Beyond 80 % Efficiency for Standalone Production of Bio-Methane from Wet Biomass

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Vision of the research at Chalmers

Demonstrate how to produce Bio-Methane with a thermal efficiency of 85% (10-15% units higher than today) from biomass delivered with a moisture content of 50% on mass.

$$\eta = \frac{m_{prod} LHV_{prod}}{m_{wet,biomass} LHV_{wet,biomass}} > 85\%$$

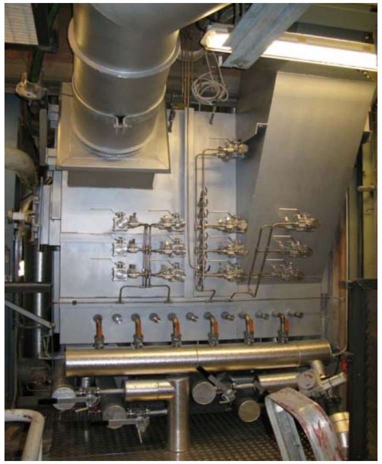
Delivered from plant

Delivered to plant

Commercialization

Chalmers lab reactor

Chalmers
2-4 MW Raw Gas
Demonstration Plant



1.5 Million €

GoBiGas Phase 1 Hisingen
20 MW Bio-Methane Pilot Plant
Göteborg Energi

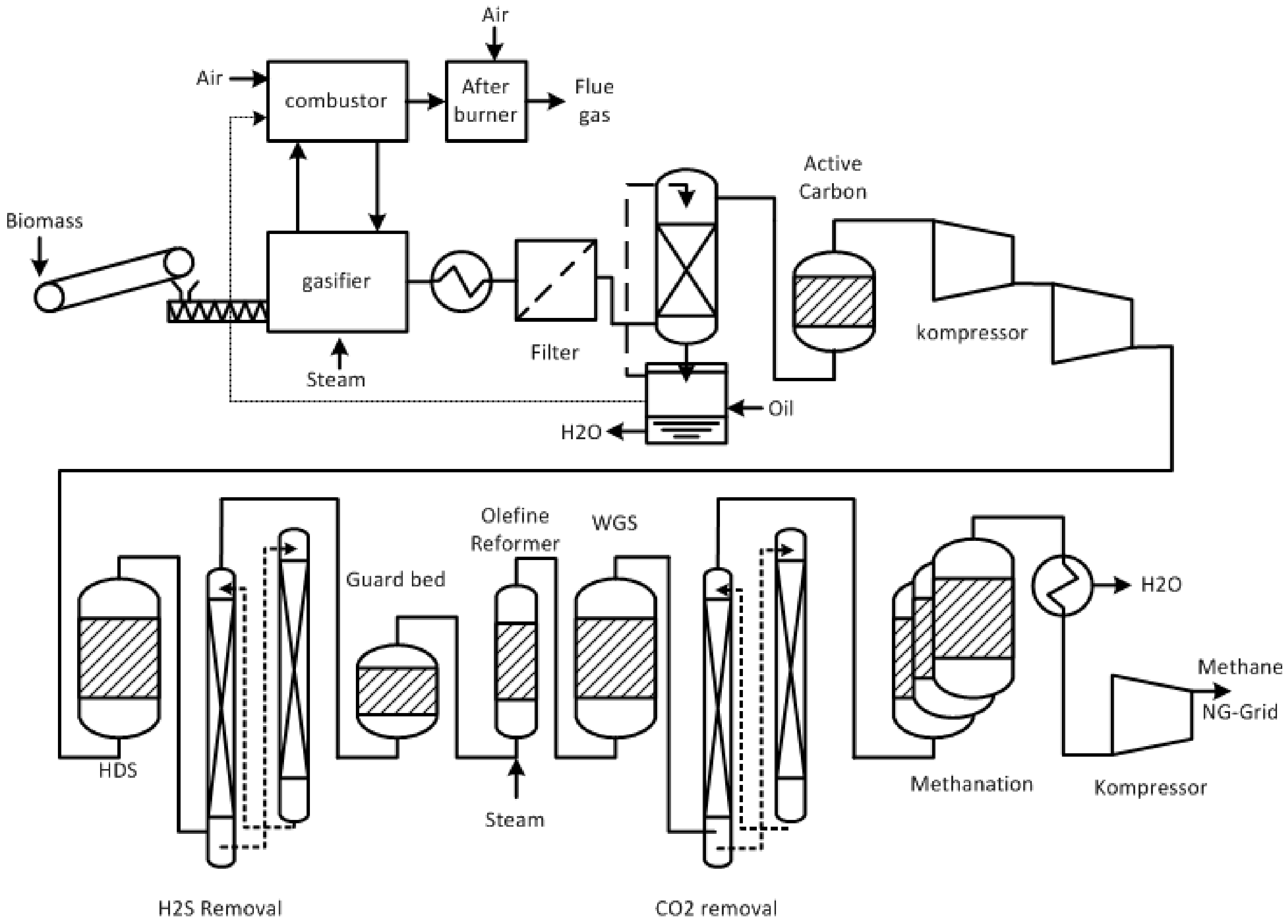
160 Million €

GoBiGas Phase 2 Hisingen
80-100 MW Bio-Methane
Commercial Plant
Göteborg Energi

380 Million €

2008 2013 2017

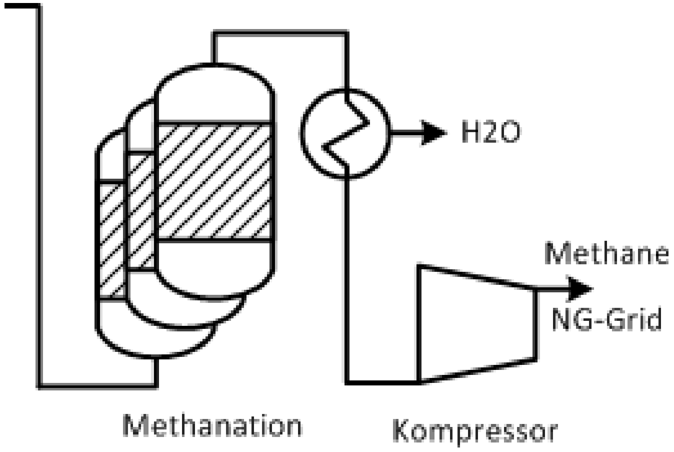
Process Scheme Biomass to Bio-Methane in the GobiGas plant



1. Indirect Gasifier
2. Afterburner
3. Filter
4. Oil Scrubber
5. Active carbon guard bed
6. Compressor
7. Hydrodesulfurization
8. Amine scrubber (H2S)
9. H2S-guard bed
10. Olefin reformer
11. Shift reactor
12. Amine scrubber (CO2)
13. Three step Methanation
14. Compressor

Complemented with steam cycle for internal electricity production and drying the present process would have an **efficiency** according to the given definition around **70%**

Optimization of the process



Optimization:
Maximize the amount of methane that is initially formed in the gasification process to reach the methanation step.

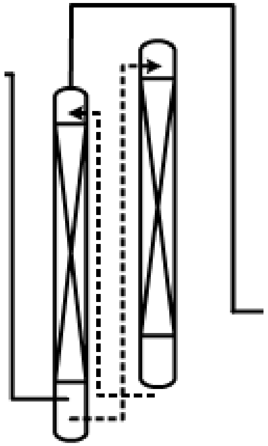
Exergy loss for the system

$CH_4 + H_2O \Rightarrow CO + 3H_2$ $\Delta H = 212$ J/mole CH_4 In process at >850 °C

$CO + 3H_2 \Rightarrow CH_4 + H_2O$ Methanation at <600 °C

⇨ As much methane as possible in syngas

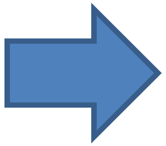
Optimization of the process



CO2 removal

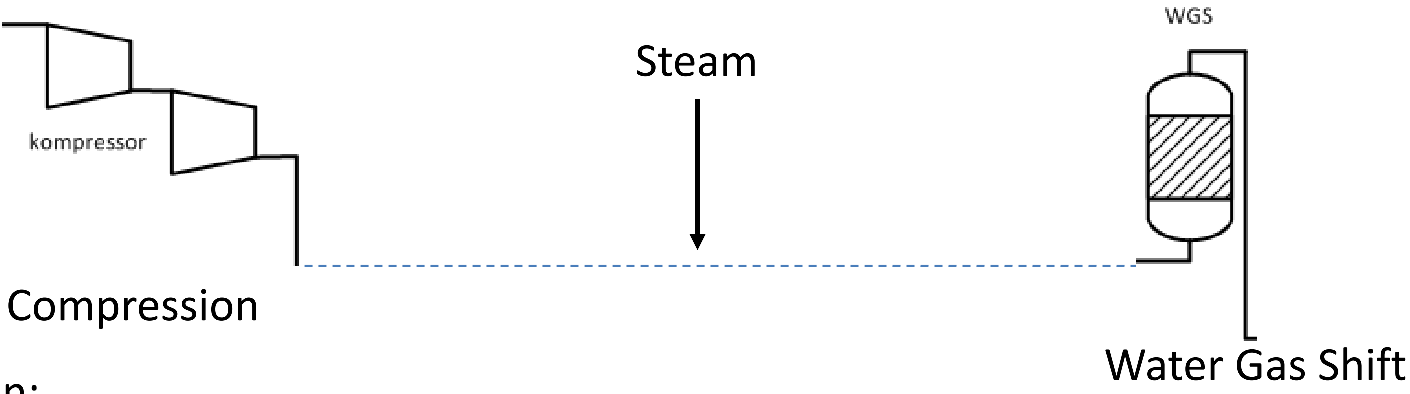
Optimization:
Minimize the amount of CO2 in the product gas

Loss for the system
90-130 kJ/mole$_{CO2}$ heat at ~ 140°C



Minimize the amount of oxygen that is added to generate heat for the gasification process to be mixed with the product gas

Optimization of the process



Steam

Compression

Water Gas Shift

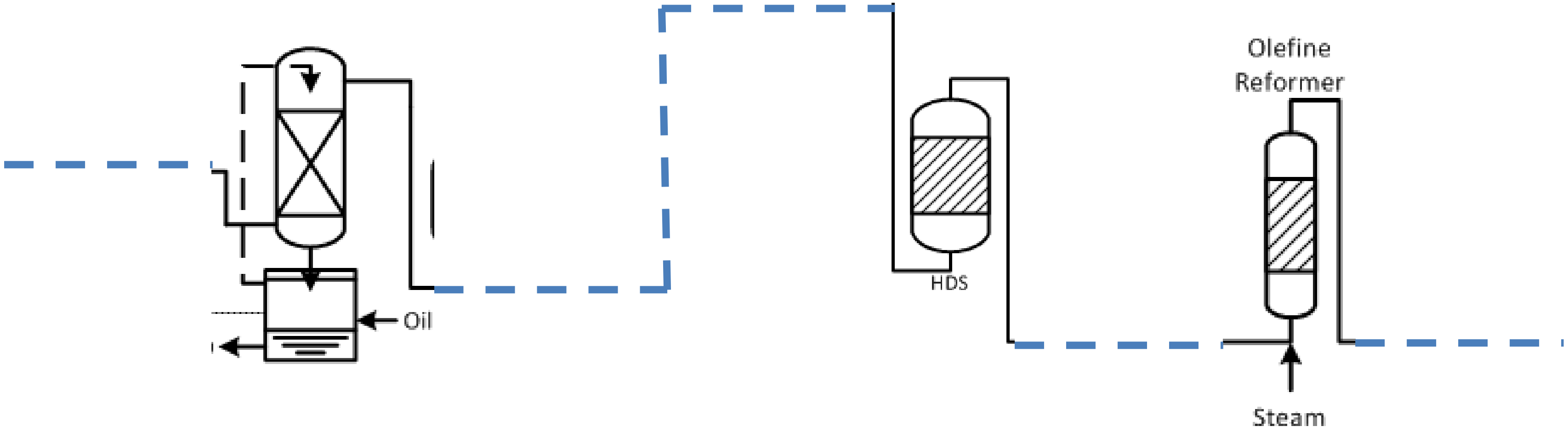
Optimization:
H_2 to CO ratio in raw gas between 0.7 and 0.8
(approximately equilibrium at 900 °C for gas originating from the biomass)
H_2 to CO ratio for methanation ~ 3

Heat generation $CO + H_2O \Rightarrow CO_2 + H_2$ ΔH_{reak} -44 kJ/$mole_{CO}$
Additional power consumption compression to 6 bar ~ 7.5 kJ (electricity)/$mole_{CO}$ (converted)
Minimum steam demand to reach H_2 to CO ratio = 3

In gasifier	850 °C	1.93 $mole_{H2O}/mole_{CO}$	Heat of evap.	85 kJ/$mole_{CO}$
Shift reactor	400 °C	0.67 $mole_{H2O}/mole_{CO}$	Heat of evap.	29 kJ/$mole_{CO}$

No additional steam should be fed to the gasifier to promote the shift reaction

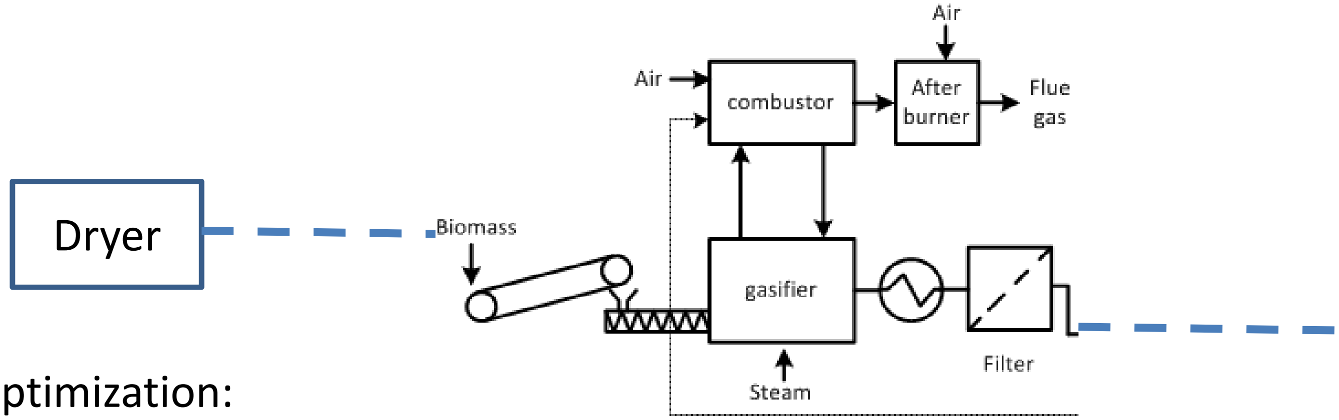
Optimization of the process



Optimization:
This introduce a second gasification where the product gas is reheated to convert unwanted hydrocarbons and cooled to the temperature of the water gas shift. This step could be avoided if the conversion of the hydrocarbons in the first gasification step was sufficient.

➡ The conversion of all hydrocarbons except methane should be converted in the gasification step

Optimization of the process



Optimization:

In the gasification process the losses of chemical bound energy is related to:

- Heating of Combustion Air
- Heating of Steam
- Heating of Fuel
- Evaporization of Moisture
- Unconverted Char

The heat demand for drying and heating of combustion air, steam and fuel need to be minimized as well as unconverted char

Challenges to be Addressed by Research

- As much methane as possible in syngas
- Minimize the amount of oxygen that is added to generate heat for the gasification process to be mixed with the product gas
- No additional steam should be fed to the gasifier to promote the shift reaction
- The conversion of all hydrocarbons except methane should be converted in the gasification step
- The heat demand for drying and heating of combustion air, steam and fuel need to be minimized as well as unconverted char

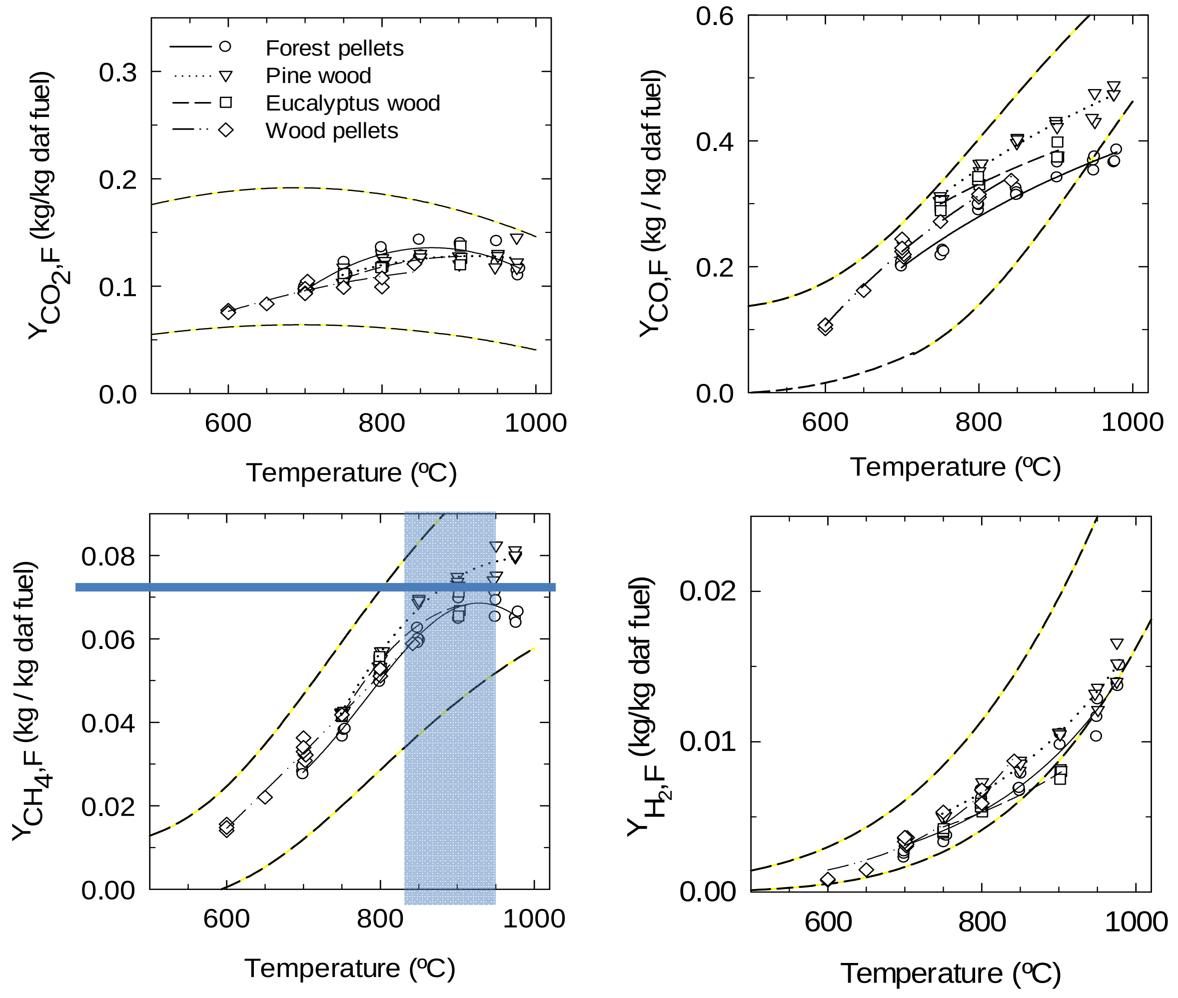
Methane in Raw Gas

Primary Product Yields of Biomass

Methane peaks between 825 and 975 °C

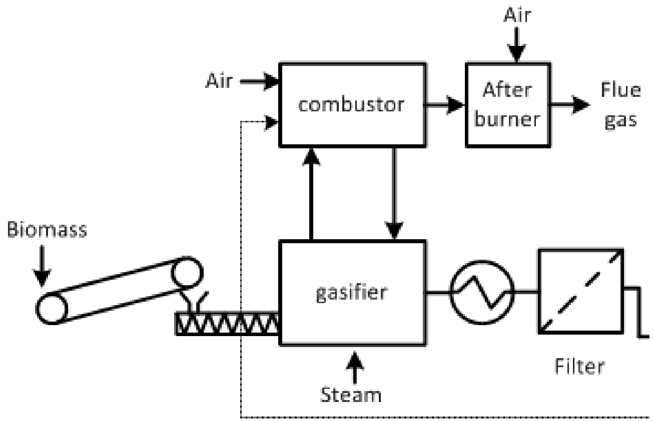
7%$_{mass}$ or 18 %$_{energy}$ of the dry biomass is Methane.

If this is reformed to H_2 and CO this would reduce the conversion efficiency with up to 4%



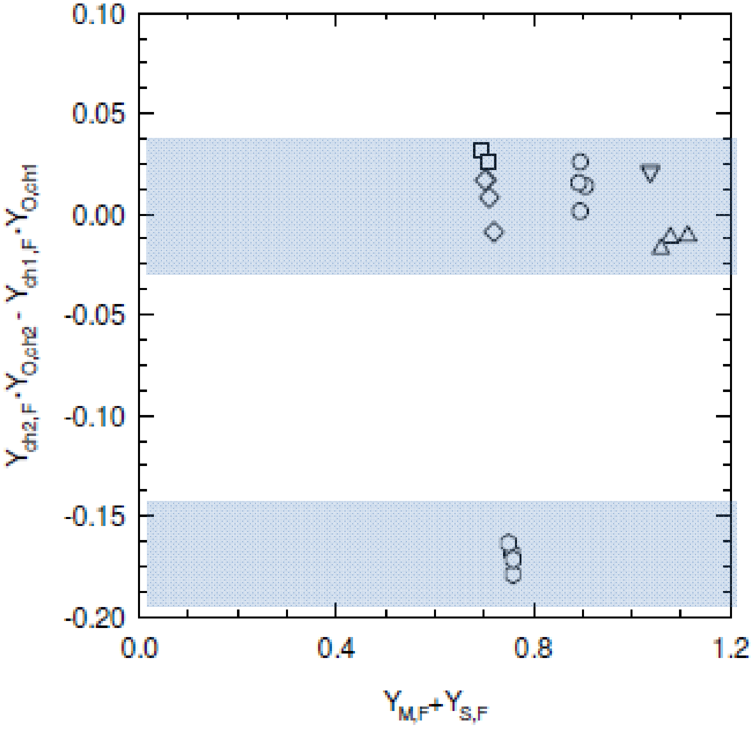
Thesis of Daniel Neves

Oxygen Transport in Indirect Gasifiers



Comb. Me + O2 => MeO
Gasi. MeO+CO => CO2 + Me

Measured Oxygen Transport
in Chalmers Gasifeier

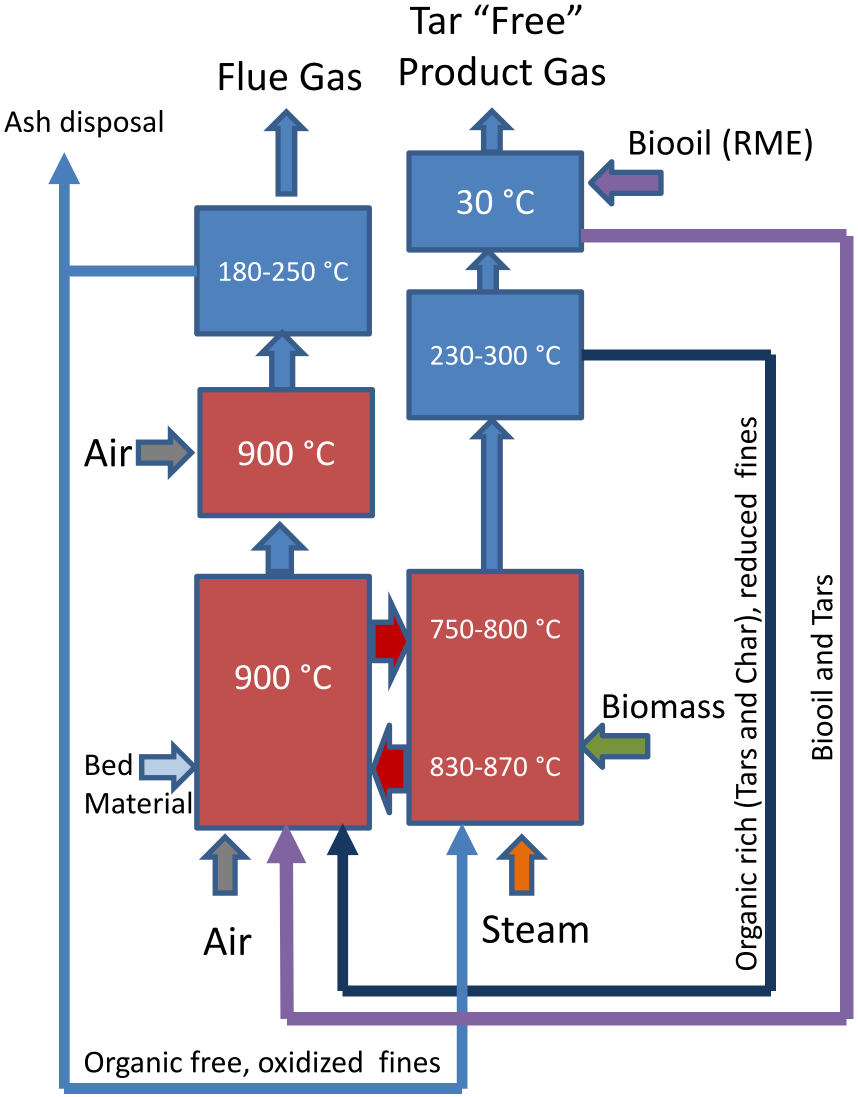


Silica Sand

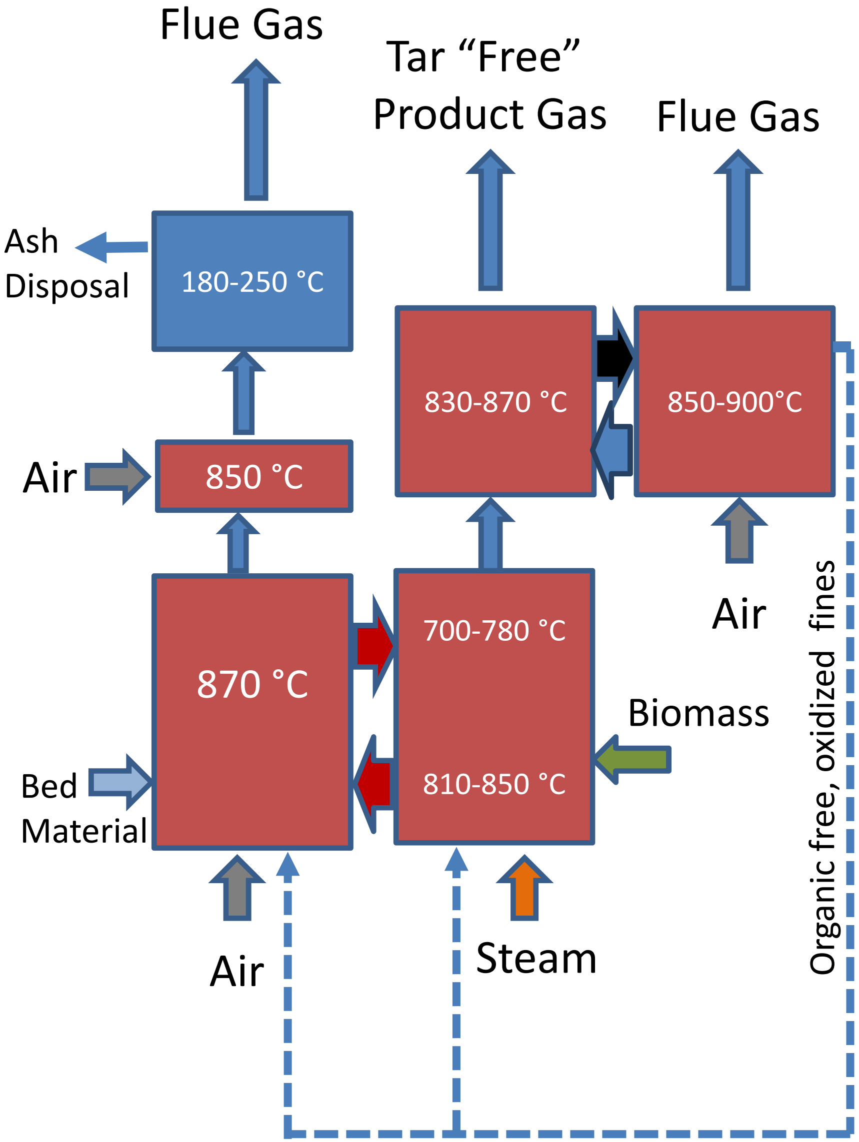
“Olivine”

Neves et al Applied Energy 2014

Reforming of Hydrocarbons

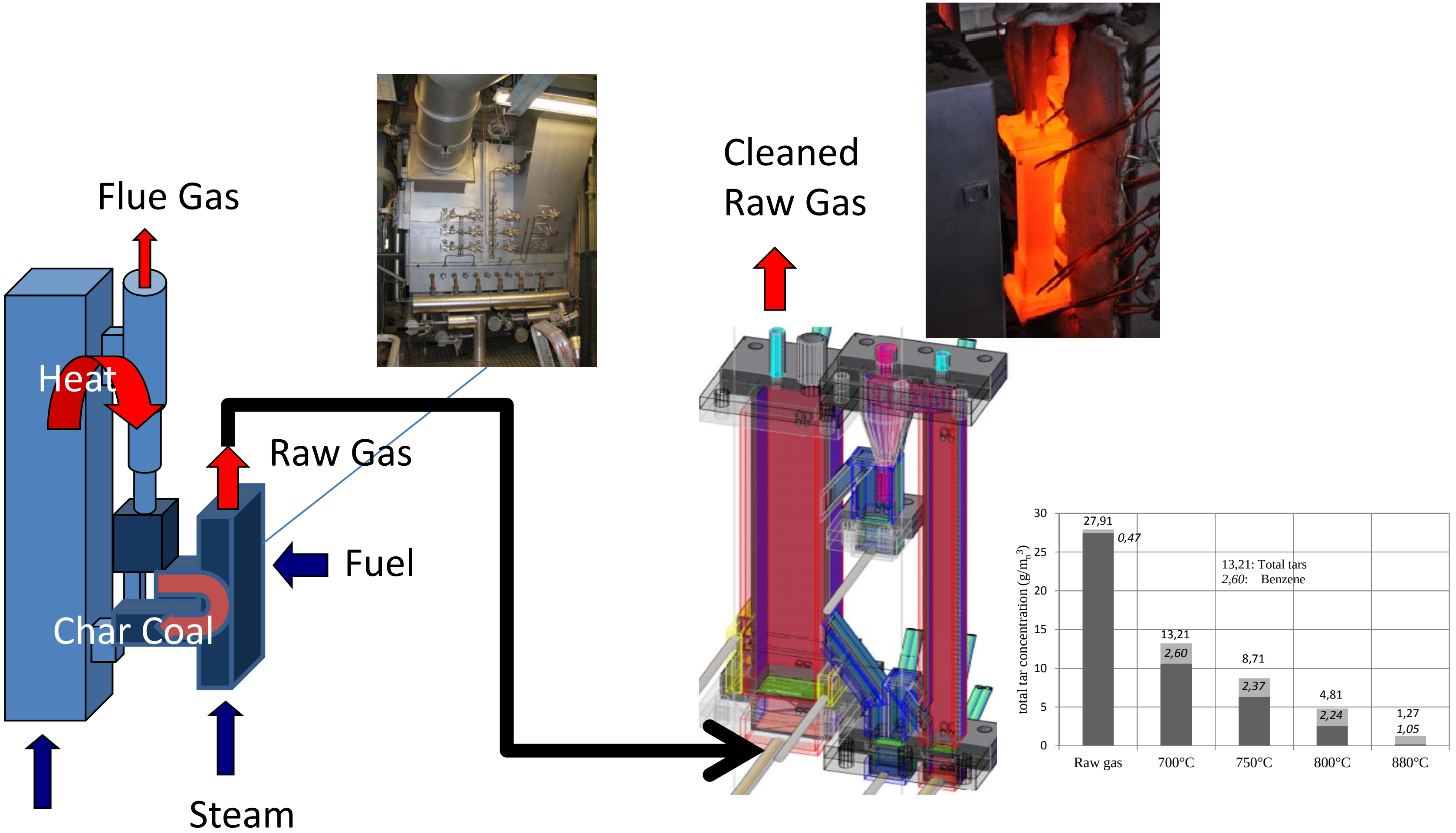


GoBigas



Development

Advanced Circulation of Fines



Flue Gas

Heat

Raw Gas

Fuel

Char Coal

Air

Steam

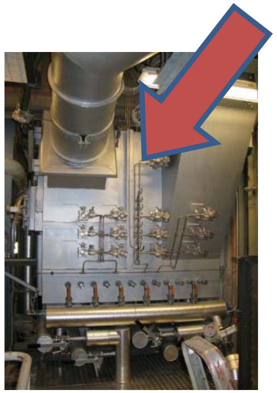
Cleaned Raw Gas

Gasifier

Gas Cleaning

Berguerand et al 2012

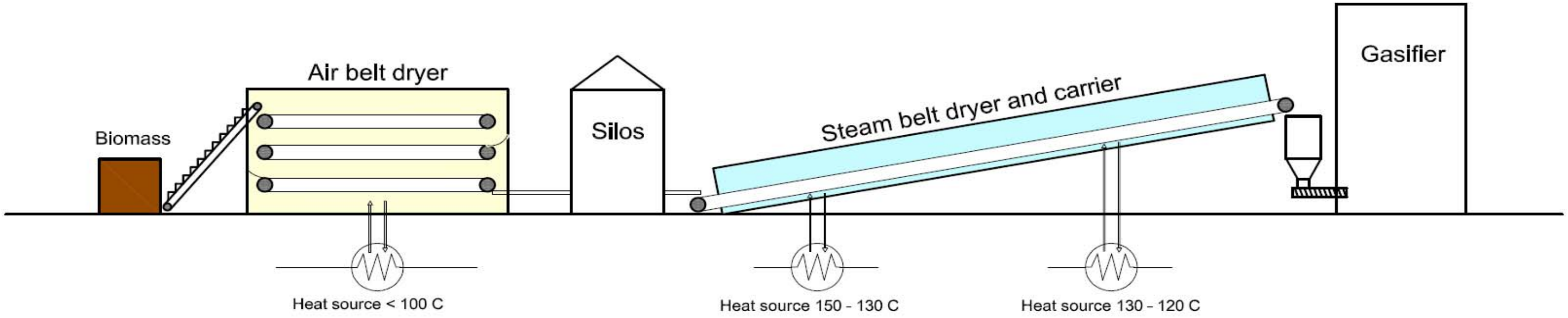
Optimize Fuel Conversion



Video made by Erik Sette/Rustan Marberg 2011

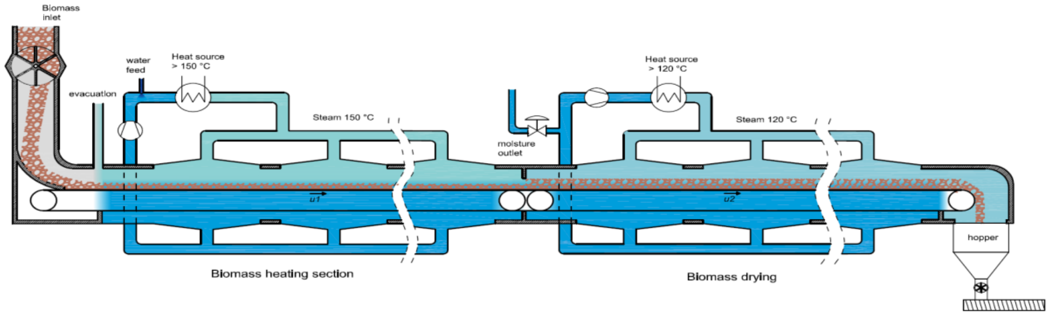
Steam to Fuel Ratio ≠ Char Conversion

Preheating and Drying of Fuel



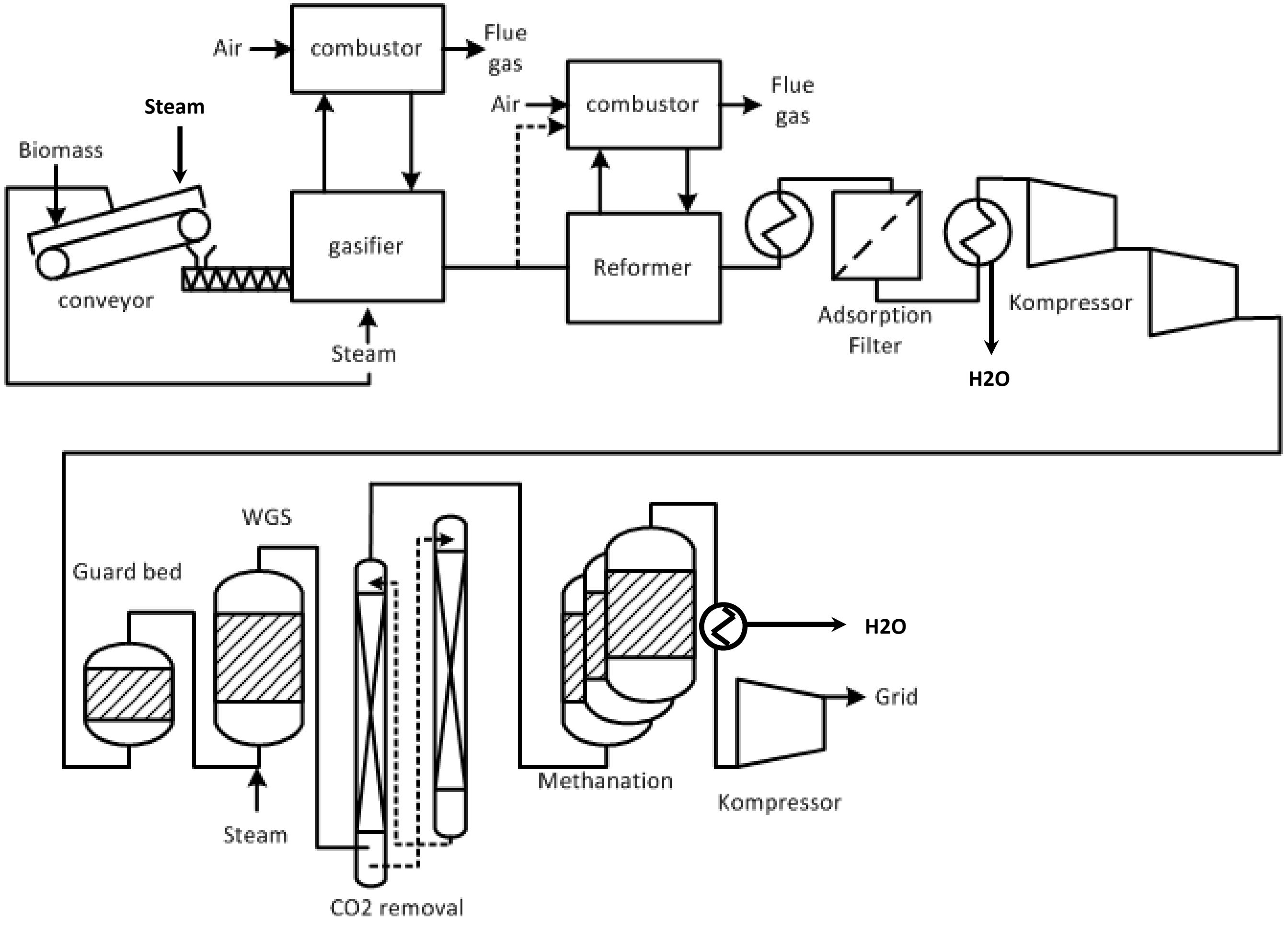
Preheating of fuel correspond to an average temperature of 100 °C and 0% moisture

Fuel moisture is used as purge gas for inertisation



Alamia et al (submitted for publication)

Optimized process



1. Preheating/drying
2. Indirect Gasifier
3. CLR
4. Adsorption Filter (H_2S,HCl)
5. Compressor
6. H_2S-guard bed
7. Shift reactor
8. Amine scrubber (CO_2)
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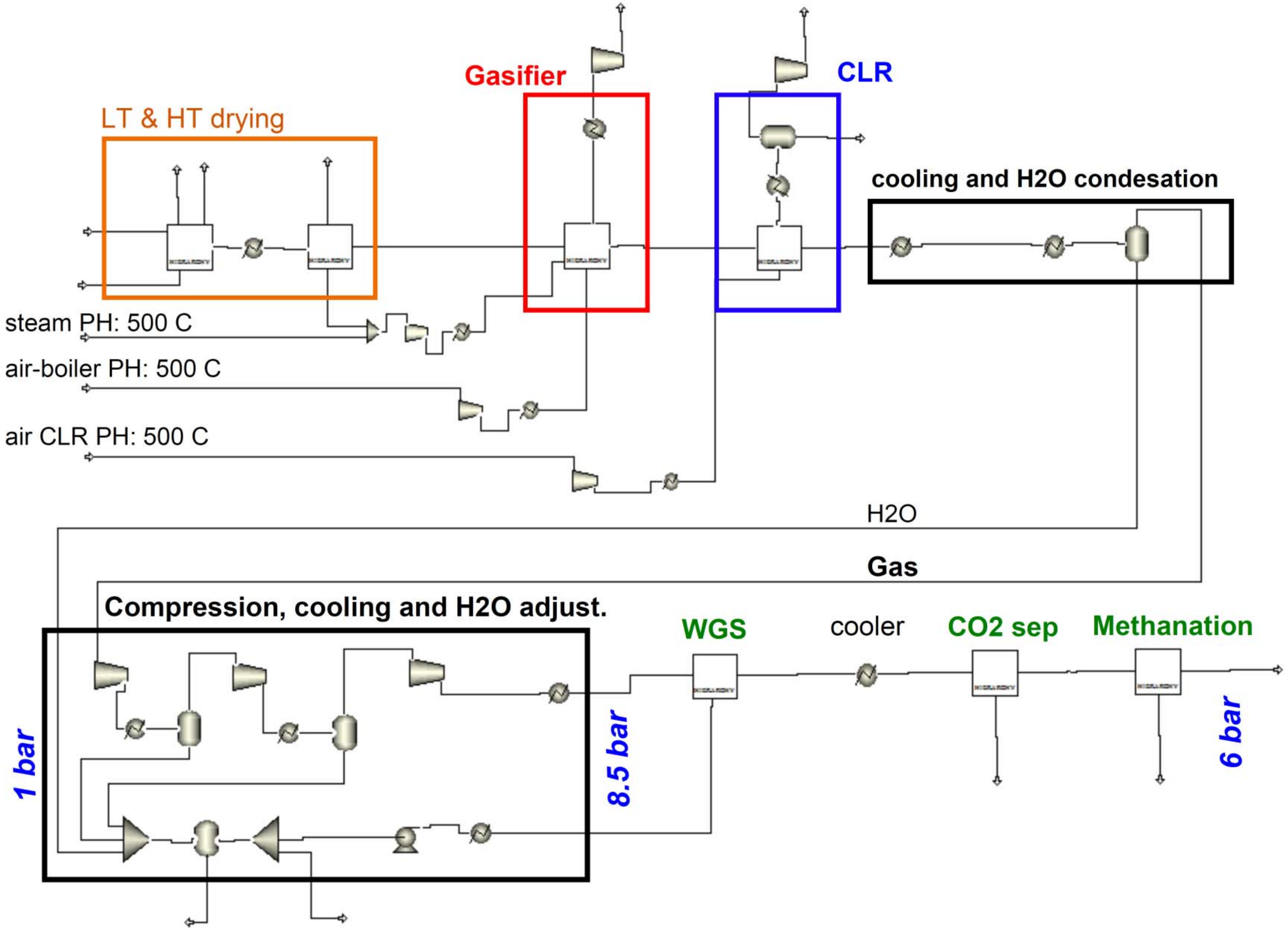
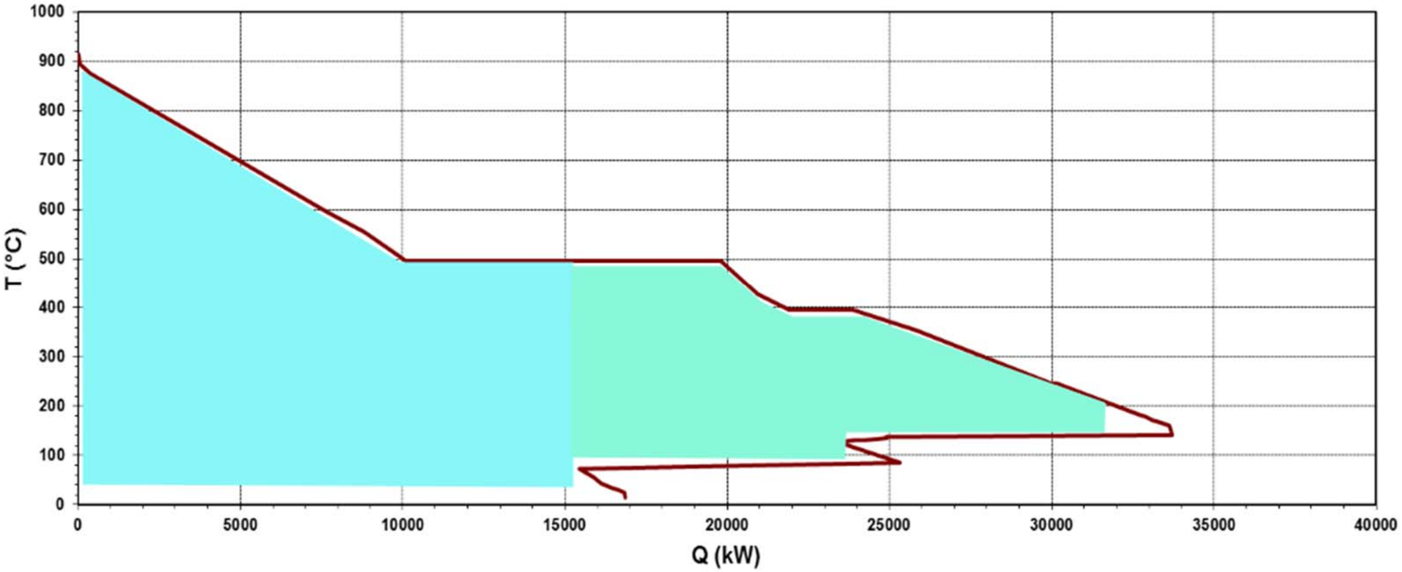
Process Simulation - Aspen



CH4 >98 %
25 C
6 bar

GCC curve at Optimized Process

η =80%, 48% of the char is Gasified => Combustion unit 13.5 MW_{th} per 100 MW dry biomass

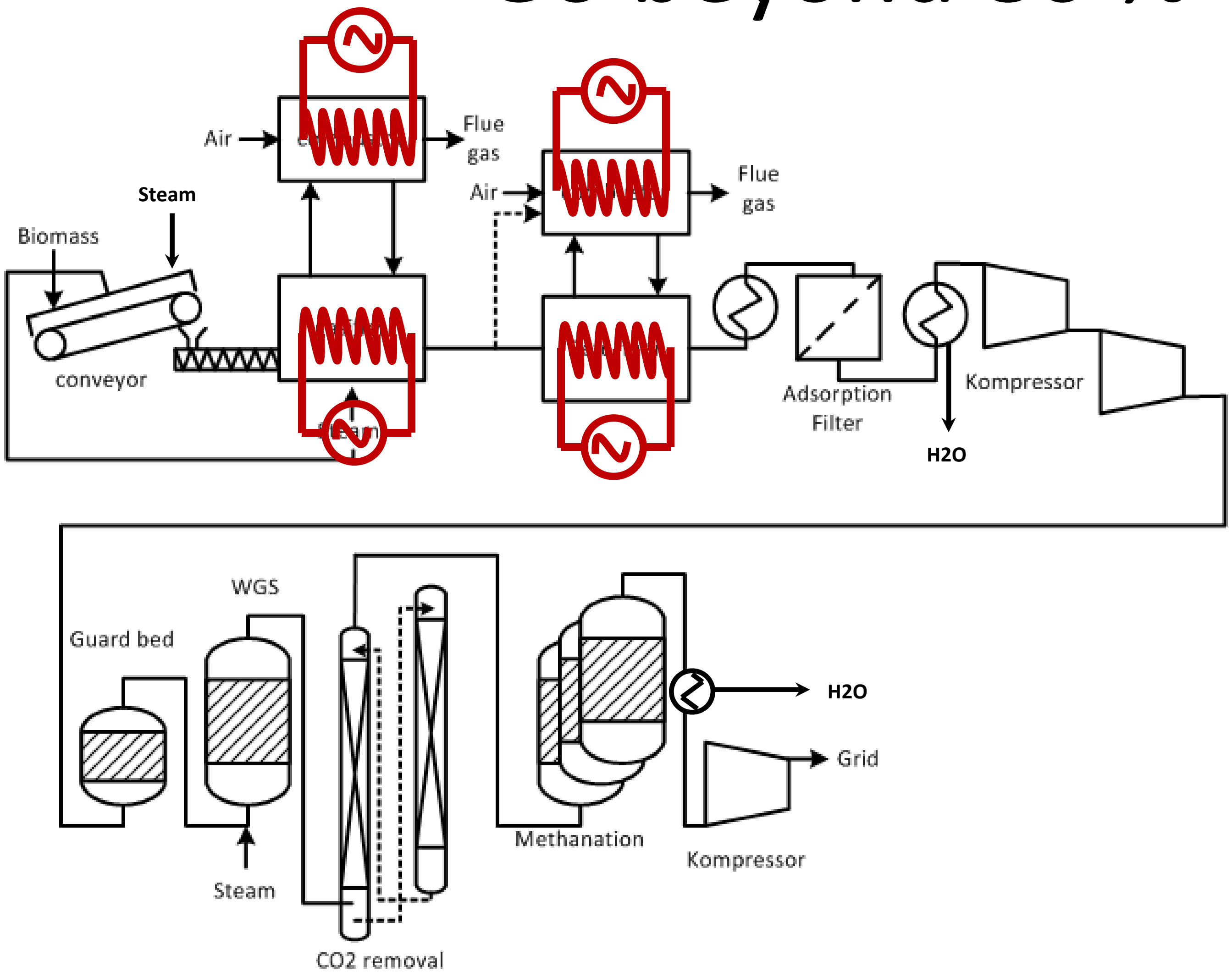


Heat available : around 31 MW_{th} per 100 MW dry biomass (15,4 between 900 C and 500 C)

El consumption in the process : 4,1 Mw_{el} per 100 MW dry biomass

η st.cyl.	20 %	25%	30%
Excess Electricity (MW)	2,1	3,65	5,2

Go beyond 80 %



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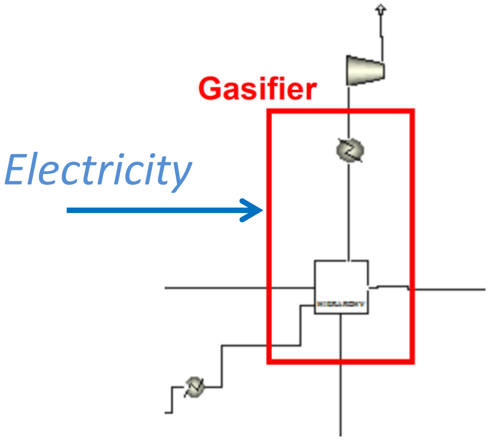
Biomass to SNG efficiency



MORE CHAR
IS GASIFIED

Xchar gasif. (%)	Steam cycle eff.	Electricity input (MW)	Produced CH4 from 100 MW dry biomass input (MW)	Efficency Based on LHV (%)
48 % (max)	14%	0	70.0	80.1
56,5 %	20%	2.1	72.0	82.4
61,5 %	25%	3.6	73.4	84.0
66,5 %	30%	5.1	74.7	85.5

Conclusion

- It is possible to reach above 80% efficiency for a stand alone Biomass to Bio-Methane production unit

- The main challenges to reach this goal are:

  - Reforming of all hydrocarbons except methane to CO and H_2 already in the gasification step without introduction of additional oxygen

  - Obtain high conversion of char in gasifier

  - High efficient small scale steam cycles