Flexible chemical looping combustion pathways for sustainable bioenergy conversion

BioNETzero Joint Webinar

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What is needed from the CHP plants of tomorrow?

Heat

Power

CO2 removal (CCS)

Preferably from waste or low grade fractions

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What do we achieve in the CHP plants today?

Heat



- 23 TWh heat / year
- 42% of Swedish district-heating demand

Power



- 6 TWh electricity / year
- 4% of Swedish electricity demand

CCS



- No full-scale CCS in operation yet
- 0.8 Mt CO_2/year under construction

Preferably from waste or low grade fractions



55% of Swedish household waste → energy recovery
CHP fuel mix: ≈93% bio + waste

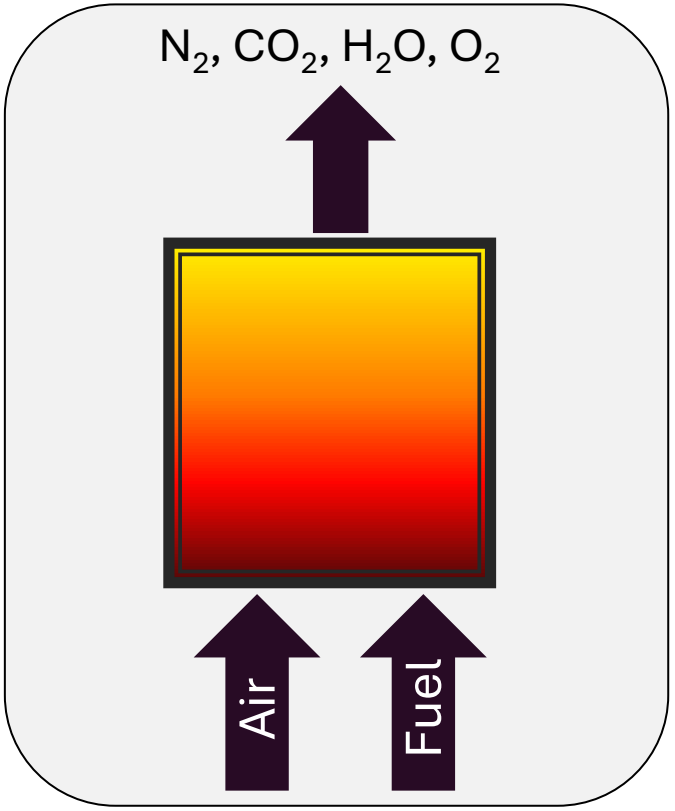
A problem with mixtures

”Normal” combustion
4-15 vol% CO_2, water, nitrogen, some oxygen, impurities, ash

Heat exchangers are exposed to the corrosive flue gas

To begin, we need
>95 vol% CO_2

Range of gaseous streams available:
0.04 – 99% CO_2



Normal combustion

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What can CLC achieve?

Heat



Power



- Low corrosion = high electrical efficiency

CCS



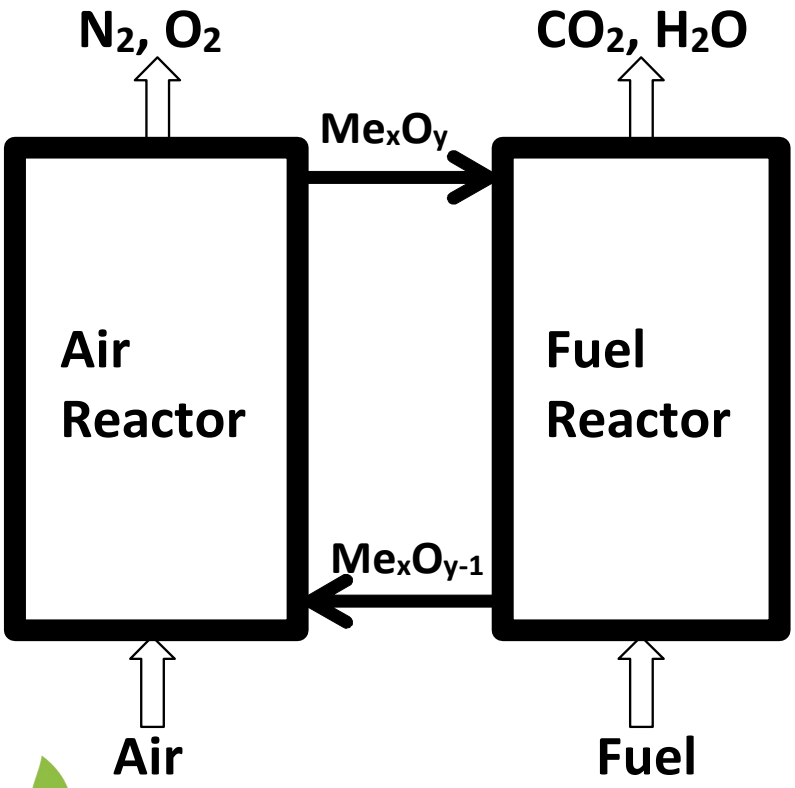
- No energy penalty for separation of CO2

Preferably from waste or low grade fractions



CLC is less sensitive to corrosive fuel compared to traditional combustion

Carbon capture and chemical-looping



Air Reactor:

$$(n+\tfrac{1}{2}m)O_2+(2n+m)Me_xO_{y-1}\leftrightarrow(2n+m)Me_xO_y$$

Fuel Reactor:

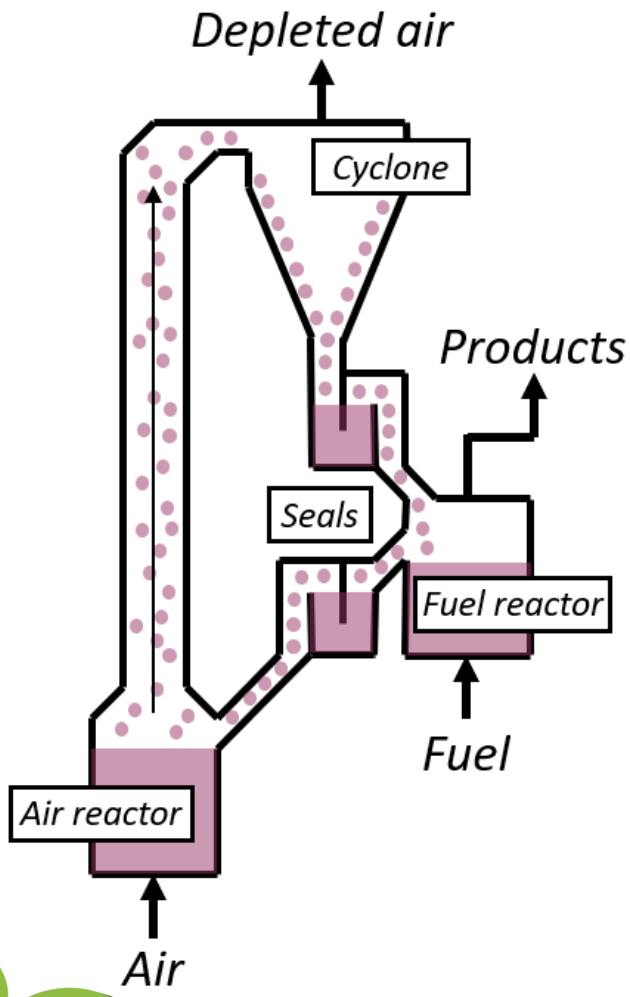
$$C_nH_{2m}+(2n+m)Me_xO_y\leftrightarrow nCO_2+mH_2O+(2n+m)Me_xO_{y-1}$$

Net Reaction:

$$C_nH_{2m}+(n+\tfrac{1}{2}m)O_2\leftrightarrow nCO_2+mH_2O$$

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Basic reactor design



Sand-like particles of **oxygen-carrier** material (0.1-0.4 mm) as bed material.

High **gas velocity (2-5 m/s)** in the air reactor which acts as riser, particles are blown upwards and into a cyclone.

The particles are transported by gravity to the fuel reactor in which they are reduced by fuel, then continues to the air reactor.

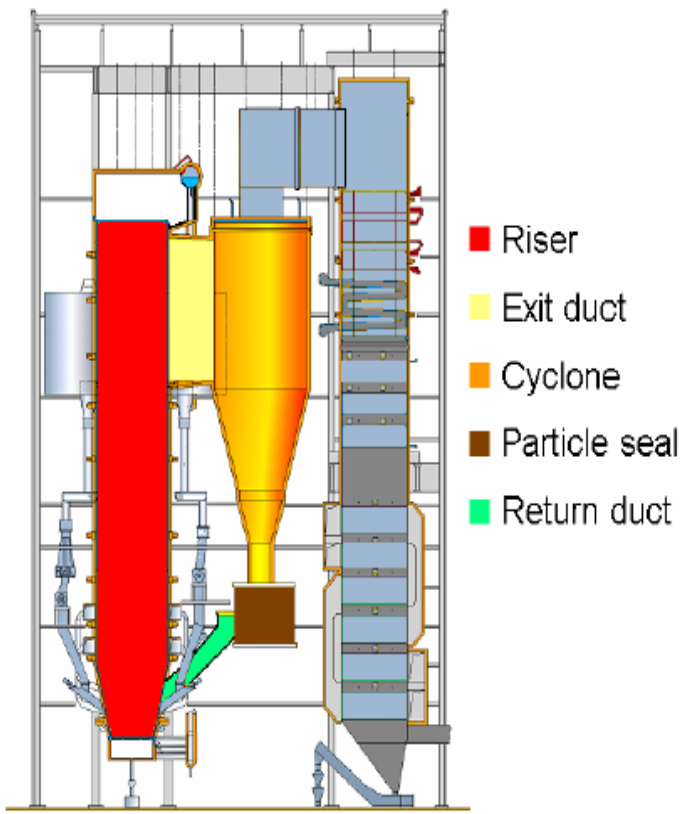
Gas leakage between the reactors is prevented by **fluidized particle seals**.

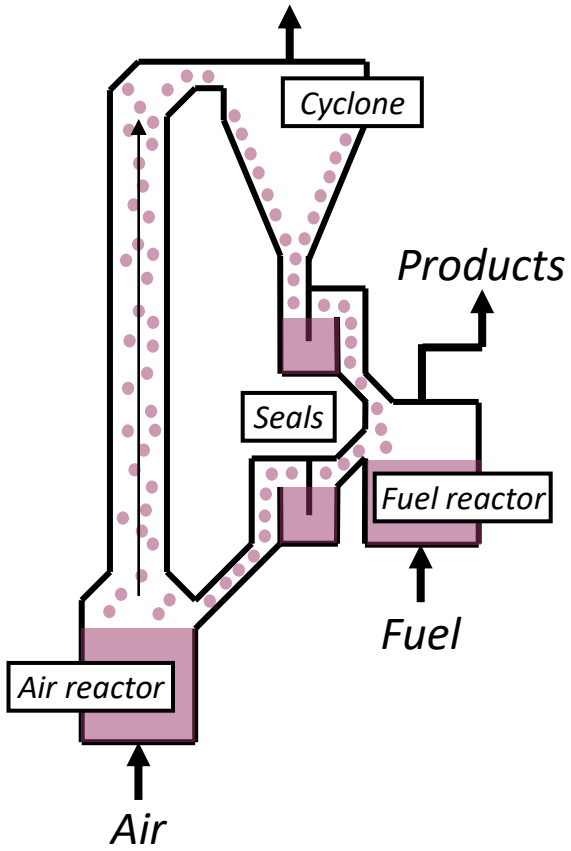
Typically, near **atmospheric pressure** and temperature **800-1050 °C**.

Many variations have been proposed and tested. Still, the basic setup serves its purpose well.

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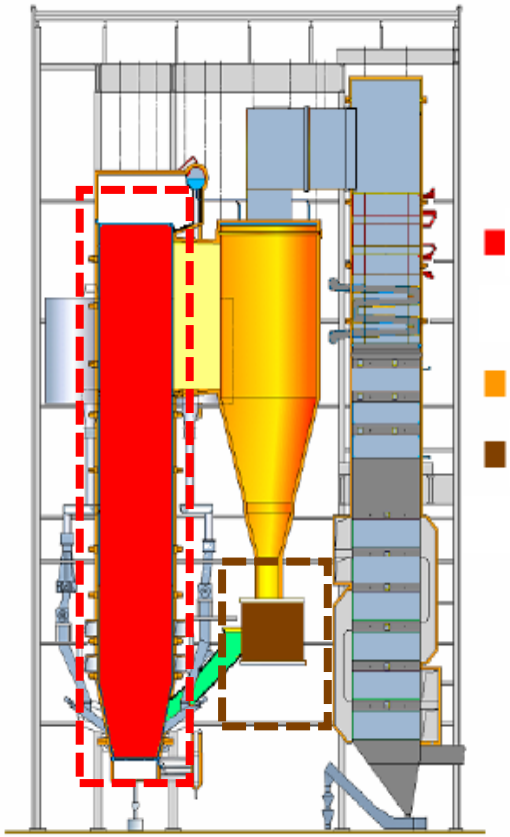
Circulating Fluidized Bed boiler (CFB)





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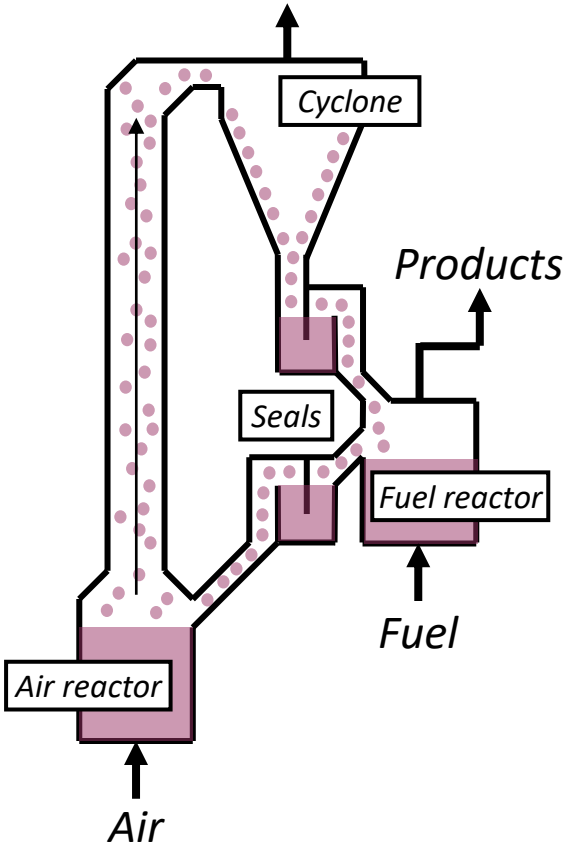
Circulating Fluidized Bed boiler (CFB)



Air reactor

Cyclone

Fuel reactor



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Chemical-looping at Chalmers

Overall goals

- *Develop technologies for negative emissions, focus on chemical-looping processes*
- *Develop adjacent technologies with oxygen carriers*

Research questions

- *How do different impurities behave in the special environment? Can we improve the mass transport in the fluidized bed? Are there unexplored phases which could be used as oxygen carriers ? Can we produce hydrogen efficiently? How can we best support development for rapid deployment?*

Tools to answer research questions

- *Different sizes of research from XS to L*

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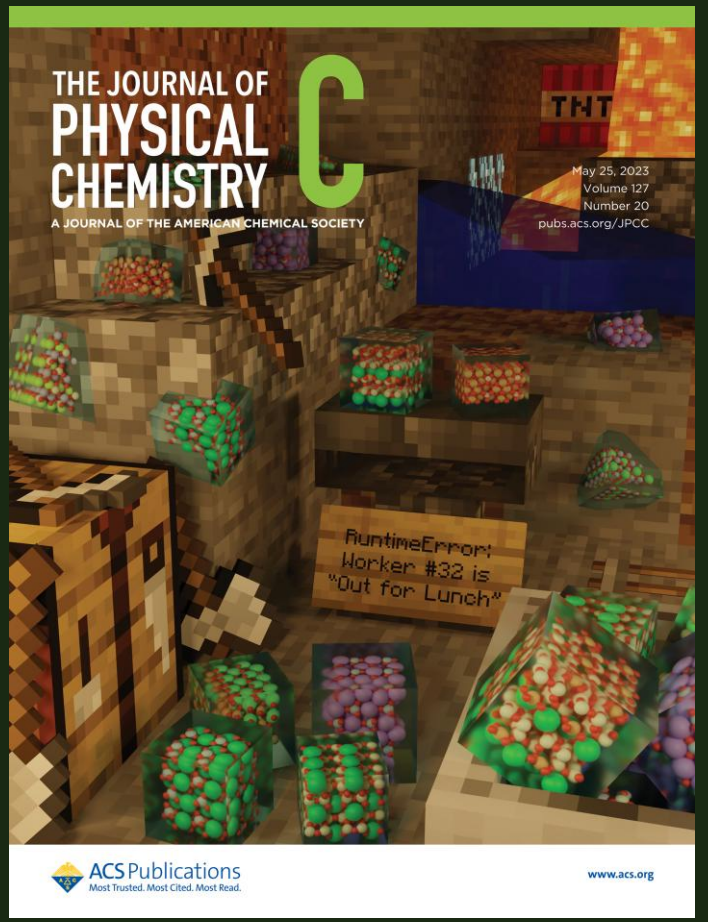
Extra Small (XS)

Main goals

Establish methodologies for discovering and evaluating new oxygen carriers using a combination first-principles calculations, machine learning and data mining

Method/tools

- Density functional theory
- Machine learning
- Big data



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Thermodynamics by DFT

Main goals

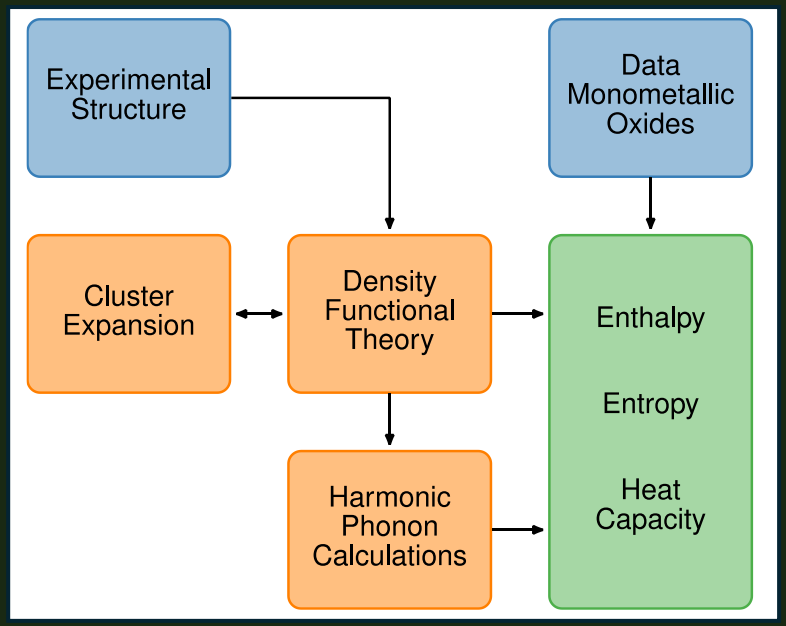
Estimate the properties of materials missing from thermodynamic databases

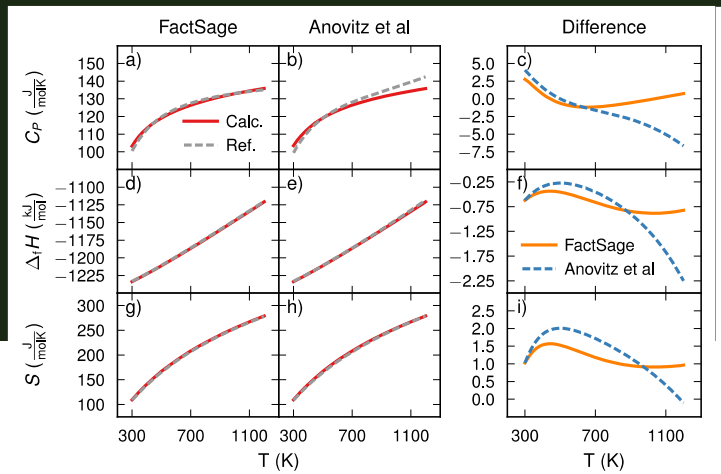
Tools

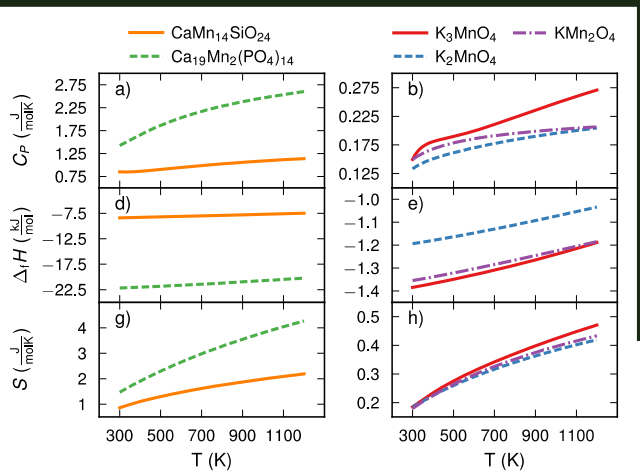
- Density functional theory
- Cluster expansions
- Harmonic phonon calculations

Main result

- Exceptional agreement for $FeTiO_3$
- Improved predictions for K-Fe-Ti-O and K-Mn-O systems







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Small (S)

Main goals

- Oxygen carriers in chemical looping
  - Ash interaction with oxygen carriers
    - Mechanisms of sulfur interaction with ilmenite
  - Fate of important impurities, trace elements

Method/tools

- XRD (CMAL, Physics)
- SEM/EDX (CMAL, Physics and Chemistry and Chemical Engineering)
- BET (Applied Chemistry)
- XPS (Industrial and Materials Science)
- Thermodynamic calculations

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Medium (M)

Main goals

- Reactivity with different fuels
- Heat and mass transfer

Method/tools

- Batch fluidized beds
- Signal analysis
- TGA





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Large (L)

Main goals

- Evaluation of CLC and CLG at realistic conditions
- Investigating alkali release and tar formation in CLC/CLG of biomass
- Improving gas-solid interactions using cold flow model

Method/tools

- Pilot units up to 100 kW
- Cold flow models
- Gas analysis, alkali and tar measurements, attrition measurements

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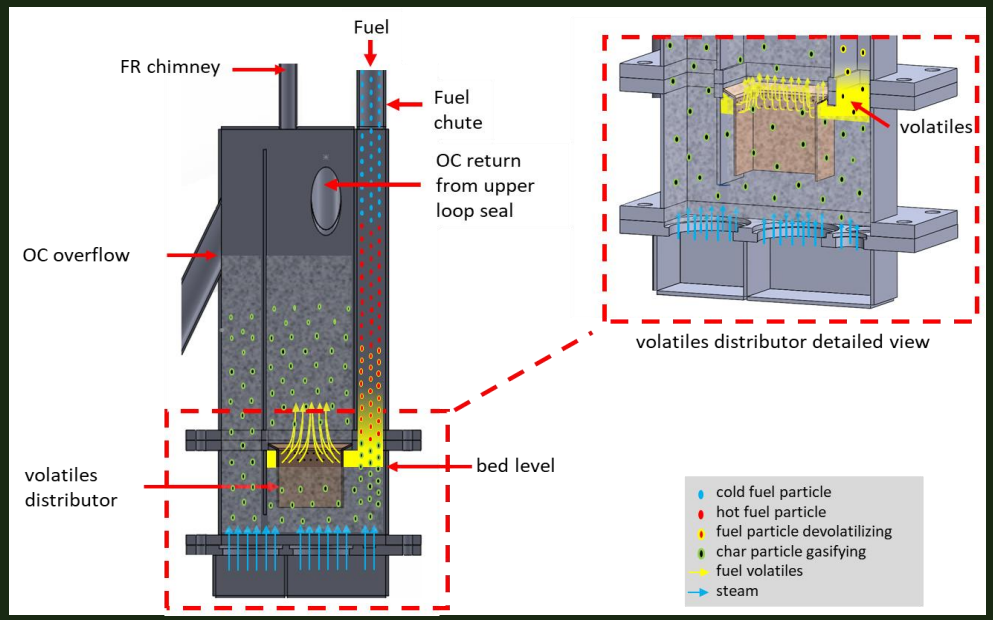
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10 kW CLC/CLG unit for solid fuels

- Commissioned the new 10 kW pilot for CLC and CLG of high volatiles solid fuels
  - ✓ Up to 10% gas conversion improvement due to volatiles distributor
  - ✓ Newly implemented solid and tar sampling systems

- Commissioned the modular SID system for ash chemistry studies





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Confined Fluidized Beds

- In confined fluidization also known as packed-fluidized bed, inert stagnant packings of much larger size than the fluidized particles are applied to break down the larger bubbles.
- Packed-fluidized beds could be of high interest for CLC.
- Application of packings can improve gas-solid mass transfer as well as fuel conversion. Thus, facilitating complete combustion of fuel gases, volatiles, and char particles originating from the reactions in FR.

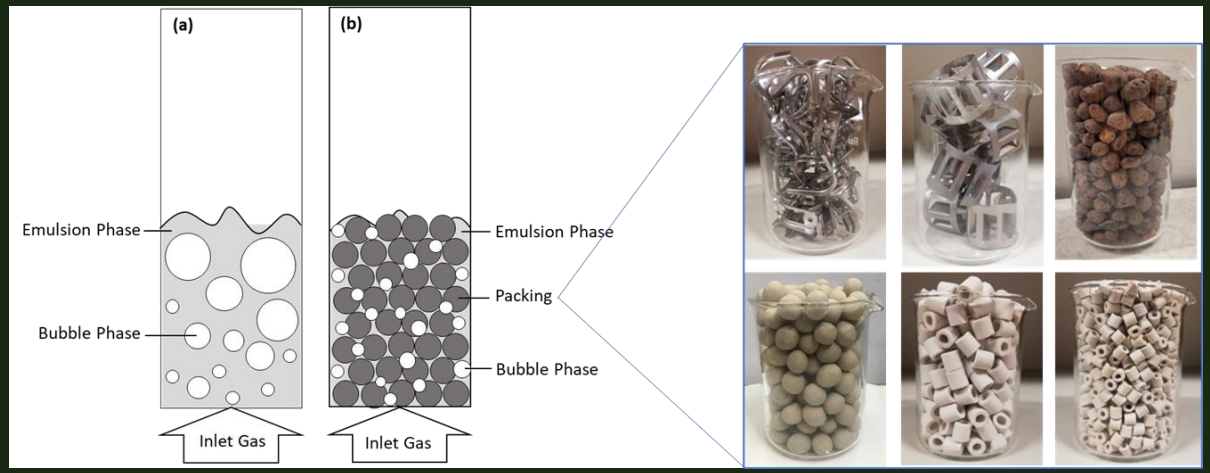


Figure. Illustration of a) conventional BFB, b) packed-fluidized bed.

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Bio-Flex CLC Project Pitch

- There is a need for rapid deployment of negative emissions
- Incentives are currently insufficient
- In northern Europe, biomass and forestry waste are important domestic fuels.
- In Europe as a whole, the use of waste-derived fuels seems destined to increase.
- Difficult to convert, being inhomogeneous and rich in problematic ash species.
- In the Bio-Flex CLC project the ambition is to devise a technology which can convert difficult fuels in “CFB”-mode or “CLC”-mode.

Bio-Flex CLC partners
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CHALMERS TEKNISKA HOGSKOLA
SPANISH NATIONAL RESEARCH COUNCIL
TECHNISCHE UNIVERSITAT DARMSTADT
AICHERNIG ENGINEERING
BABCOCK & WILCOX VOLUND AB
NATIONAL CERTH CENTER FOR RESEARCH AND TECHNOLOGICAL DEVELOPMENT
1CUBE
FORTUM POWER AND HEAT POLSKA
VÄXJÖ ENERGI AB

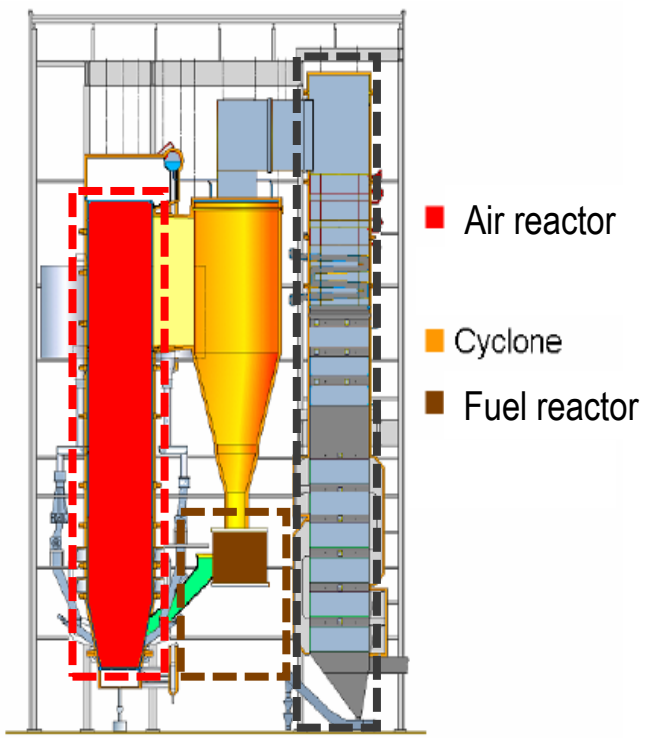
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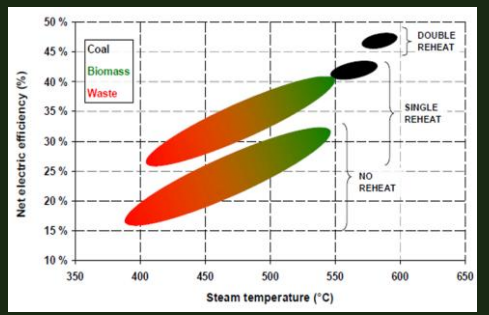
Bio-Flex CLC Project Pitch



- The CFB-CLC system takes advantage of the similarities between conventional CFB and CLC.
- We argue that we can design a system which can be operate in two main modes
  - CLC with CCUS
  - CFB without CCUS

Important to consider that a Flexible CFB-CLC system is basically a conventional CFB with an added reactor (FR) on the return side

Would provide end-users with lower economic and technical risk



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Project Activities

- Demonstration CFB-CLC at 1 MW scale with at least three relevant domestic fuels.
- Work on pilot and lab scale related to fuel conversion pathways and ash chemistry. This includes development of new methods of improving fuel conversion.
- Down stream treatment and CO2 liquefaction for Bio-Flex CLC.
- Process evaluation and optimization of BioFlex-CLC.
- Sustainability analysis and social life cycle analysis of Bio-FlexCLC





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Questions / Comments

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