Processes for the Gasification of Biomass and current Developments

MSE – Colloqium
04.07.2013 Munich

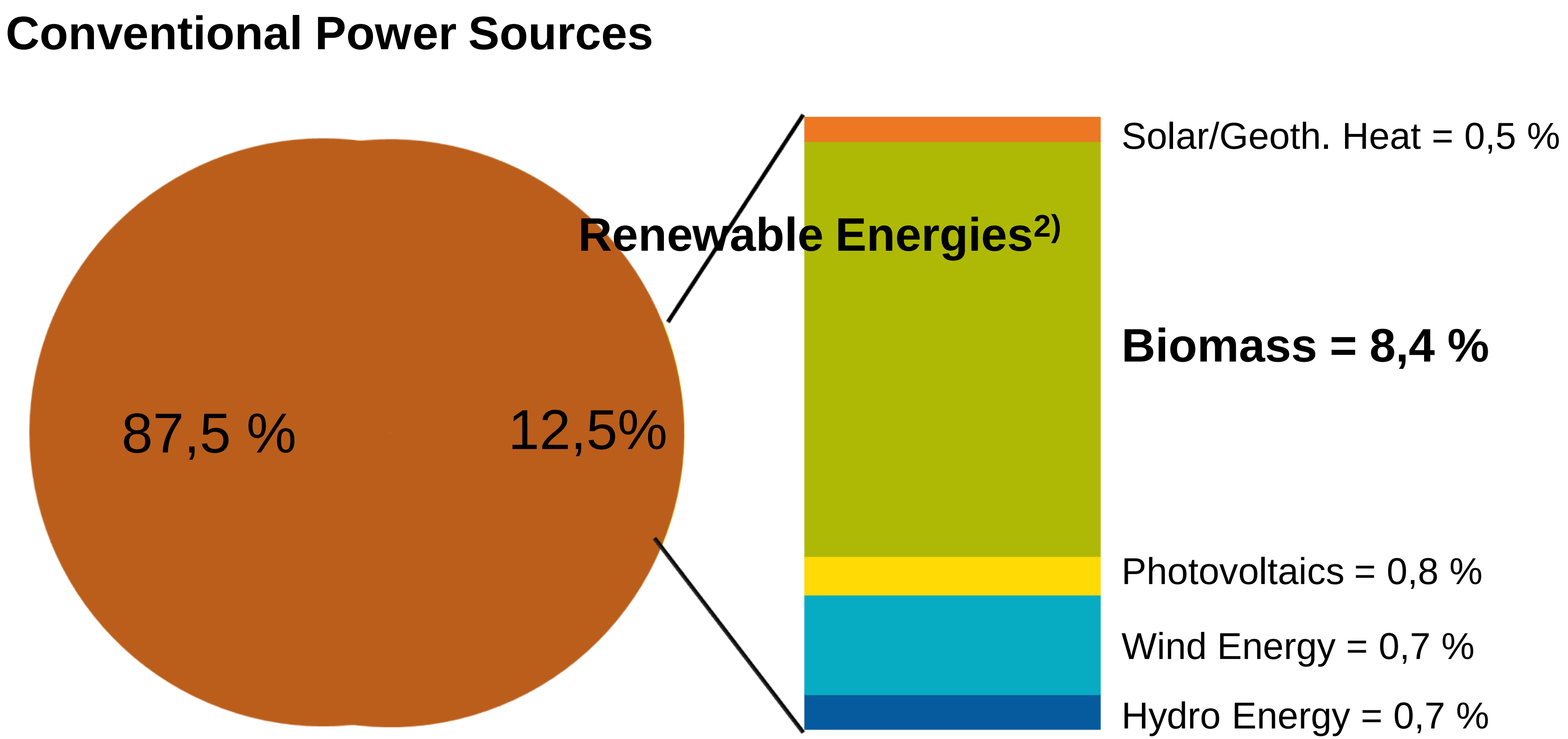
Markus Ulbrich, Michael Kremling, Sebastian Fendt, Ludwig Briesemeister, Stephan Herrmann, Hartmut Spliethoff, Matthias Gaderer

Outline

1. Challenges of power generation from biomass
2. Biomass upgrading – transforming biomass into coal-like products
3. Concept for biomass gasification
4. Utilization of the product gas for power generation and SNG

Demand of Biomass in the Mix of renewable Energies

Primary Energy demand Germany 2011 : 8.692 PJ



Biomass Properties and Challenges

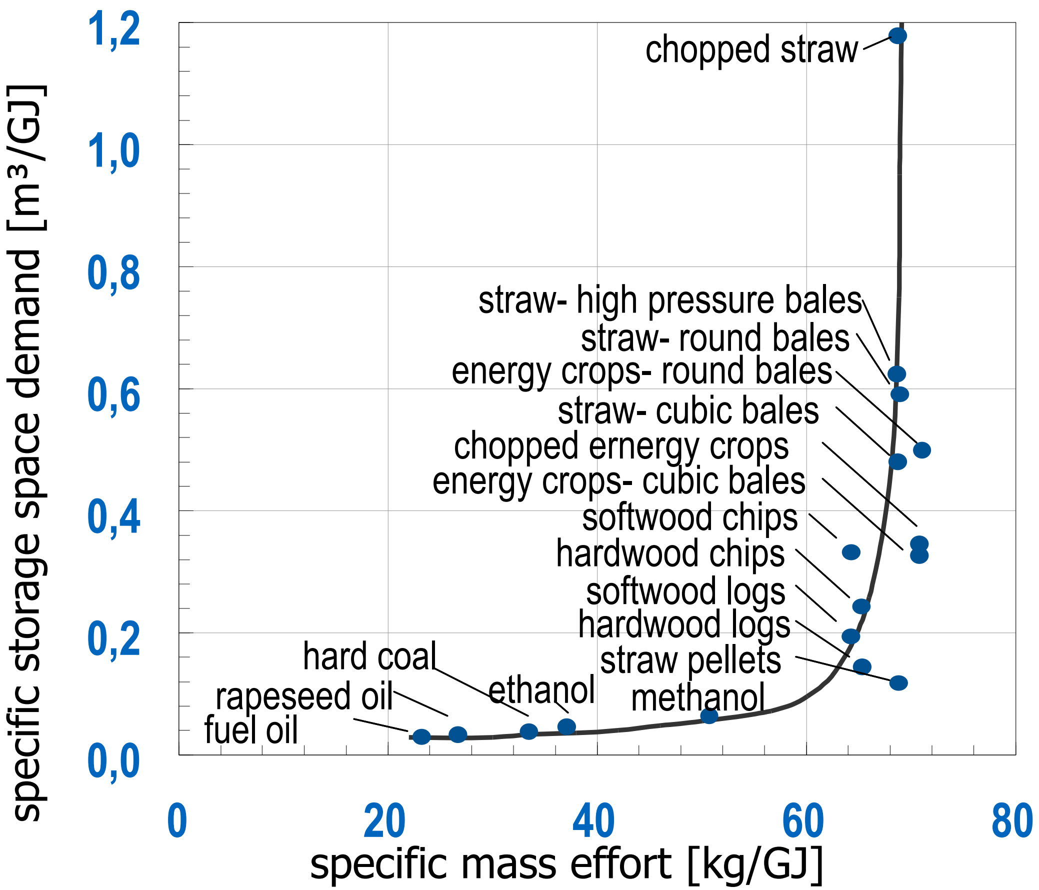
Biomass properties are inhomogeneous

Humidity	10 – 50 %
Ash	0,5 %
	18 – 20 MJ / kg

	10 – 20 %
	10 %
	17 MJ / kg

	40 – 80 %
Ash	10 %
Heating Value	17 MJ / kg

Biomass Properties and Challenges



Need of:

- Highly flexible combustion and gasification systems
- Concepts for decentralized power generation

1. Challenges of power generation from biomass
2. Biomass upgrading – transforming biomass into coal-like products
3. Concepts for biomass gasification
4. Utilization of the product gas for power generation and SNG

Biomass Upgrading via HTC and Torrefaction

Hydro**t**hermal **C**arbonization

Transformation of Biomass to Charcoal under application of hydrothermal reaction conditions ➔ **Biomass immersed in water, high p, high T**

190-250°C

$p > p_{v,water}$

3 – 24 h

- Energy density ↑
- Grindability ↑
- Ash forming compounds ↓
- Hydrophobicity ↑
- Wet biomasses usable

Torrefaction

Transformation of Biomass to Charcoal under application of mild pyrolisis reaction conditions ➔ **Anoxic, athmospheric pressure, high T**

200-300°C

p = atm

3 – 10 h

- Energy density ↑
- Grindability ↑
- Carbon content ↑
- Water content ↓

Biomass Upgrading via HTC

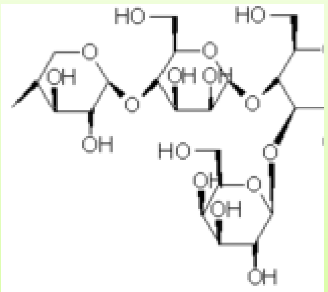
Hydrothermal Degradation of Biomass
190°C – 240°C ; 12,5 bar – 33,5 bar

Repolymerisation Elimination of O ; H ➔ Increase of C content

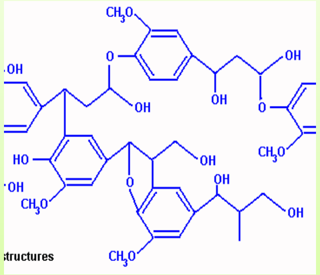
H_2O

H_2O

Hemicellulose



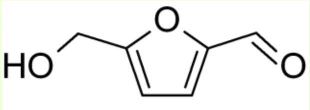
Lignin



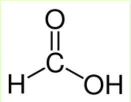
hydrolysis

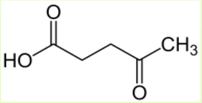
degradation

HMF
Hydroxymethylfurfural



Organic Acids
z.B. Formic Acid





Aromatic Compounds
Various Tar Compounds

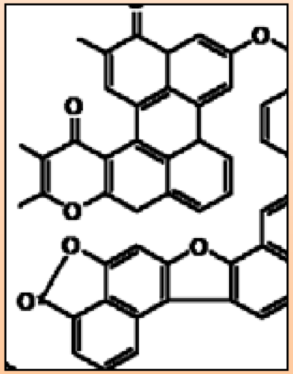
condensation

polymerisation

decarboxylation

CO_2

HTC-Coal



Biomass Upgrading via HTC and Torrefaction

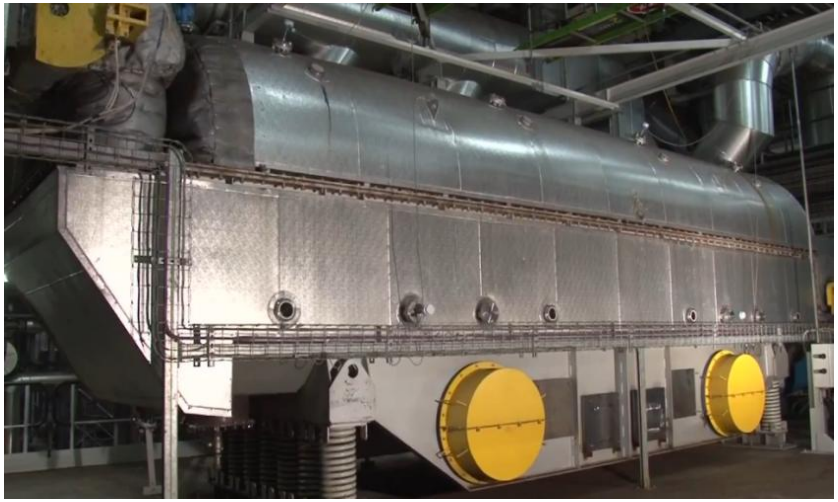
HTC

AVA-CO2 - multibatch plant 8,4 t/a

- Multibatch operation with three autoclaves
- Energy recuperation of pressure and temperature from previous batch
- 26.10.2010, Karlsruhe

Torrefaction

Stramproy Green Torrefaction Plant, 90 kt/a



- Continuous operation with a vibrating grate
- Fully integrated process with torrefaction, pelletizing and heat recirculation
- 2011/12, Steenwijk, Niederlande

1. Challenges of power generation from biomass
2. Biomass upgrading – transforming biomass into coal-like products
3. Concepts for biomass gasification
4. Utilization of the product gas for power generation and SNG

Entrained flow reactor at the ES

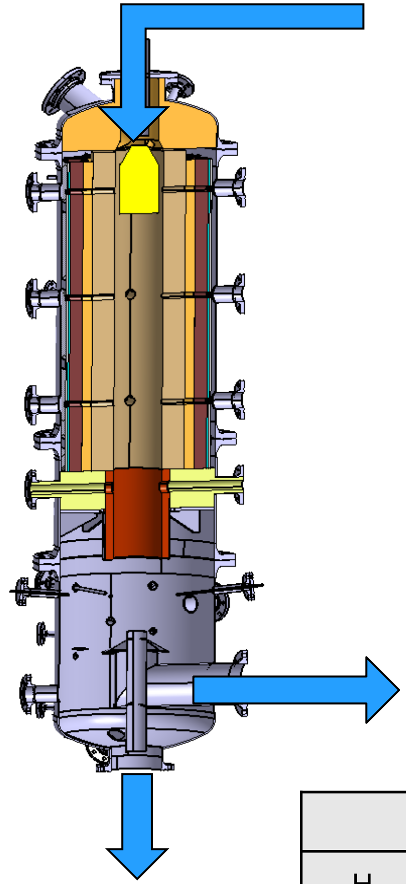
Possible solid fuels

- butiminious / brown coal
- biomass in ground form

} 100 µm

Technical data

- Autothermal process
- Fuel: HTC-coal, torrified biomass
- Fuel input: 100 kW
- Temperature: up to 1500 °C
- Flexible operating mode:
  - Pressure (1 – 6 bar absolute)
  - Variation of gasifying medium



T_{out} = 1390 °C
CGE = 68%

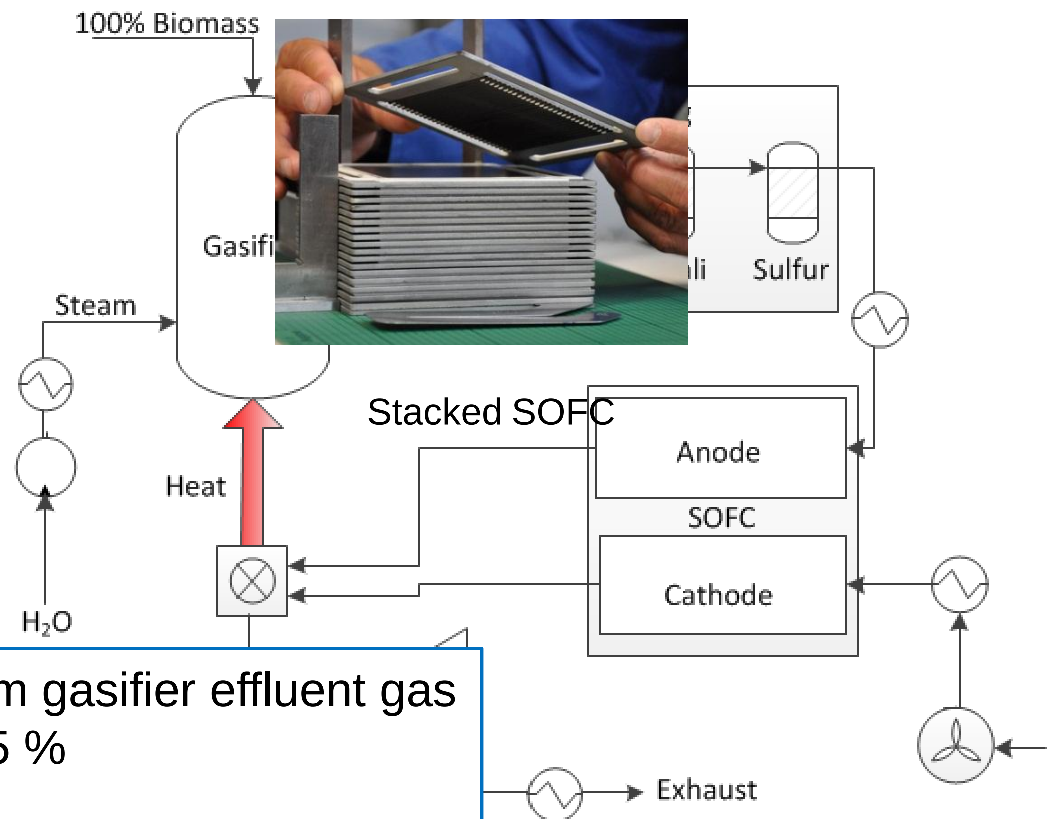
Product gas composition				
H_2	CO	H_2O	CO_2	N_2
20 %	33 %	24 %	12 %	~10 %

1. Challenges of power generation from biomass
2. Biomass upgrading – transforming biomass into coal-like products
3. Concepts for biomass gasification
4. Utilization of the product gas for power generation and SNG

Power Generation from SOFC (Solide Oxide Fuel Cells)

Technical data

- Power range up to 500 kW in stacks, single cell ~ 25W
- T = 700 – 900°C
- p = 0 – 5 barg
- Anode: YSZ (yttria stabilized zirconia)
- Cathode: LSM (lanthanum strontium manganite)
- Electrolyte: YSZ



Direct generation of electricity from gasifier effluent gas

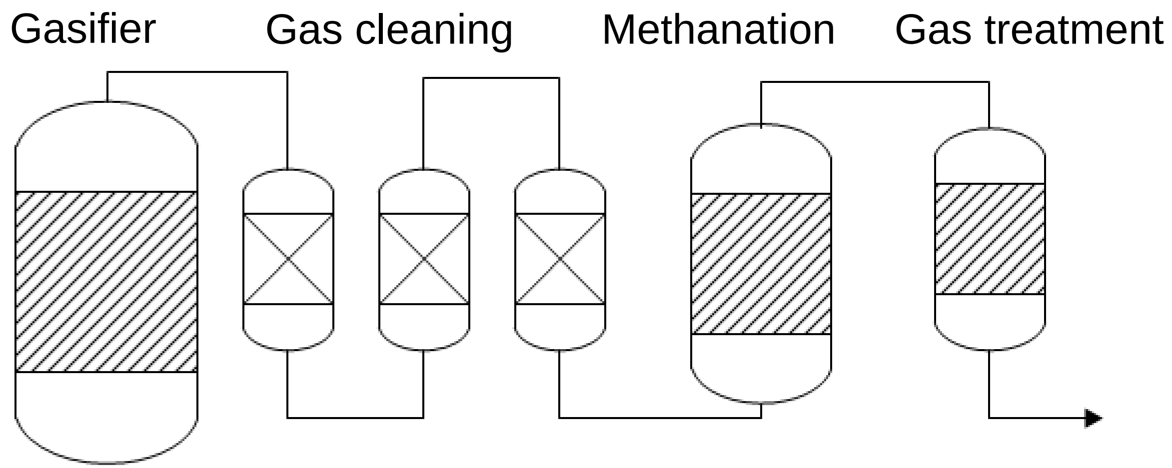
$\eta_{electric}$ = 35 – 55 %

Applicable for decentralized power generation

Concept "Biomass-to-SNG" at ES

Technical data

- Small scale (~ 500 kW – 5 MW)
- Power generation in (off-site) CHP unit or CCPP→ Flexible
  → Adjustable to local heat and power demand



Cleaning

- Tar removal 850°C, Ni Cat.
- Cl and S removal via adsorption

Methanation

- $CO + 3H_2 \rightarrow CH_4 + H_2O$ ΔH_R = - 206 kJ/mol
- $CO_2 + 4H_2 \rightarrow CH_4 + 2\ H_2$ ΔH_R = - 165 kJ/mol
- Ni catalyst 350°C

Gas treatment

- CO_2 removal via PSA
- H_2O removal via conden-sation

Product gas composition		
CH_4	H_2	N_2
77 %	9 %	14 %

η_{SNG} = 67 %
Power generation with CCPP: $\eta_{SNG+CCPP}$ = 40 %

Thank you for your attention!

…Questions?

Sources

Numbers in Slide 1:

Working group on Energy Balances e.V. (AGEB) ;
Solid and liquid biomass, sewage and landfill gas, biogenics of waste, biofuels ->
BMU-KI III 1

Mechanisms slide 8:

The production of carbon materials by hydrothermal carbonization of cellulose
M. Sevilla*, A.B. Fuertes
Carbon (2009) 2281 –2289

Hydrothermal carbonization of biomass residuals: a comparative review of the chemistry, processes an application of wet and dry pyrolysis
Judy A Libra, Jürgen Kern & Karl Heinz Emmerich
Biofuels 2011 2, 89-124

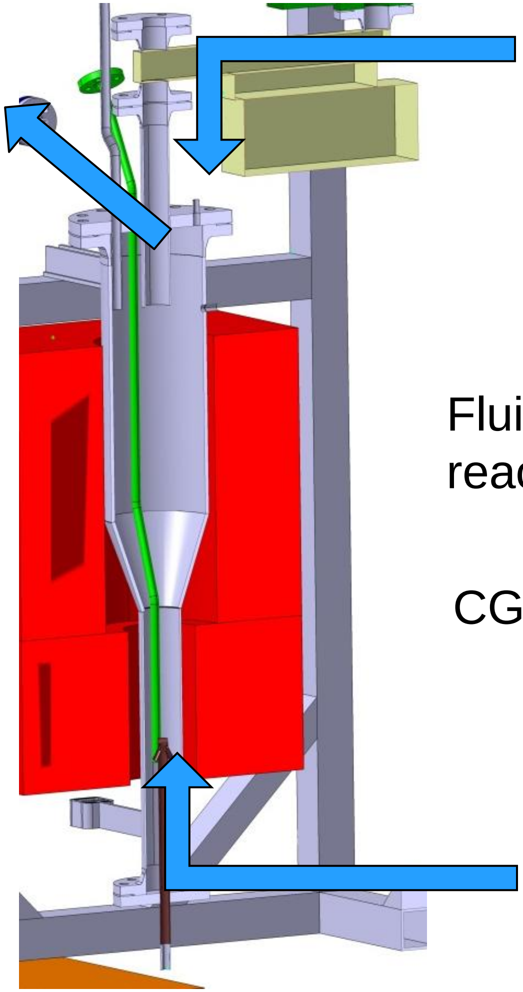
Hydrothermal carbonization of biomass: A summary and discussion of chemical mechanisms for process engineering
Axel Funke, Felix Ziegler
Biofuels, Bioprod. Bioref 4:160 – 177 (2010)

Fluidized **bed reactor at the** ES

Technical data

- gasification and combustion processes
- fuel: wood/HTC pellets ~ 6 mm
- fuel performance : 5 kW
- bed material: olivine sand
- fluidizing medium: steam / air
- max. operating temperature: 850°C
- max. operating pressure: 5 bar

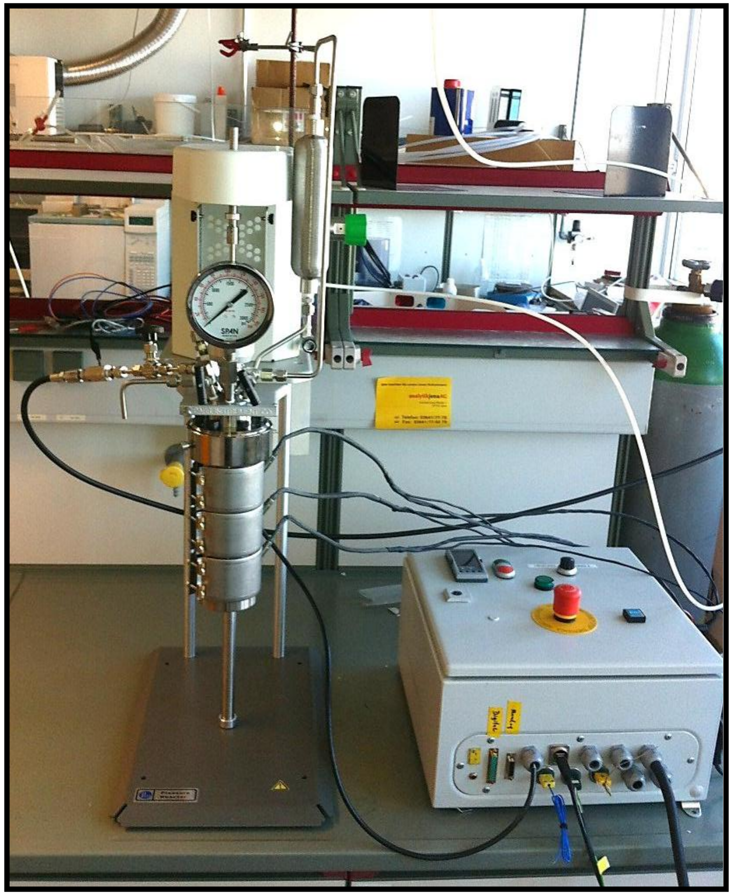
Product gas composition					
H_2	CO	H_2O	CO_2	CH_4	N_2
26 %	13 %	40 %	12 %	5 %	10 %



Fluidized bed reaction zone

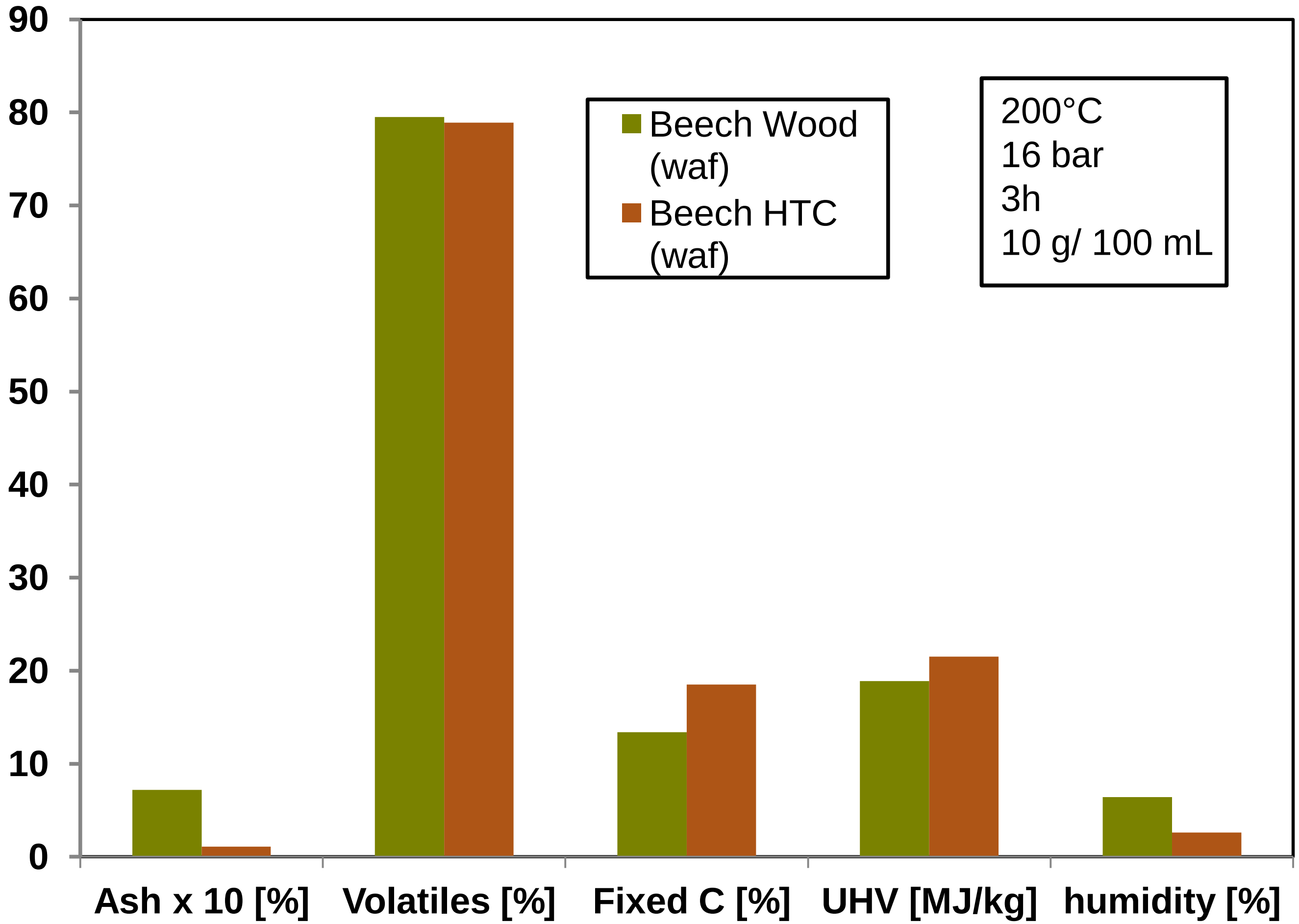
CGE = 75 %

Laboratory Scale Experiments of the HTC-Process at the LES

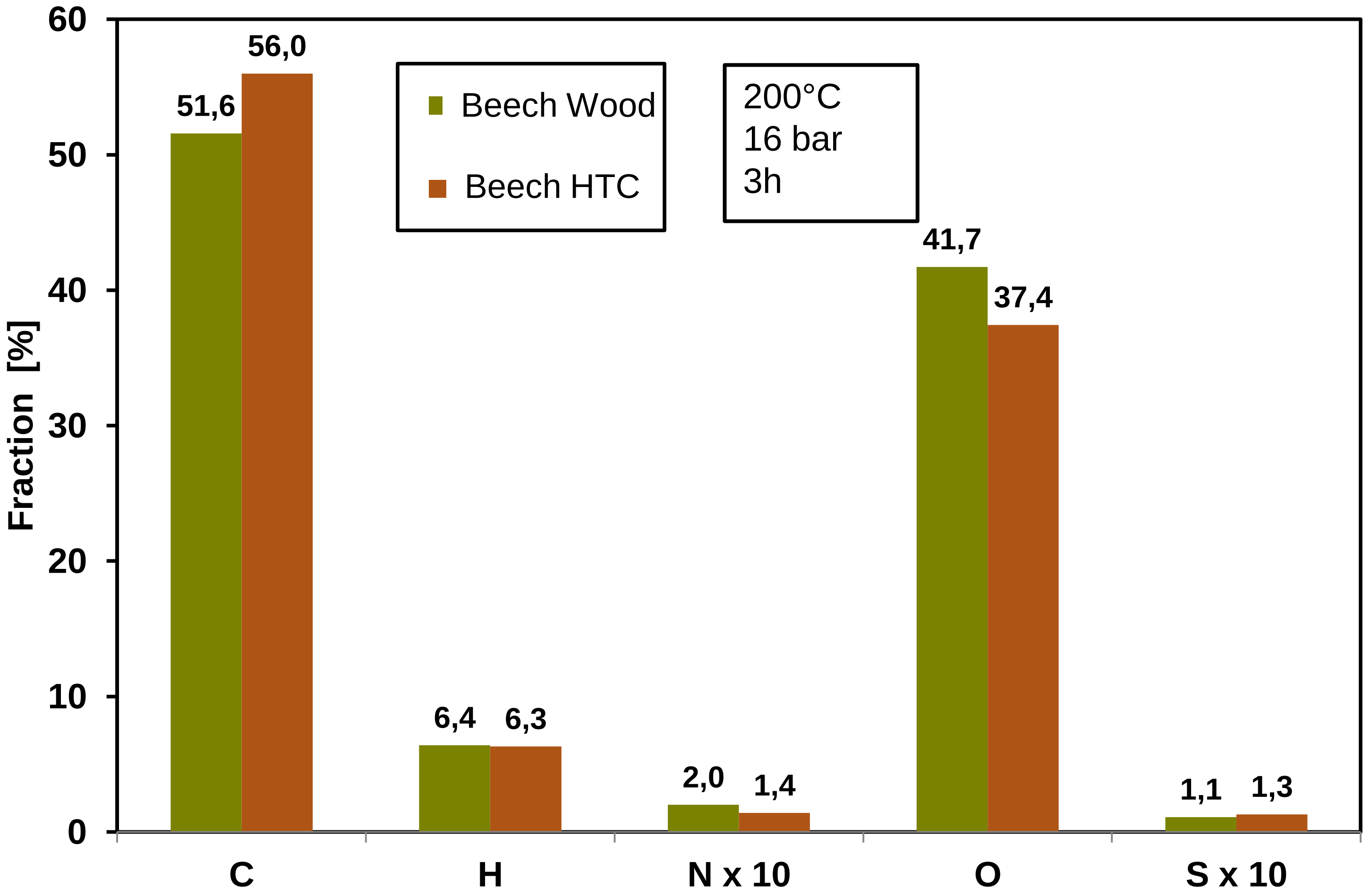


- Stirred high pressure batch-reactor (350°C, 200 bar)
- Volume = 600 ml, pressure controlled and temperature controlled
- Investigaton of reaction parameters of HTC and Torrefaction

Vorläufige Ergebnisse



Vorläufige Ergebnisse

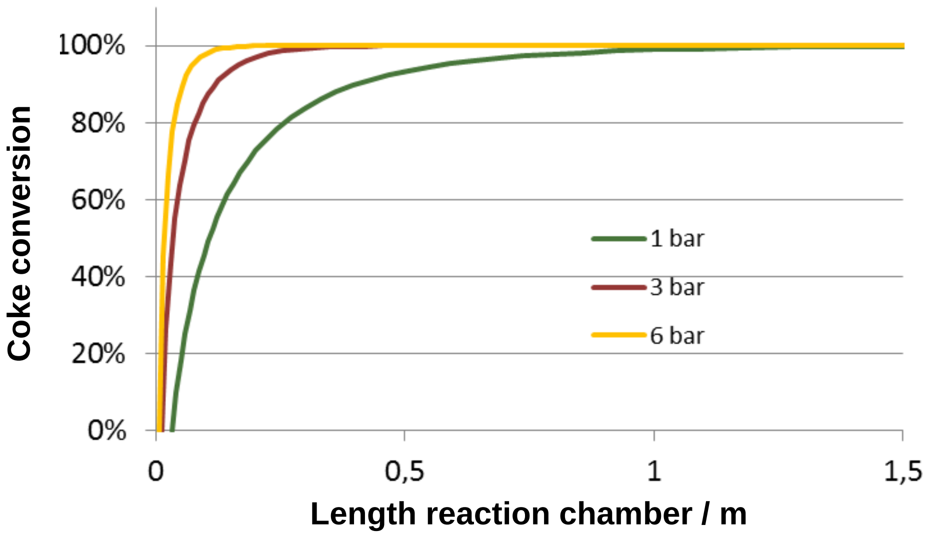


Expected coke conversion / product gas composition

Input parameters:

- HTC-coal (100 kW)
- Gasifying medium:
  - O_2+H_2O
  - 0,2 kg_{steam}/kg_{coal}
  - O/C = 1 (molar ratio)
- Carrier gas (N_2): 0,2 Nm^3/kg_{coal}
- Heat loss: 10 %

Output:



Product gas composition				
H_2	CO	H_2O	CO_2	N_2
20,4%	33,3%	24,2%	12,2%	10,0%

$T_{out\_reaction\ chamber}$ = 1390 °C
CGE = 68%

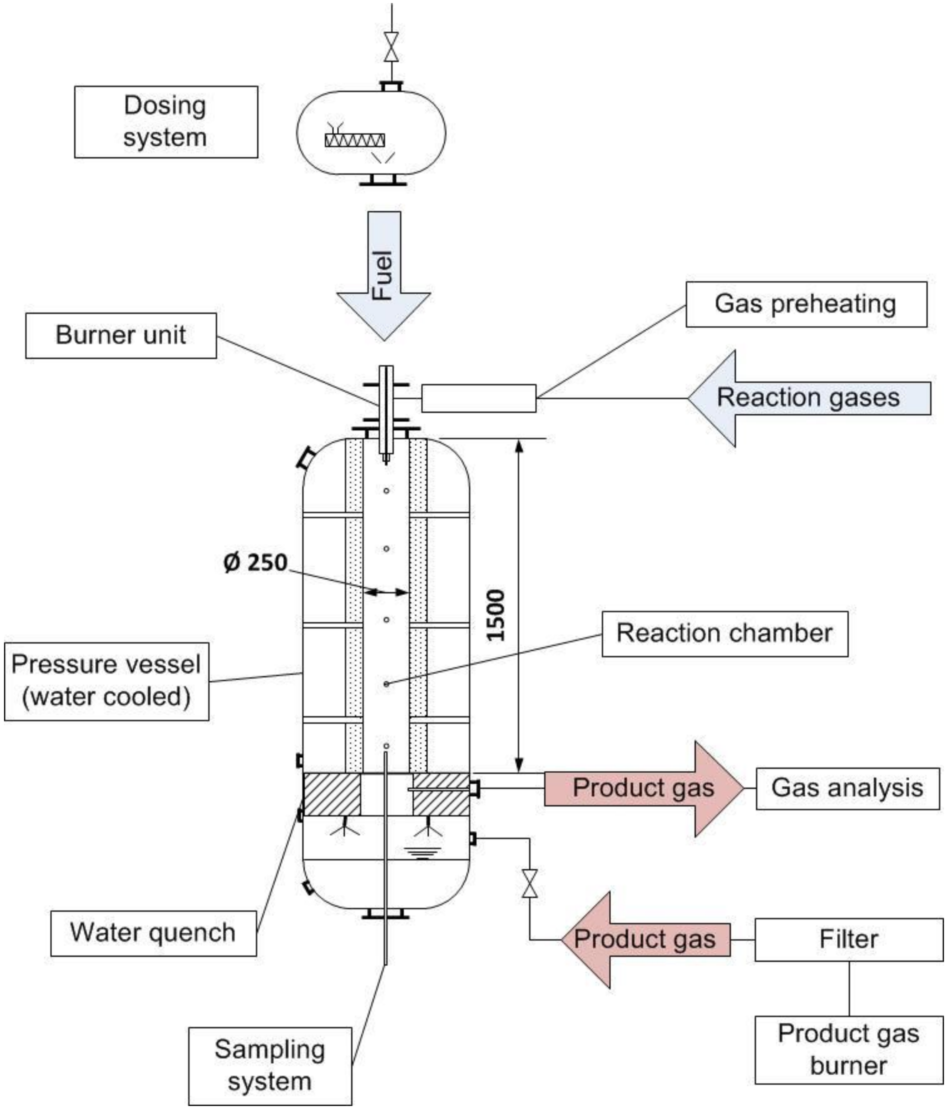
Optimization:

- Variation of O/C ratio
- Variation of steam content

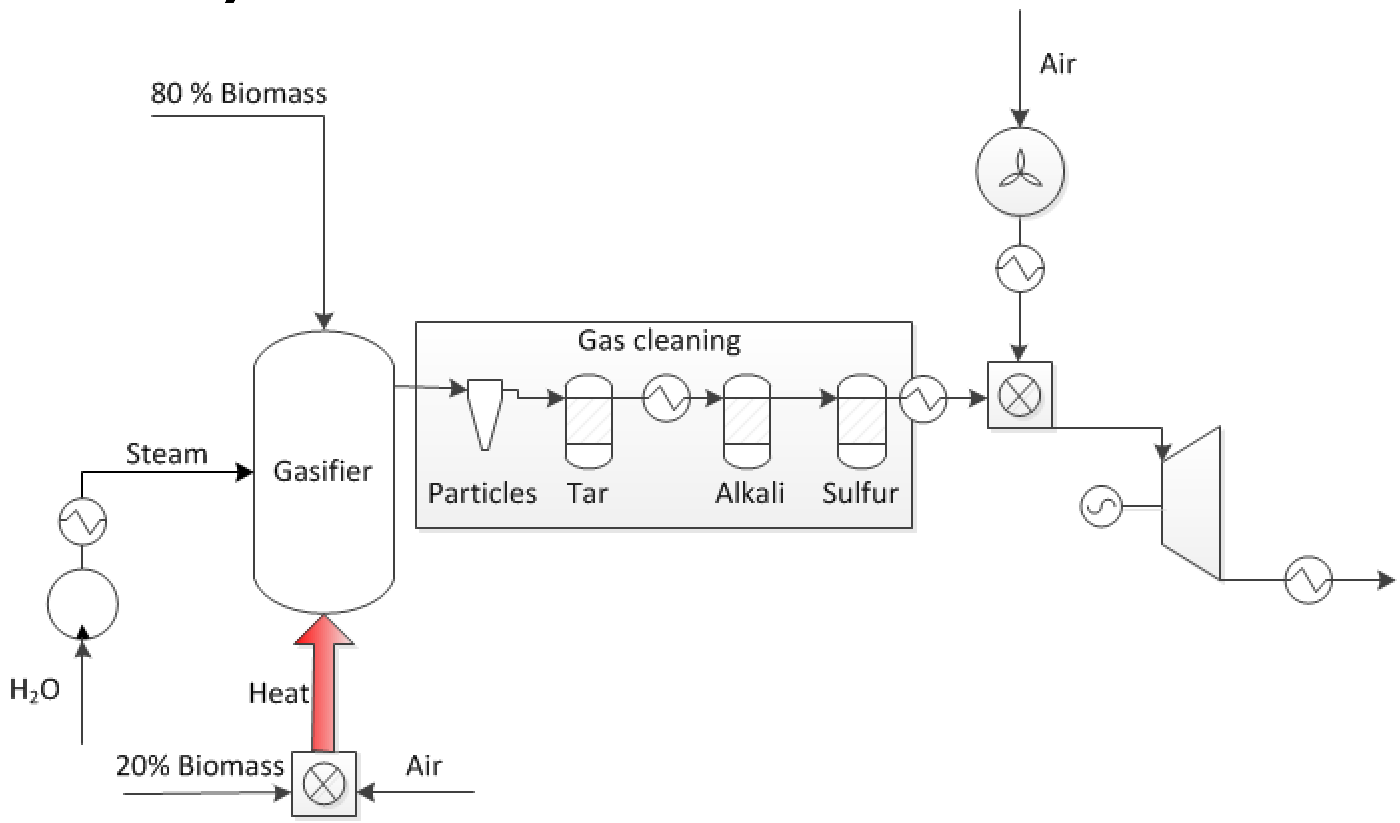
Gasifier design

Specifications:

- Autothermal process
- Fuel: HTC-coal, torrified biomass
- Fuel input: 100 kW
- Temperature: up to 1500 °C
- Test duration: up to 8h
- Flexible operating mode:
    - Pressure (1 – 6 bar absolute)
    - Variation gasifying medium

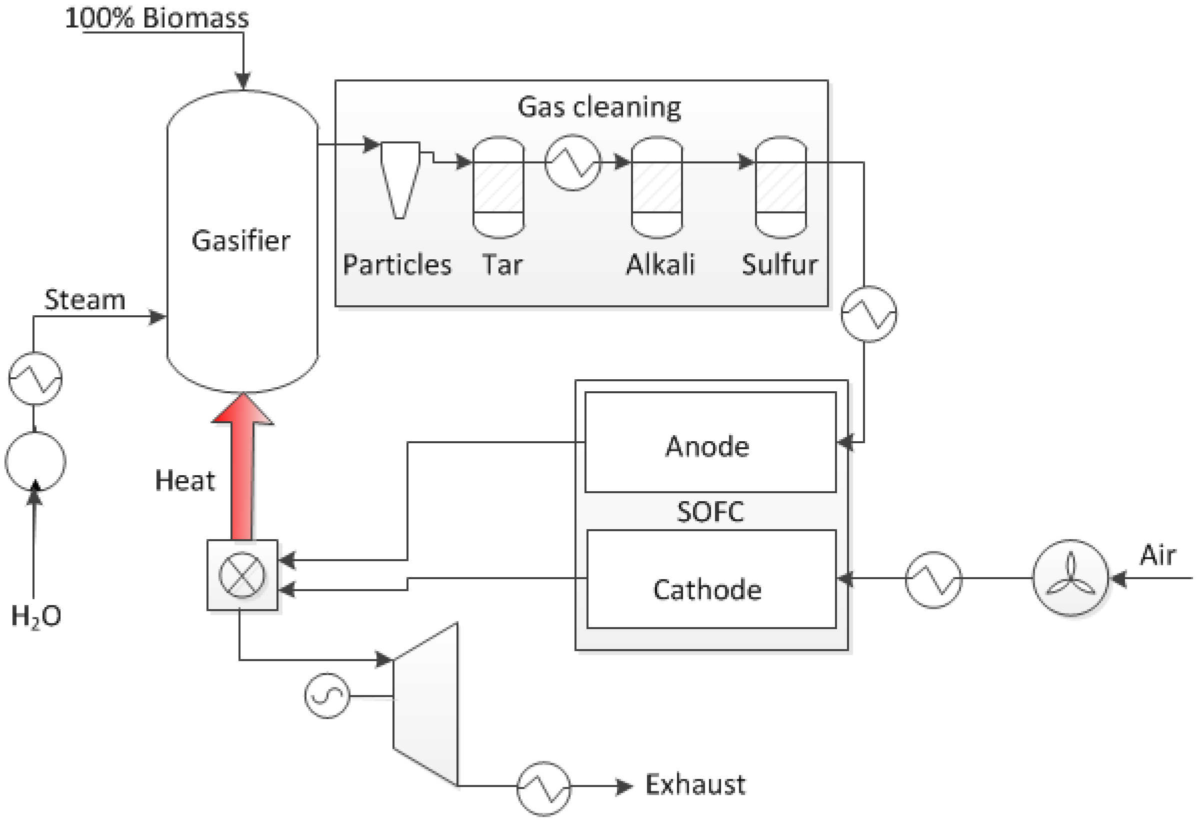


"Conventional" gasifier-GT system (indirect steam gasification)



- Efficiency ~20-30%

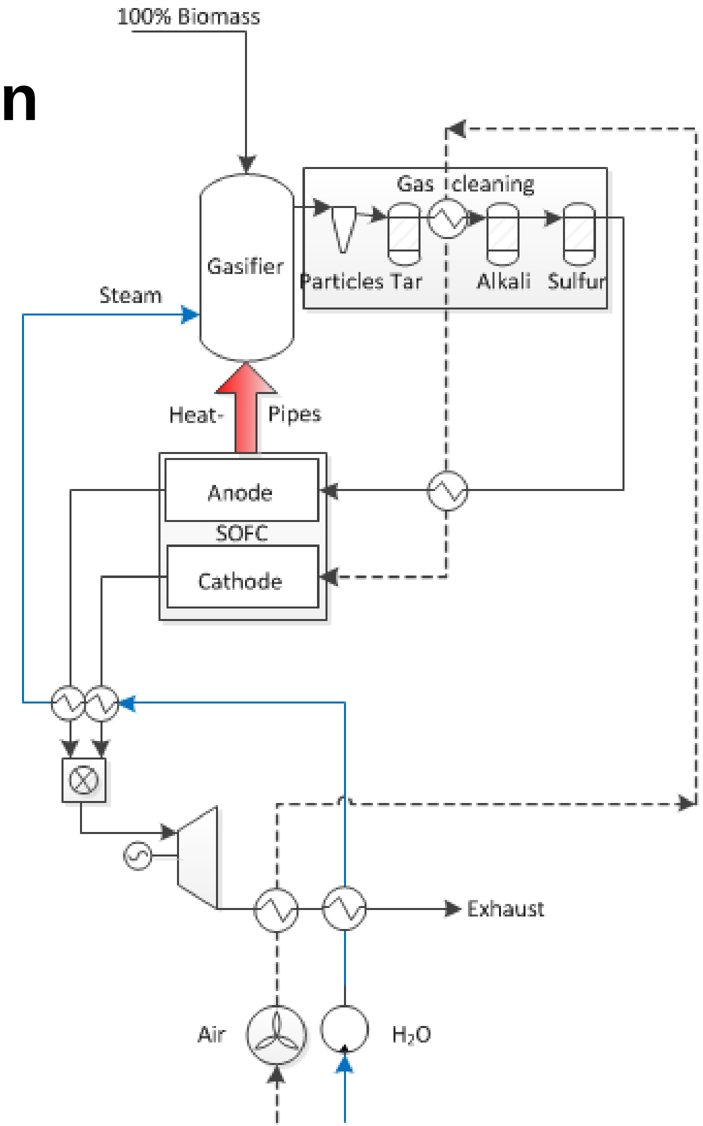
Integrated gasifier-SOFC-GT system



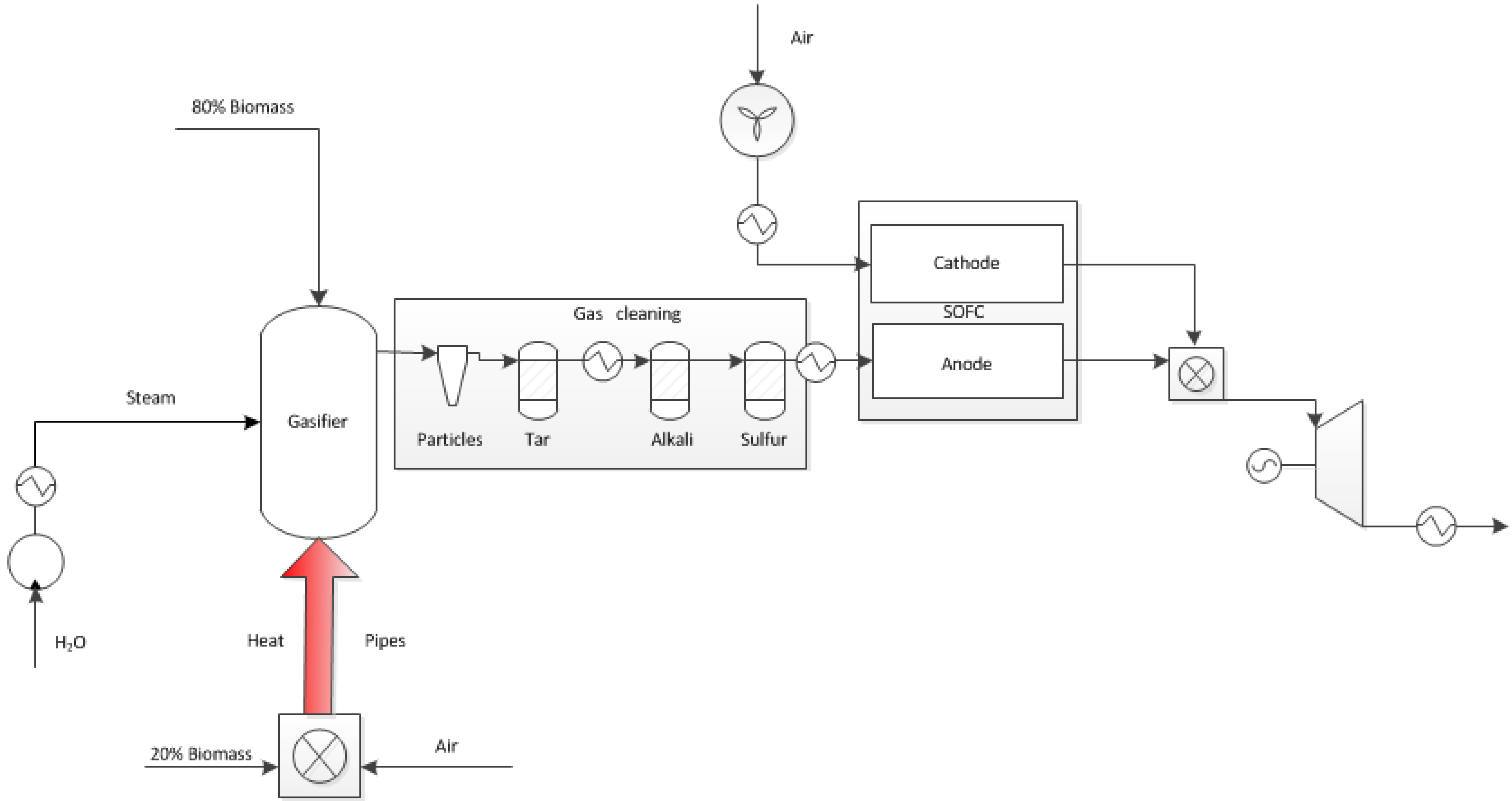
- SOFC waste heat utilization for gasification
- Efficiency ~50-60%

Example with heat integration

- SOFC waste heat utilization for steam production and gasification
- Efficiency ~50-60%

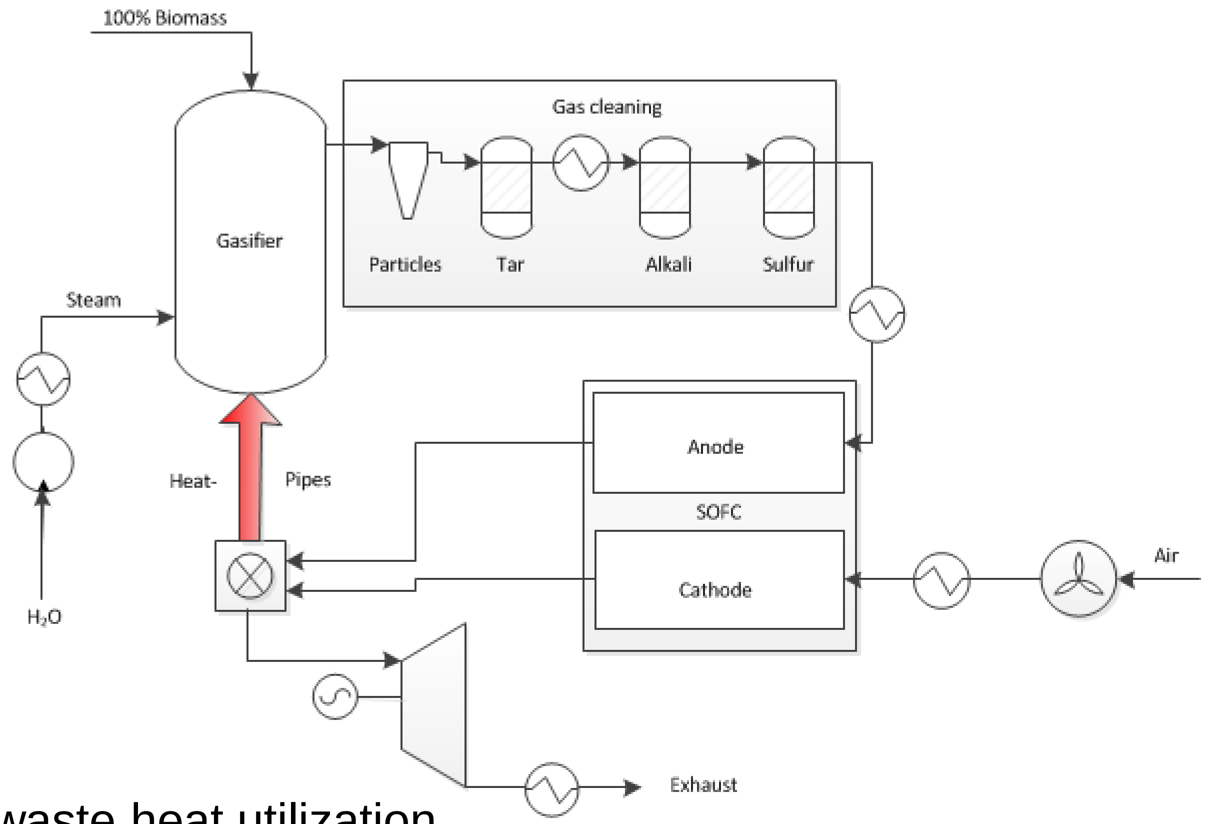


Separate gasifier + SOFC-GT system



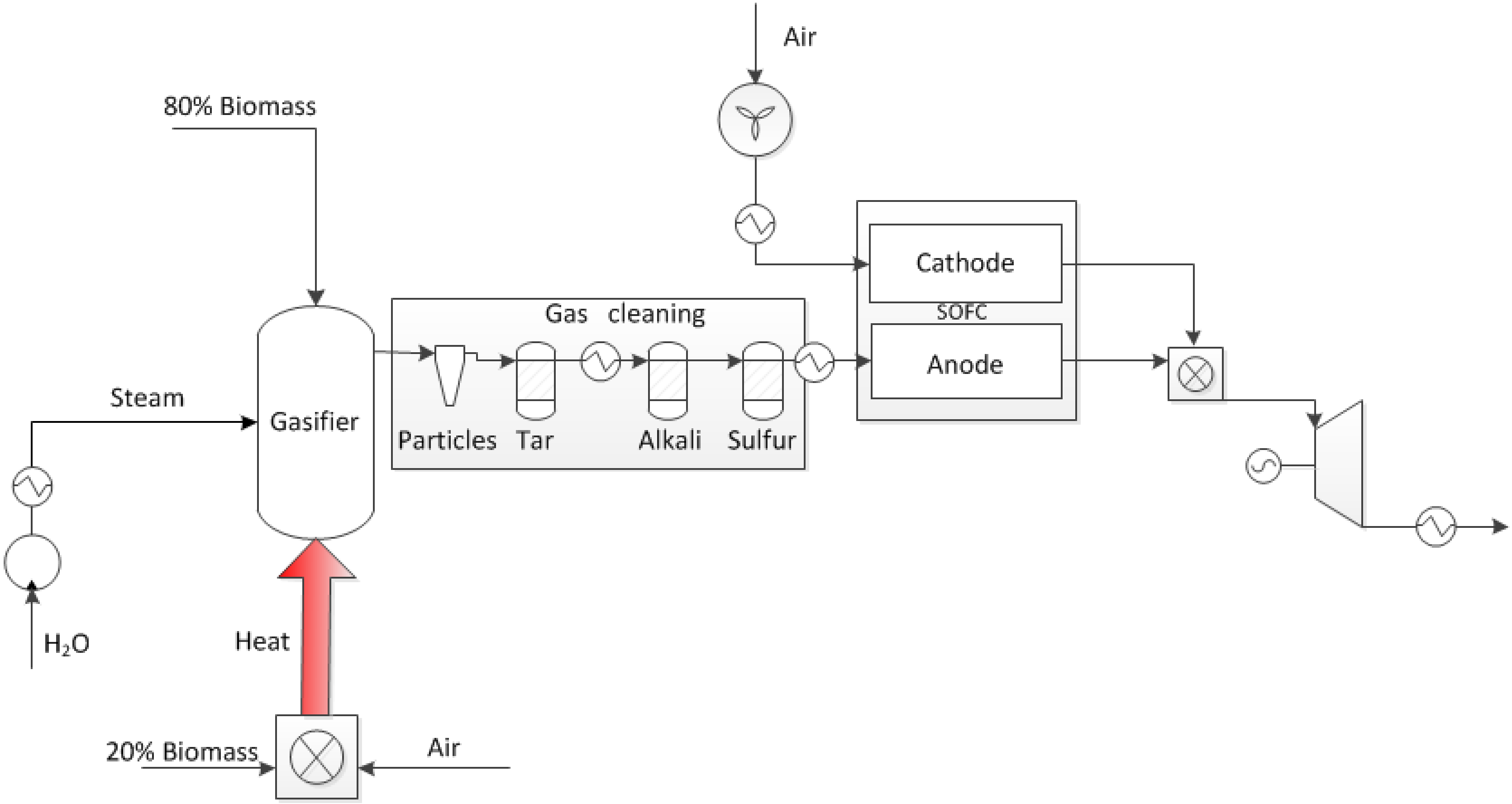
- Efficiency ~40-50%

Integrated gasifier-SOFC-GT system



- SOFC waste heat utilization
- Efficiency ~50-60%

Separate gasifier + SOFC-GT system

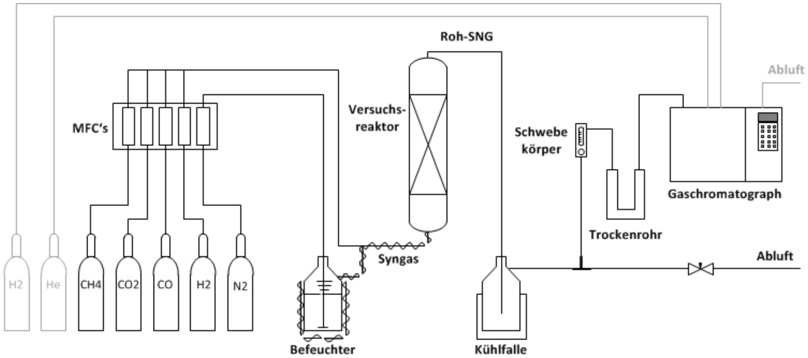


- Efficiency ~40-50%

Laboratory test rig
(methanation with synthetically mixed gases)

- Flexible investigation of different reactor concepts
  → Possibility to compare fixed bed, fluidized bed and 3-phase (slurry) reactor concept

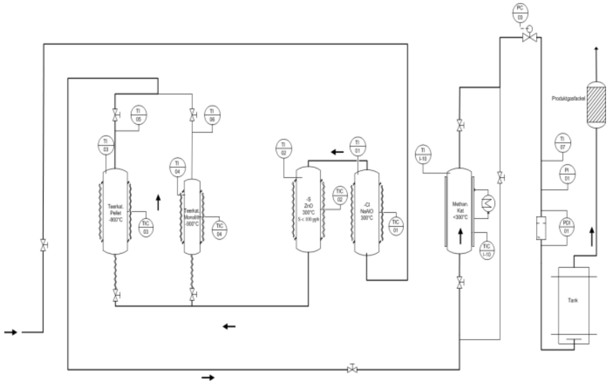
- Research focus:
  - CO und CO_2 methanation (as well as combinations)
  - Simulation of different possible gas compositions (simulation of synthesis gas compositions from entrained flow, fixed bed and fluidized bed gasifiers)
  - Investigation of heat and gas transport phenomena
  - Investigation of carbon formation on catalysts



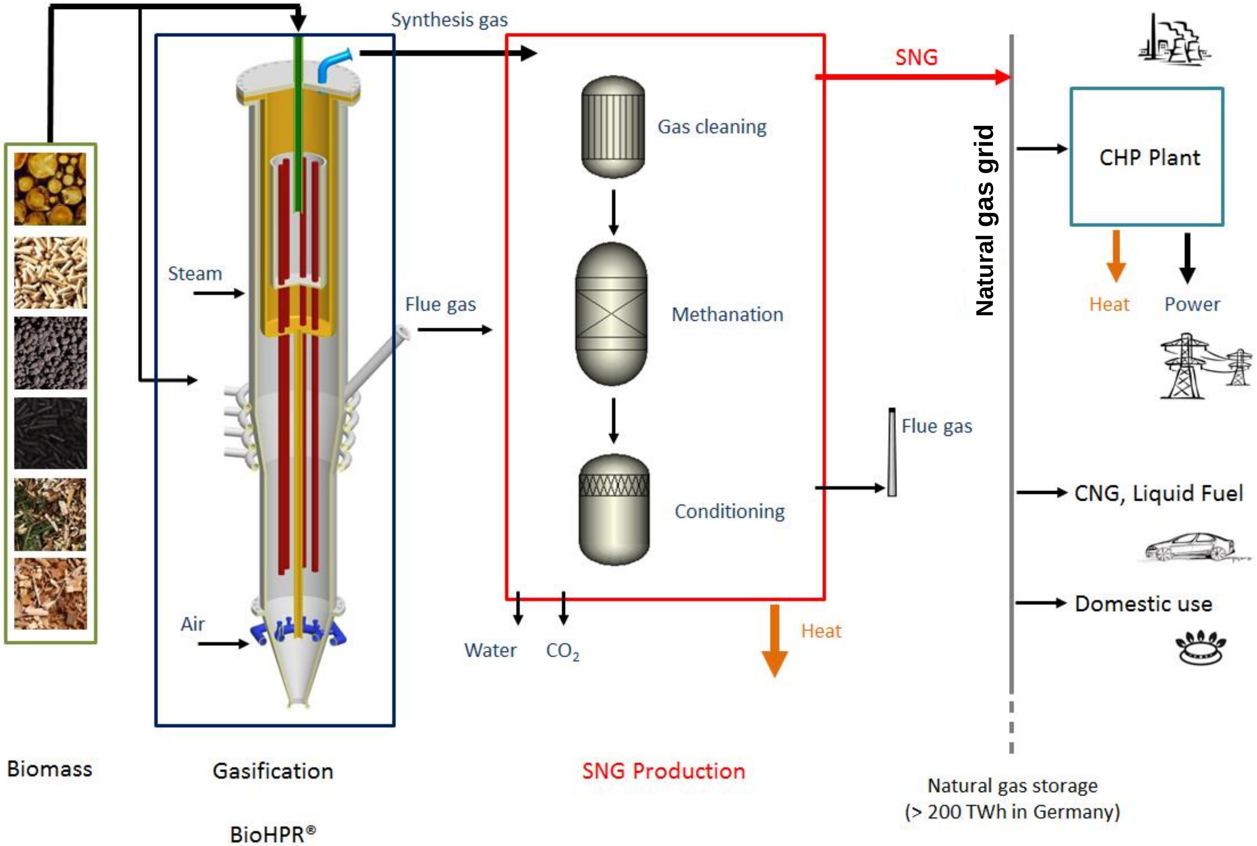
Small-scale pilot test rig

(gas cleaning and methanation unit with real synthesis gas from biomass gasifier)

- Experiments regarding gas cleaning and methanation of real synthesis gas from allothermal biomass gasifier
- Specification:
  - HPR-Input: max . 25 kW
  - Volumetric gas flow: 0,1 – ca. 2 Nm^3/h
  - Pressure: 1 bar (max. ca. 3 bar)
  - Temperatures:
    - » HPR: ca. 800°C
    - » Tar: ca. 850°C
    - » Adsorb.: ca. 320°C
    - » Methan.: ca. 300°C
  - Space velocities: 1000 – 5000 1/h
  - Control / data logging through stored program control



Concept "Biomass-to-SNG"



- Small scale (~ 500 kW – 5 MW)
  - → Reduced biomass transport logistics
  - → Efficient heat utilization
  - → Low environmental impacts
- Power generation in (off-site) CHP unit or CC plant
  - → Flexible
  - → Adjustable to local heat and power demand