertaken including CFD modelling, dynamic process modelling, lab/pilot/commercial scale experimental campaigns
- Technical achievements beyond the state of the art will include:
    - Lower technical minimum load
    - Flexible operation: high ramp-up rates and faster start-up procedures
    - Flexible fuel utilization
    - New operation concepts: TES, External heat exchanger
    - Optimized utilization of currently used materials

Research, development and its application of circulating fluidized bed boiler technology in China

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Coal is a main energy source in China that is why CFB boilers are widely used there. The CFB boiler number increases every year, and at the end of 2015, there were about 2800 units in commercial operation and more than 300 were under construction.

350MW & 600MW supercritical CFB boilers dominate nowadays the Chinese CFB market. The total capacity of CFB units is more than 100 GW. Now, the ultra-super critical CFB boiler with capacity of 660MW is being developed.

350MW SC CFB boilers in Hequ Power Plant

350MW SC CFB boilers in Guojin Power Plant

350MW SC CFB boilers in Datuhe Power Plant

350MW SC CFB boilers for oversea

Figure 20: Examples of supercritical CFB boilers

One of the CFB boilers advantage is low cost emission control, CFBs match most regulation by limestone injection and low NOx combustion. Also sulphur is an important component during the combustion process. The temperature should be balanced because the higher temperature causes higher SO_2 capture reaction speed, however, the decomposition speed of desulfurization products is also increased. The optimal combustion temperature is around 850°C.

Conclusions:

- CFB is the best choice for low grade coal utilization for the countries where coal is major energy source.
- Chinese spend several decades to study CFB boiler. Now there are several boiler workers in China could supply CFB boilers.
- By the end of 2015, there are more than 2800 CFB boilers with total capacity of more than 100GW were in commercial operation in China.
- The achievements of supercritical CFB and ultra-low emission CFB are successful, and this encourages the CFB boiler future in China.

Results from the 100 kW dual fluidized bed gasifier at Vienna University of Technology

F. Benedikt, Vienna University of Technology, Austria

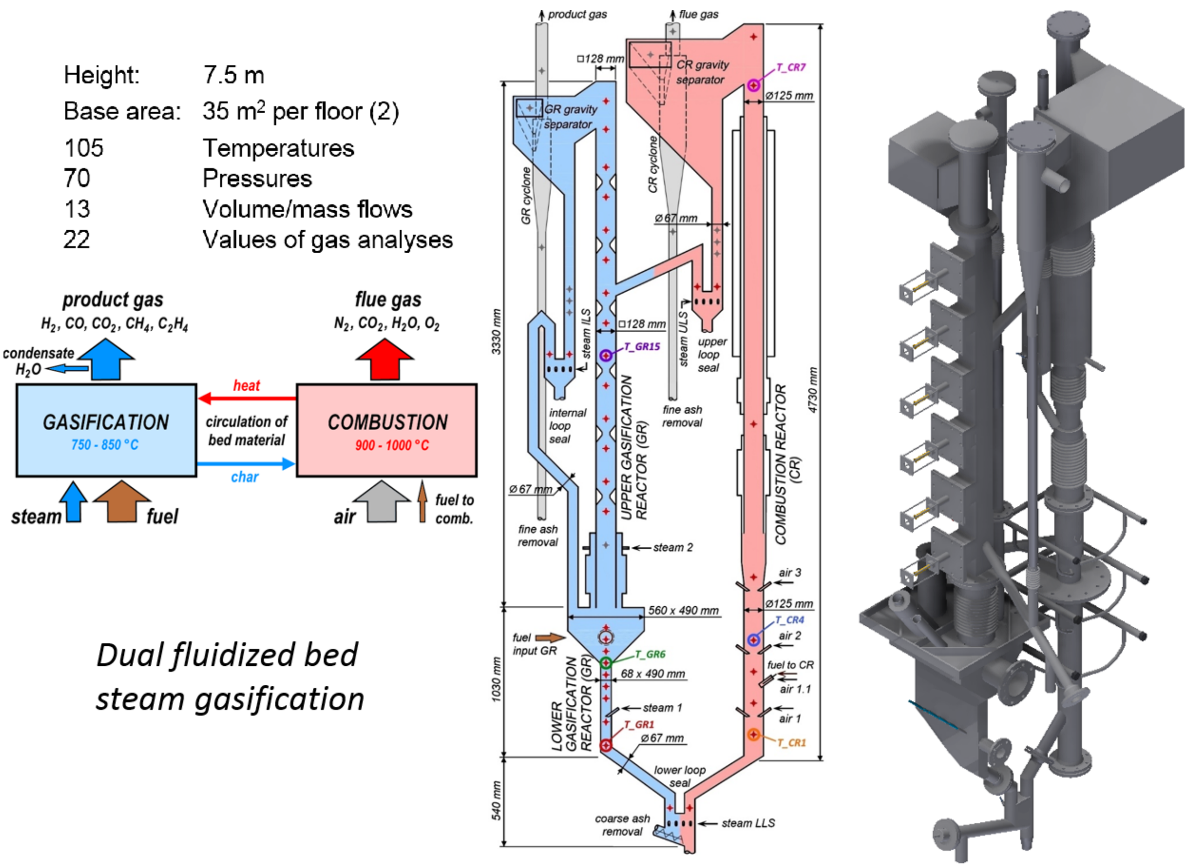

Figure 21: Principle and reactor system of the 100 kW DFB plant

Different feedstock- and bed materials were tested using DFB gasification unit. The test results such as gas quality and tar components can be found in the presentation.

Figure 22: Feedstock tested using the gasification unit

SER (Sorption enhanced reforming):

- limestone/calcite was used as bed material
- Variation of
  - feedstock
  - bed material circulation
  - temperature

Differences between steam gasification and SER with limestone/calcite as initial bed material and soft wood as a feedstock are shown in the following table.

Table 4: Differences between steam gasification and SER

	Classical dual fluid bed steam gasification	**SER process**
Gasification temperature	780-850 °C	600-700 °C
Combustion temperature	900-950 °C	800-900 °C
Bed material	Olivine	Calcite/limestone
Gasification agent	Steam	Steam
Product gas composition		
H_2 [vol.-%db]	37-47	55 -**75**
CO [vol.-%db]	19-24	4-13
CO_2 [vol.-%db]	20-25	6-15
CH_4 [vol.-%db]	9-11	8-16
Net calorific value [MJ/Nm^3]	12-14	13-15

Conclusions:

- Novel design: fuel and bed material flexible
- Low-cost fuels can be gasified
- Alternative, residual fuels increase requirements on the gas cleaning system significantly
- Hydrogen rich gas can be produced (SER)
- H2/CO adjustment with the gasification process
- Novel separation system for soft bed materials

Outlook:

- Impurities or valuable substances of different fuel types
- Where are the substances (product gas, fine ash, coarse ash, fly ash,...)
- Suitable gas cleaning processes

Biggest BFB for biomass combustion in France – lessons learned

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Dalkia & Smurfit Kappa had implemented the biggest biomass CHP plant in France:

- A call for renewable CHP projects was launched in 2006 by the state in order to reach 20% of renewable energy by 2020.
- Dalkia won this project, designed and constructed the CHP on Smurfit pulp and paper plant.
- Dalkia keeps the contract with Smurfit and the state to operate and maintain the CHP for 20 years, producing heat (steam) for the pulp & paper process and power.

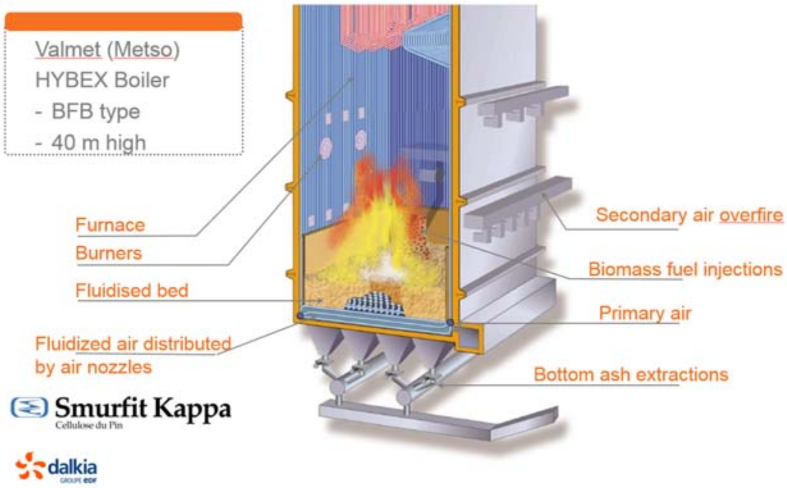

Figure 23: BFB boiler technology

An overview on advantages of BFB technology is shown in following table.

Table 5: BFB advantages of this flexible technology

	Reciprocating grate	Spreader stoker	BFB
Air Excess	40 – 60 %	25 – 35 %	20 – 25 %
Unburned	++	+	+++
Boiler efficiency	+	++	+++
NOx & CO emissions	++	++	+++
Electrical Consumption	++	+++	+
Operation & maintenance	++	++	+
Investment	++	+++	+

- By experience, biomass quality is the most important thing. The boiler technology depends on the type of biomass residues or sub products and not the opposite, so each biomass project is unique
- The BFB technology is more flexible in terms of biomass type and with respect to emissions regulation.
- Operation and maintenance of biomass CHP required more man power in comparison to other fuels (x5 vs Gas).

Summary and Technical Tour Information

Fluidized bed technology is well-suited for thermal processing of solid fuels such as biomass and waste. Combustion and gasification, in particular, are demonstrated technologies and today there are many commercial installations processing biomass-based feedstock in fluidized bed reactors.

The workshop on Fluidized Bed Conversion of Biomass and Waste was jointly organized by IEA Bioenergy Task 33 (Gasification of Biomass and Waste) and IEA-FBC (Fluidized Bed Conversion) and included 15 presentations from experts on R&D, implementation, challenges and successes of fluidized bed processing. Over 40 experts from 16 countries all over the world participated in the workshop.

The participants of the workshop had a possibility to visit Skive gasification plant as well as Østerild - National Test Centre for Large Wind Turbines on the second day.

The BFB gasification plant in Skive was designed to utilize wood pellets and/or chips. Fuel, initially pellets, is supplied from the indoor wood pellet storage site next to the gasification plant. The fuel is fed through two lock hopper systems by feeding screws into the lower section of the gasifier's fluidized bed. The gasifier is operated at a maximum of 2 bar over pressure and temperature of 850°C. Air is used as a gasification medium and olivine as a fluidized bed material. The product gas generated contains about 20% CO, 16% H2 and 4% CH4 by volume as the main combustible components, with the remaining fraction of the gas being CO_2 and N_2. It has a heating value of about 5 MJ/kg.

In June 2010 the Danish Government passed a law in order to establish a national test centre for wind turbines at Østerild, The Technical University of Denmark is appointed to be head of the establishment and operation of the new wind turbine prototype test facility.

DTU Wind Energy is operating three wind turbine test sites in Denmark. The test sites are situated at: DTU Risø Campus, Roskilde - Høvsøre Test Site for Large Wind Turbines at Lemvig - and Test Center Østerild at Thisted. At Høvsøre and Østerild.

Test Centre Østerild was established with seven test stands during 2012 and allows for erection of wind turbines of up to 210 and 250 meters respectively.

During spring 2017, the Danish Government has decided to expand at Østerild. In the future, there will be room for two more wind turbines with a height up to 330 meter.

The workshop as well as site visits presentations could be found at the IEA Bioenergy Task 33 website (www.task33.ieabionenergy.com) in the section “Workshops and Events”.