High volatiles conversion in a dual stage fuel reactor system for Chemical Looping Combustion of wood biomass

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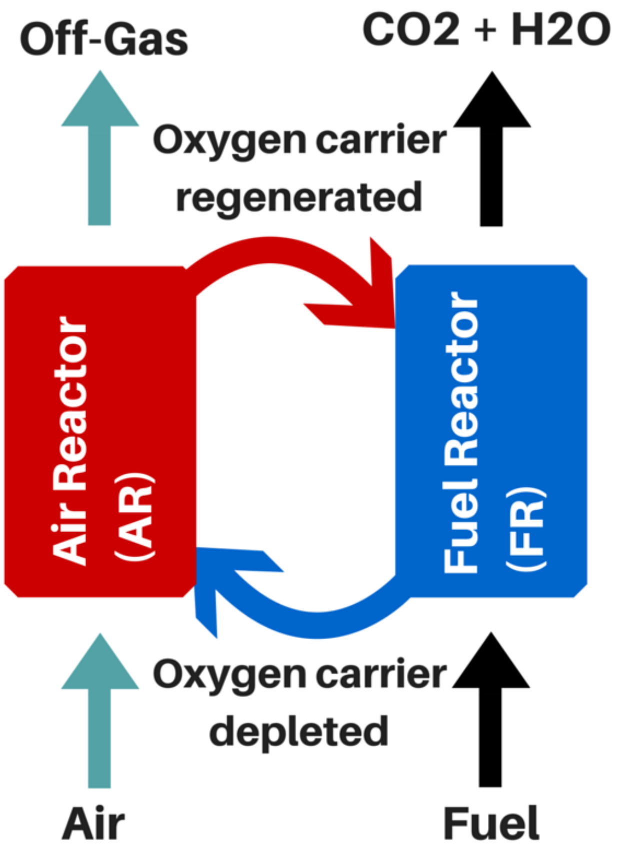
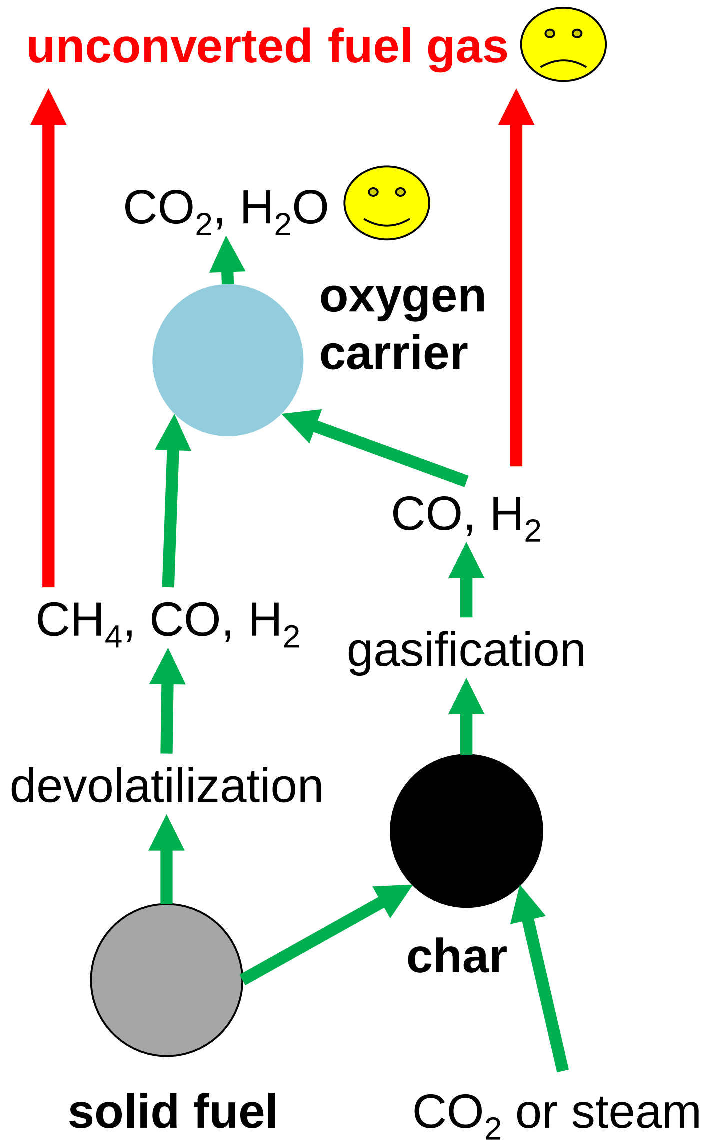
Dyn-Sim-FP
DYNAMISCHE SIMULATION VERNETZTER FESTSTOFFPROZESSE
SPP 1679

Chemical Looping Combustion

- Carbon capture process
- Solid oxygen carrier (OC) is oxidized/reduced (reactor-regenerator system)
- iG-CLC: solid fuel is gasified
- Complex heterogeneous reaction network
  - Oxygen carrier reactions
  - Solid fuel conversion
- ➢ Conversion kinetics differ from those of regular air firing





Solid fuel conversion pathway

In-situ Gasification Chemical Looping Combustion

- Solid fuel releases volatiles
- Remaining char is gasified
- CO, H_2 and CH_4 can react with oxidized carrier

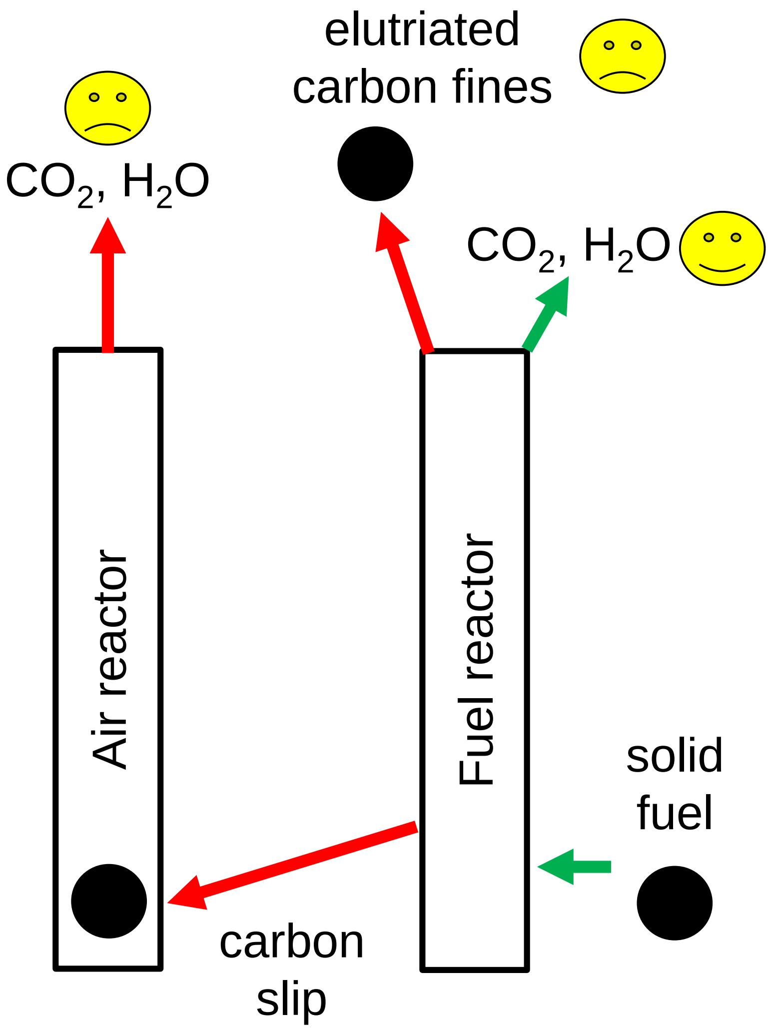
Main issue

- Parts of fuel gases do not contact or react with oxygen carrier (bypass)
- CO, H_2 and CH_4 leave system unconverted → plant efficiency ↓

Expressed by the term oxygen demand Ω_{OD}:

$$\Omega_{OD} = \frac{\text{oxygen needed for fuel gases leaving FR}}{\text{oxygen needed for total fuel conversion}}$$

Perfomance of the CLC process



Carbon slip with the oxygen carrier to AR

- CO_2 released in AR not captured
- Carbon capture η_{CC}:

$$\eta_{CC} = \frac{\text{carbonaceous gases (FR)}}{\text{carbonaceous gases (FR + AR)}}$$

Elutriated carbon fines

- Solid fuel not converted → plant efficiency ↓
- Solid fuel conversion X_{sf} :

$$X_{sf} = 1 - \frac{\text{Carbon elutriated}}{\text{Carbon introduced}}$$

Strong fuel influence on perfomance

- Biomass has high volatile fraction
- Very reactive char

➢ **Mainly oxygen demand Ω_{OD} is an issue**

Project aim: enhance gas conversion

Chemical Looping Combustion plant at SPE Hamburg

Investigation of general process behavior

- Fluid dynamics
- Chemical conversion

Experiments with various fuels

- Complex conversion behavior of lignite, bituminous coal and methane
- Interaction of fluid mechanics and chemical conversion (particle size)

Special focus on two-stage system

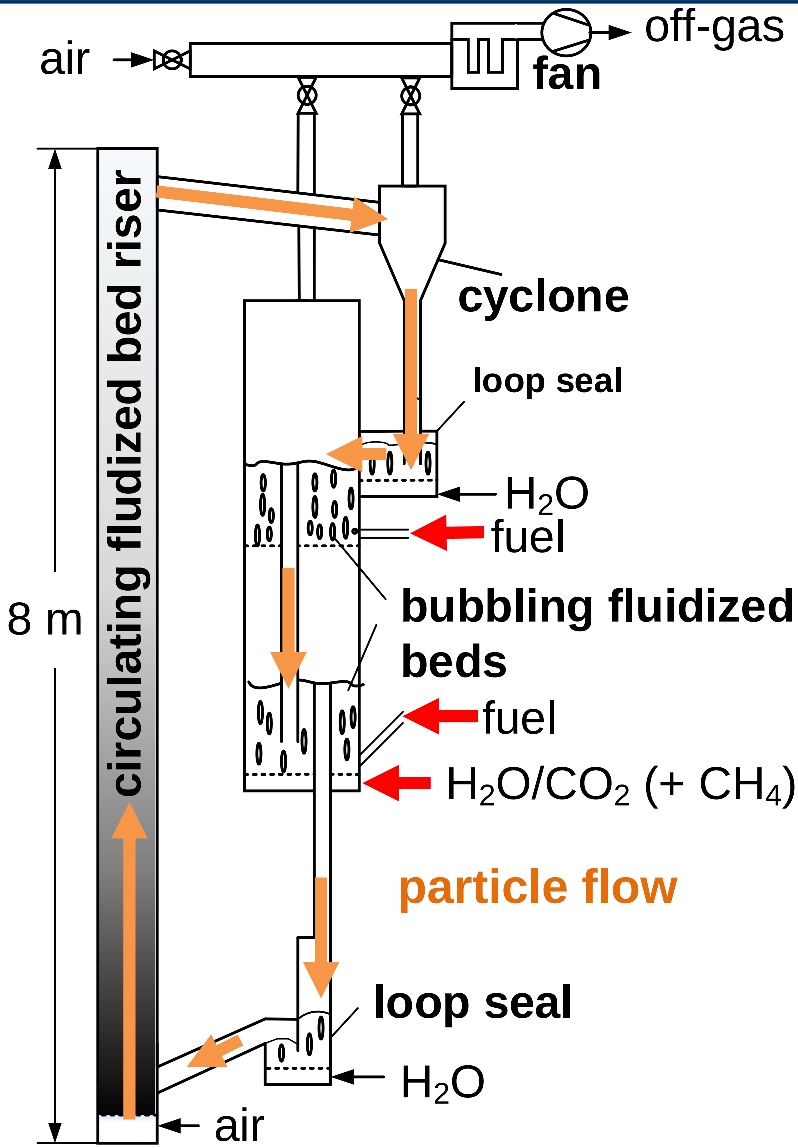
- Second stage for fuel gas conversion

✓ **Reducing oxygen demand**

✓ **Suitable design for high volatile fuels**

Maybe suitabe design for Biomass-CLC?

[1] Haus et al., Analysis of a Two-Stage Fuel Reactor System for the Chemical-Looping Combustion of Lignite and Bituminous Coal, Energy Technology (2016)



Dimensions	height / m	diameter / m
air reactor	8	0.1
fuel reactor	4	0.25
bed height FR	0.6	per stage
cyclone	0.34	0.21
	width / m	**length /m**
siphon S1	0.16	0.13
siphon S2	0.13	0.25

Operation mode

- Air reactor -> fast fluidized bed (5 m/s)
- Fuel reactor -> bubbling bed (0.25 m/s)
- Siphons -> bubbling bed (0.2 m/s)

Fuel injection

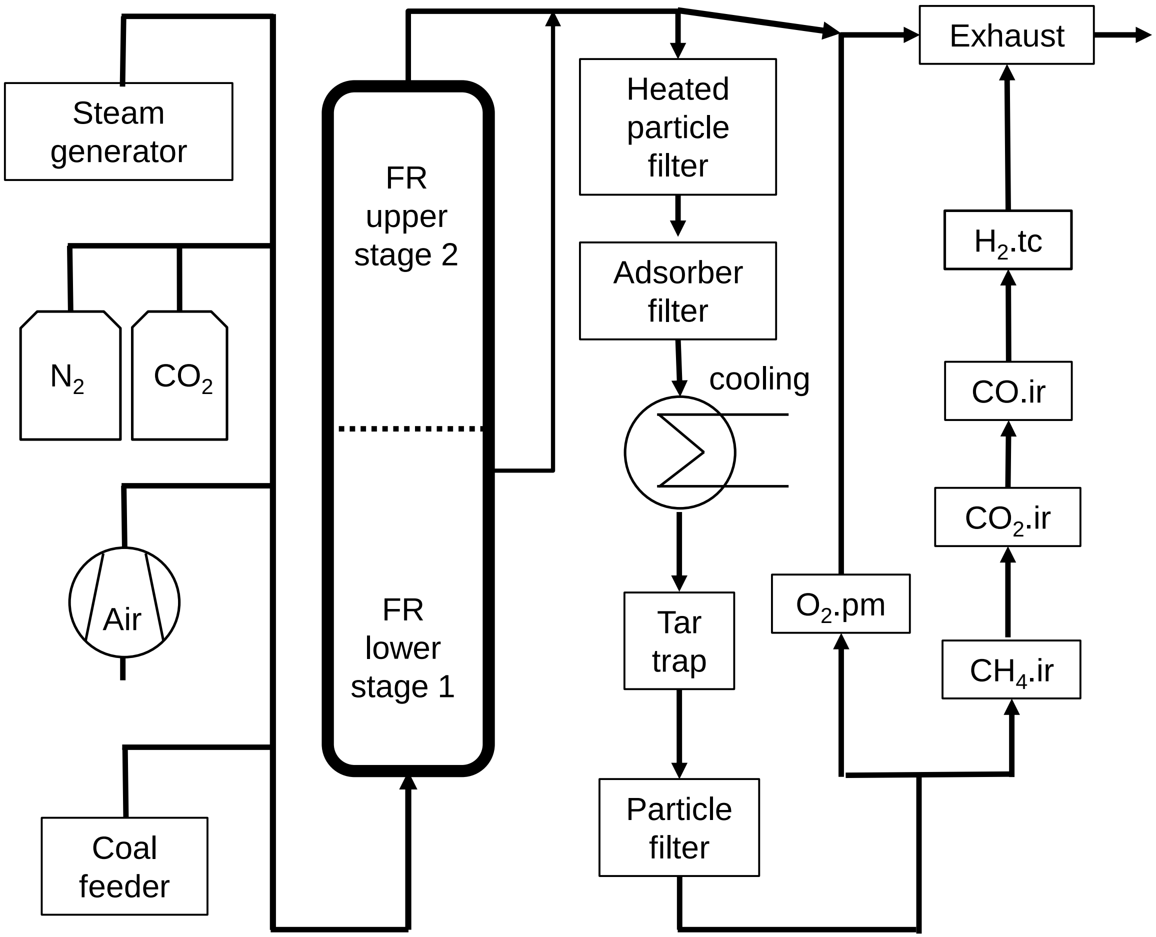
- Solid fuels: upper or lower stage
- Gaseous fuels: mixed with fluidization gas

25 kW_{th} rated power

Experimental 25 kW_{th} CLC pilot plant at TUHH

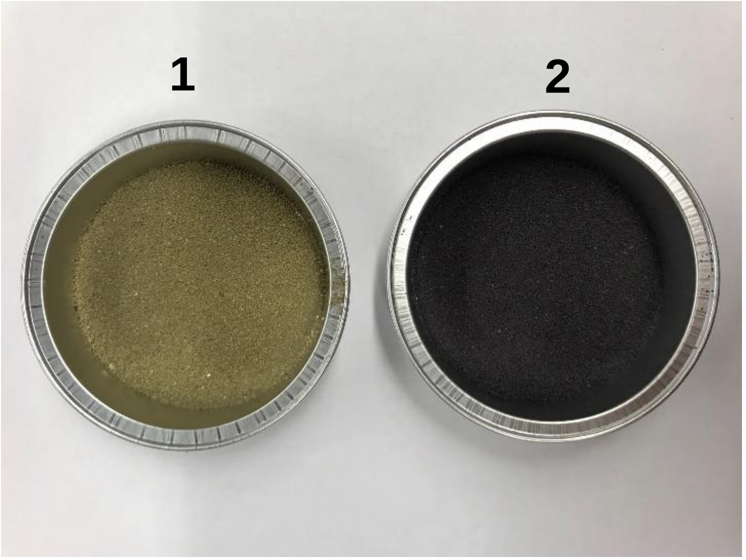
Gas measurements

- CH_4, CO, O_2, CO_2 and H_2 detected in FR exhaust
- Possibility to measure after first stage of FR
- CO_2 and O_2 measured at AR exhaust
- CO_2 concentrations include contributions from fluidization and injection gas



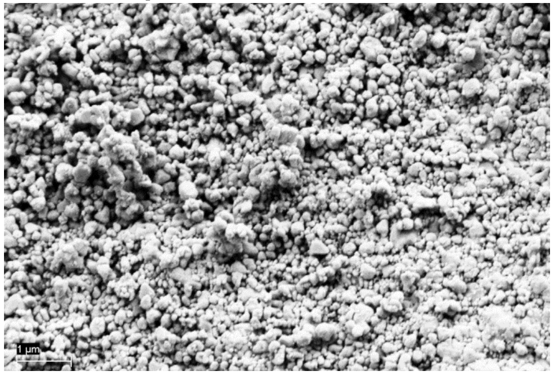
Oxygen Carrier

Molecular composition	CuO/Al_2O_3
Density [kg/m^3]	4094
Bulk density [kg/m^3]	1027
Oxygen carrying capacity R_0 [wt. %]	1.50

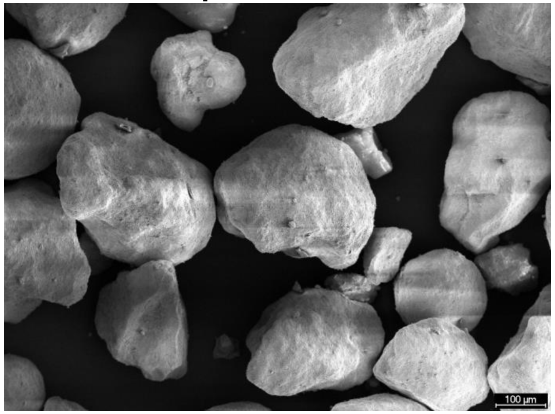


1 = Oxidized carrier
2 = Reduced carrier

↔ 1 µm



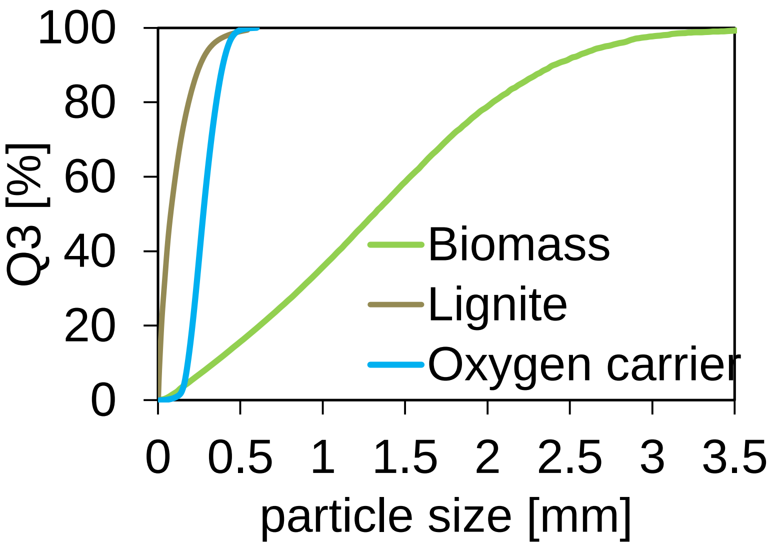
↔ 100 µm



Materials in the pilot plant

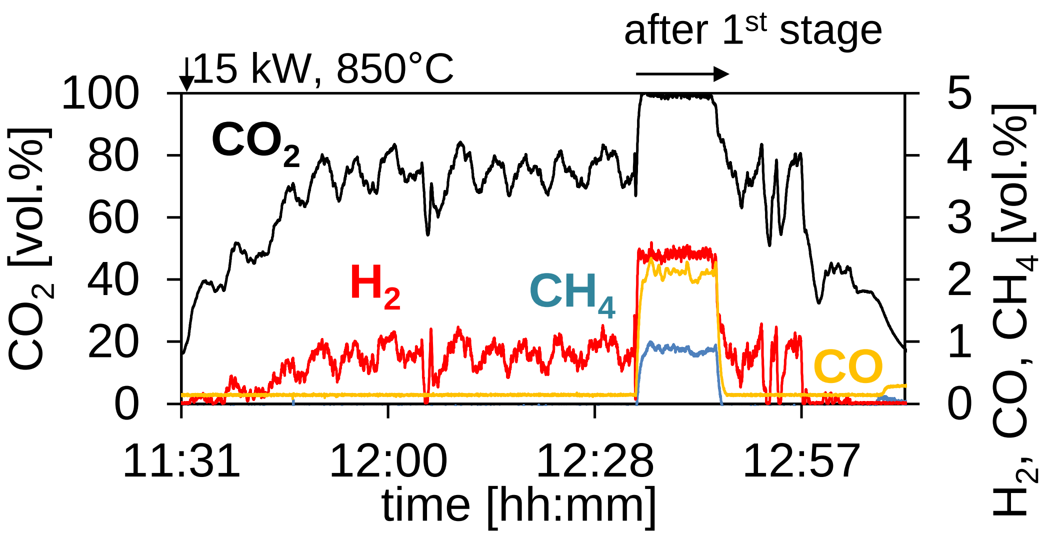
German hard wood biomass (shredded pellets)

Rhenish lignite dust

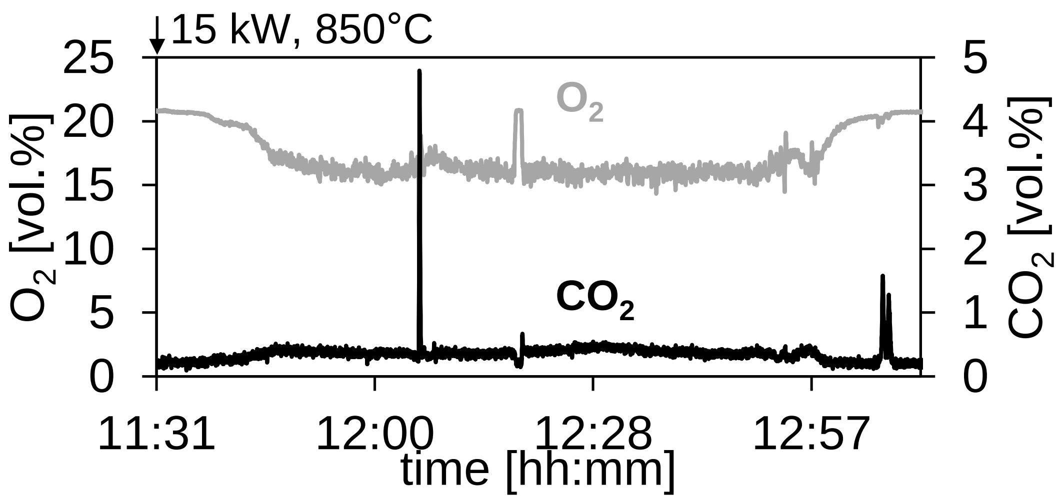


	Biomass	Lignite
Bulk density [kg/m3]	354	1000
LHV [MJ/kg]	18.7	28
Proximate Analysis		
Ash [wt.% raw]	0.2	4
Moisture [wt.% raw]	8.6	11
Volatiles [wt.% raw]	**85.5**	**45**
Fixed carbon [wt.% raw]	5.7	40
Ultimate Analysis		
Nitrogen [wt.% raw]	2.9	0.7
Carbon [wt.% raw]	47.1	59.5
Hydrogen [wt.% raw]	10.3	4.3
Sulphur [wt.% raw]	< 0,1	0.35
Oxygen [wt.% raw]	31.9	20.3

Fuel reactor exhaust gas concentrations (dry)



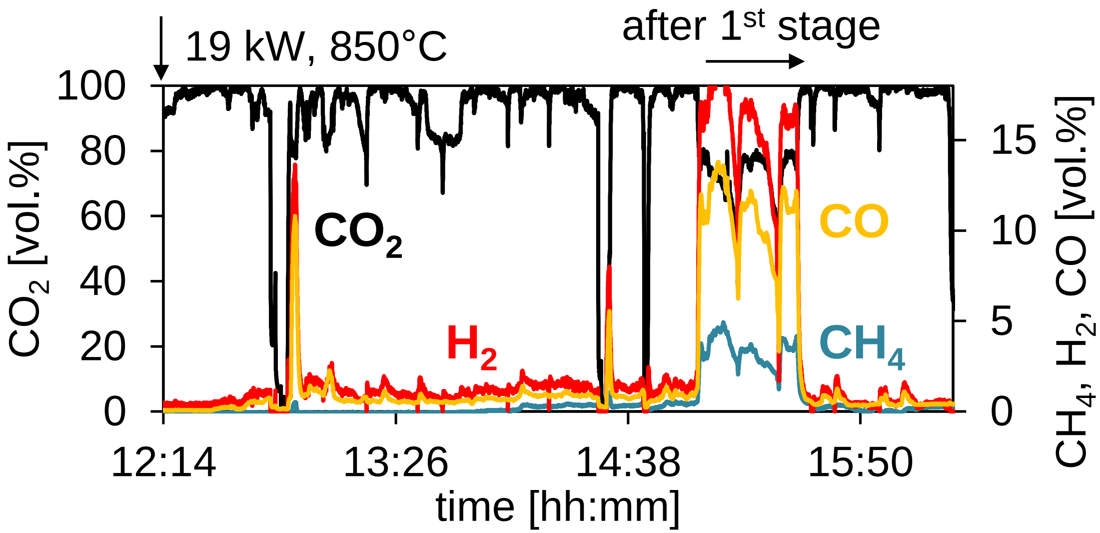
Air reactor exhaust gas concentrations (dry)



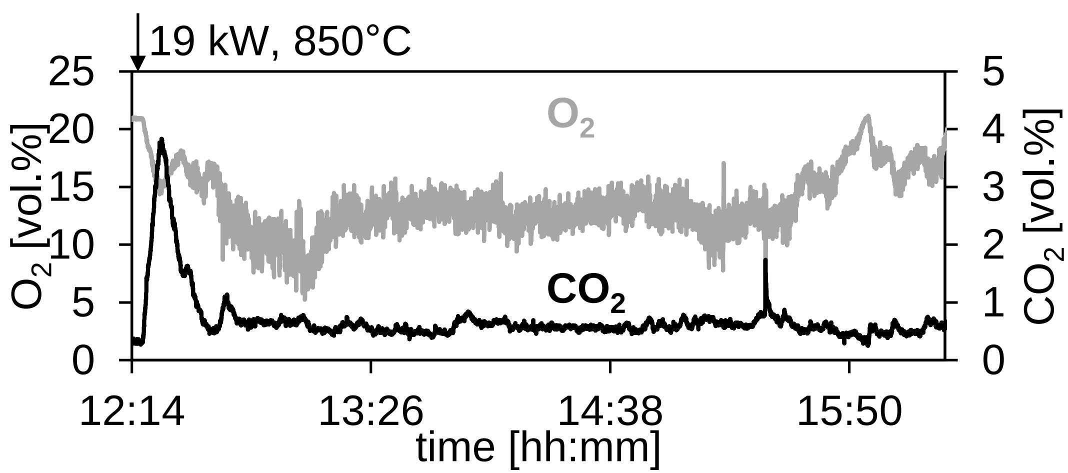
- significant amount of unconverted gases after 1st stage
- low amounts of H_2 after 2nd stage

Overall very good gas conversion, but only after both stages!

Fuel reactor exhaust gas concentrations (dry)



Air reactor exhaust gas concentrations (dry)



- high concentration of unconverted gases after 1st stage
- detectable amounts of H_2 and CO after 2nd stage
- fine particles seem to convert in the upper part of the first stage

Overall very good gas conversion, but only after both stages!

Summary

	Fuel input	Temperature	η_{cc}	Ω_{OD}	Ω'_{OD} 1 stage	X_C
Biomass	15 kW_{th}	850° C	0.93	0.016	0.075	0.99
Lignite	19 kW_{th}	850° C	0.97	0.006	$>$0.25	0.98

- Constantly low oxygen demand (< 3%) for investigated fuels
- Lignite profits strongly from two-stage design (Ω_{OD} 25% → 1%)
- Biomass profits as well from two-stage design (Ω_{OD} 7.5% → 2%)
- Excellent fuel conversion
- Fine particles reduce carbon slip

Second stage suitable to reduce oxygen demand during operation with high volatile fuels

Conclusions and outlook

- Near 100% solid fuel conversion for both fuels
- After first stage: high shares of unconverted gases were traced
- Combustible gases are almost completely converted after the second stage.
- Reactive char and fine fuel particles reduce carbon slip
- High values of the carbon capture efficiency η_{CC}:

  93% for biomass and 99% for lignite
- Lignite and biomass benefit strongly from the two stage design

Two-stage fuel reactor system suitable to tackle one of the main problems of biomass-CLC: the oxygen demand

Current work:

- Reduce pressure drop of the fuel reactor
- Use cheaper oxygen carrier materials

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