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# Flexible CFB-CLC operation strategy for biofuels combustion with negative CO<sub>2</sub> emissions

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8<sup>th</sup> International Conference on Chemical Looping

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8<sup>th</sup> International Conference  
on Chemical Looping  
31 Aug – 4 Sept 2026, Manchester (UK)





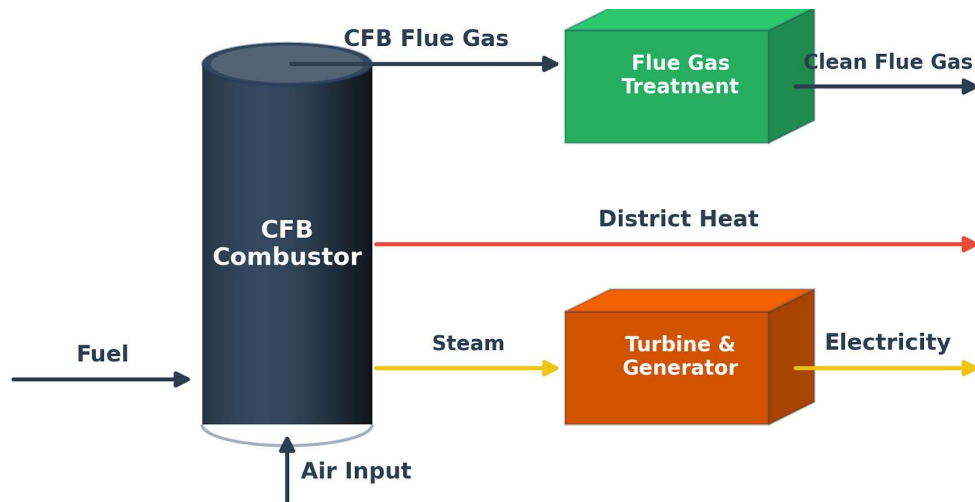
# Outline

- Introduction
- Objectives
- Experimental
- Results
- Conclusions

# Introduction

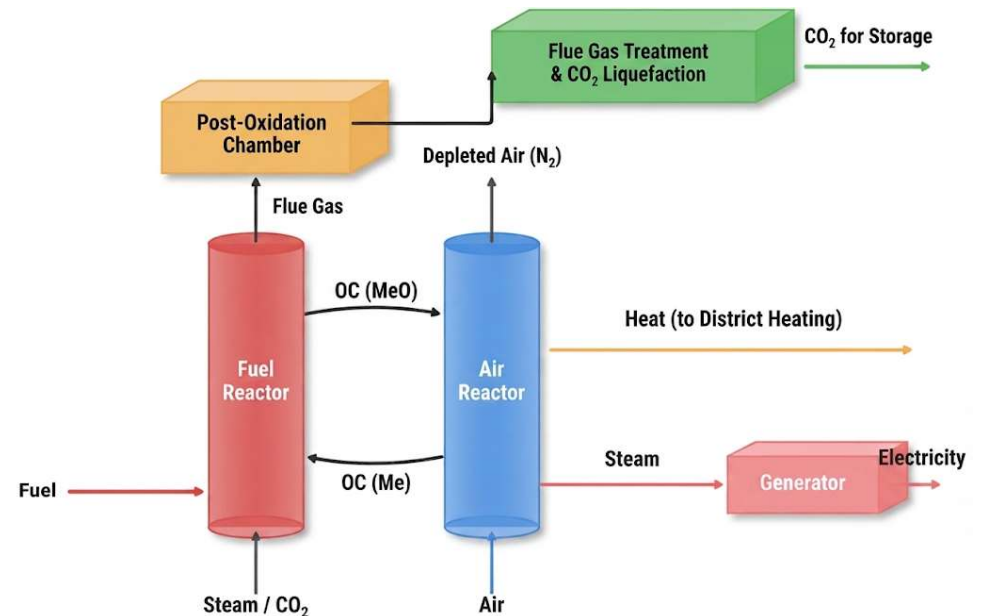


## Conventional CFB boiler



- ❖ Circulating fluidized bed (CFB) boilers are widely used for combined heat and power production
- ❖ Produces standard flue gas
- ❖ Providing net-zero emissions
- ❖ No carbon capture

## Chemical Looping combustion

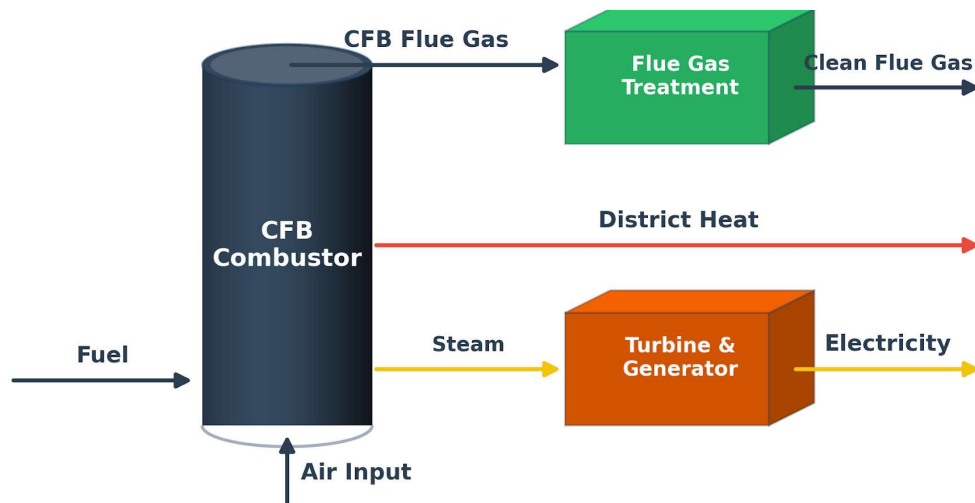


- ❖ Chemical looping combustion currently is developing for heat and power production
- ❖ Produces pure CO<sub>2</sub> stream suitable for storage
- ❖ Achieving negative emissions
- ❖ Maximize carbon credit

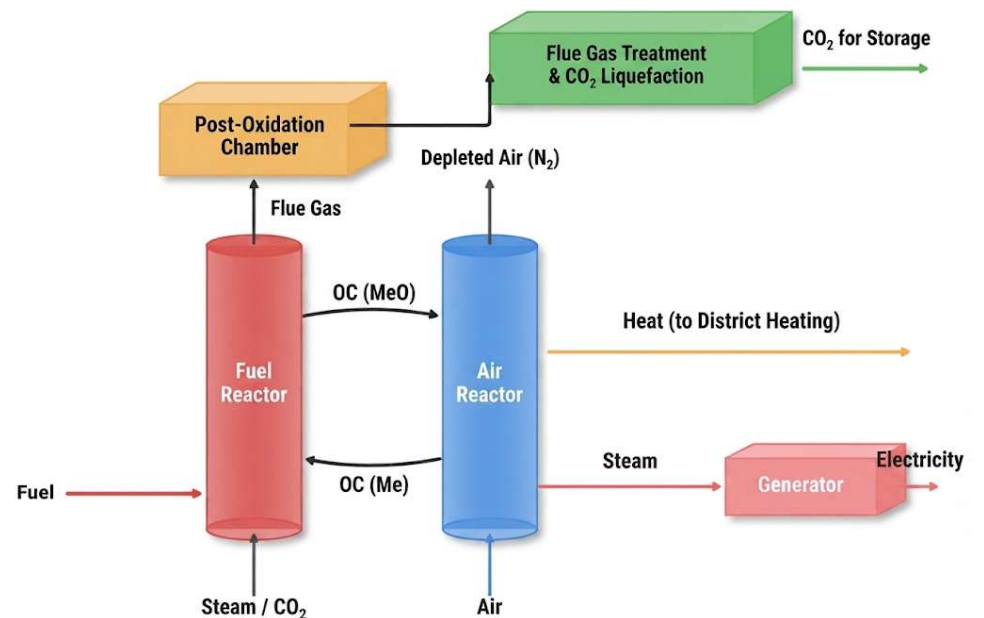
# Introduction



## Conventional CFB boiler



## Chemical Looping combustion



High economic risk based on market condition

# Objectives and Concepts

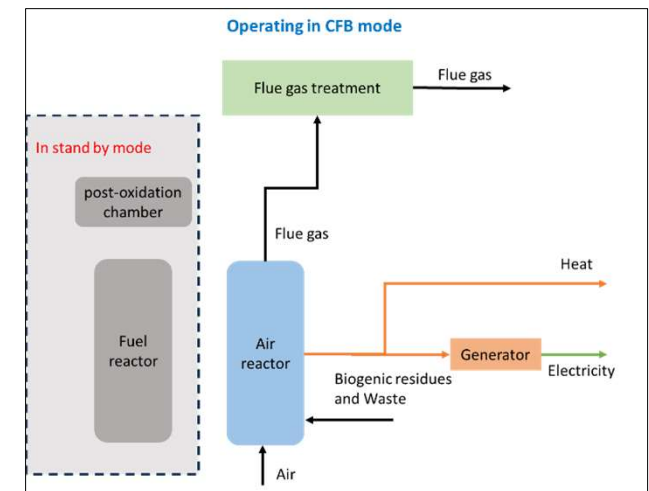
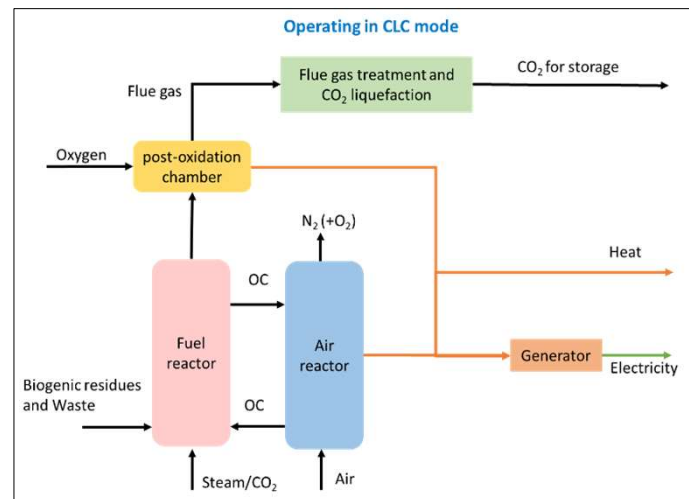
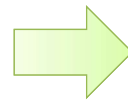


- The concept is based on dual Circulating Fluidized Bed (CFB) reactors, which can operate in Chemical Looping Combustion (CLC) mode while both reactors are in use or switch to conventional CFB operation when only one reactor is in use
- Operating in CLC mode enables combined heat & power (CHP) production with negative emissions at low-cost while the concept is flexible to switch to CFB boiler mode to produce CHP with net-zero emissions

J. Guo et.al. Forests 2024, 15(8), 1372



Biogenic waste as feedstock



## Participants: 10 consortium partners from 7 EU countries

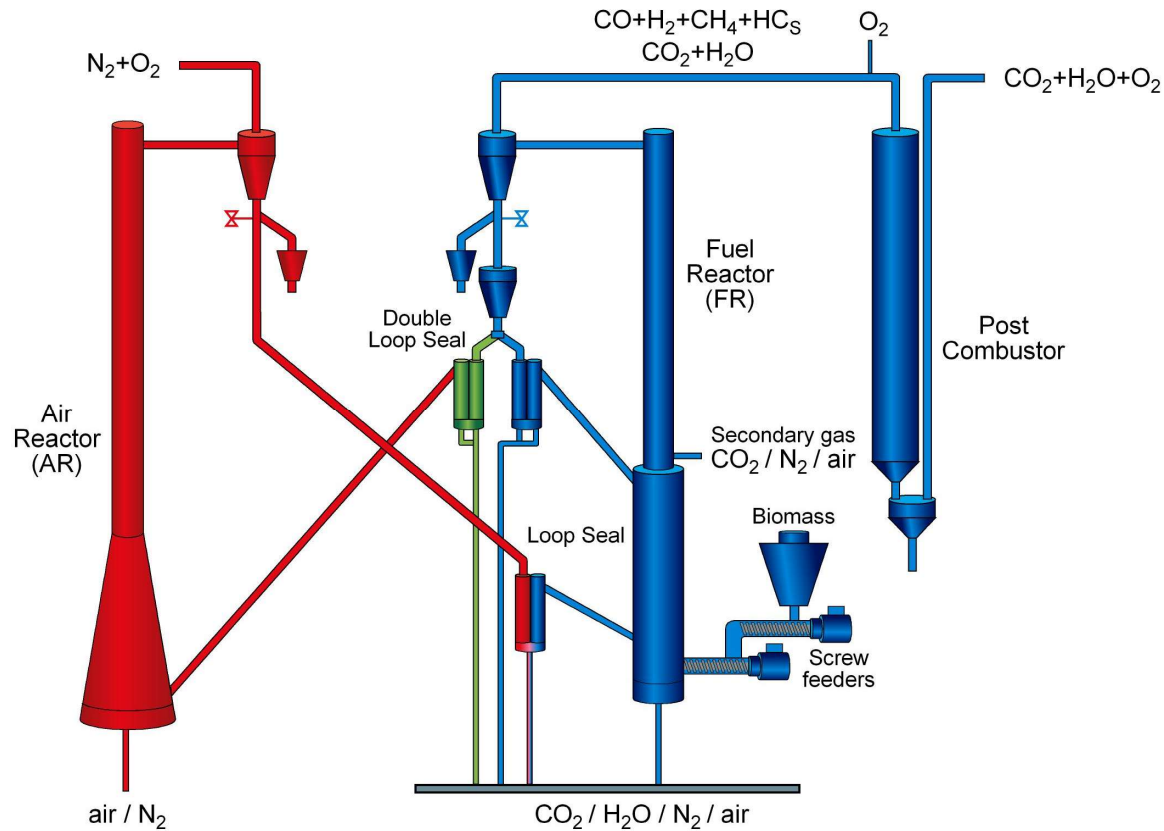
| Partner     | Role                                                                                                                                 |
|-------------|--------------------------------------------------------------------------------------------------------------------------------------|
| RISE        | Project coordination, process design and technoeconomic assessment, LCA and sLCA, developing gas cleaning and liquefaction processes |
| Repotec     | Designing the process and operating strategies                                                                                       |
| GMAB        | Designing gas treatment technologies                                                                                                 |
| CTH         | Improving process performance of flexible Bio-FlexCLC                                                                                |
| <b>CSIC</b> | Chemical looping and fluidized bed combustion                                                                                        |
| CERTH       | CFD modelling of post-oxidation chamber and fuel reactors with packings                                                              |
| TUDa        | Demonstration of Bio-FlexCLC at MW scale; process evaluation and optimization of flexible Bio-FlexCLC                                |
| 1Cube       | Exploitation, Dissemination and Communication                                                                                        |
| FORTUM      | Providing feedback and data for process and environmental analysis. Utility producer in Poland. Potential end user of the process.   |
| VEAB        | Providing feedback and data for process and environmental analysis. Utility producer in Sweden. Potential end user of the process.   |





- Introduction of Chemical Looping combustion
- Objectives
- Experimental
- Results
- Conclusions

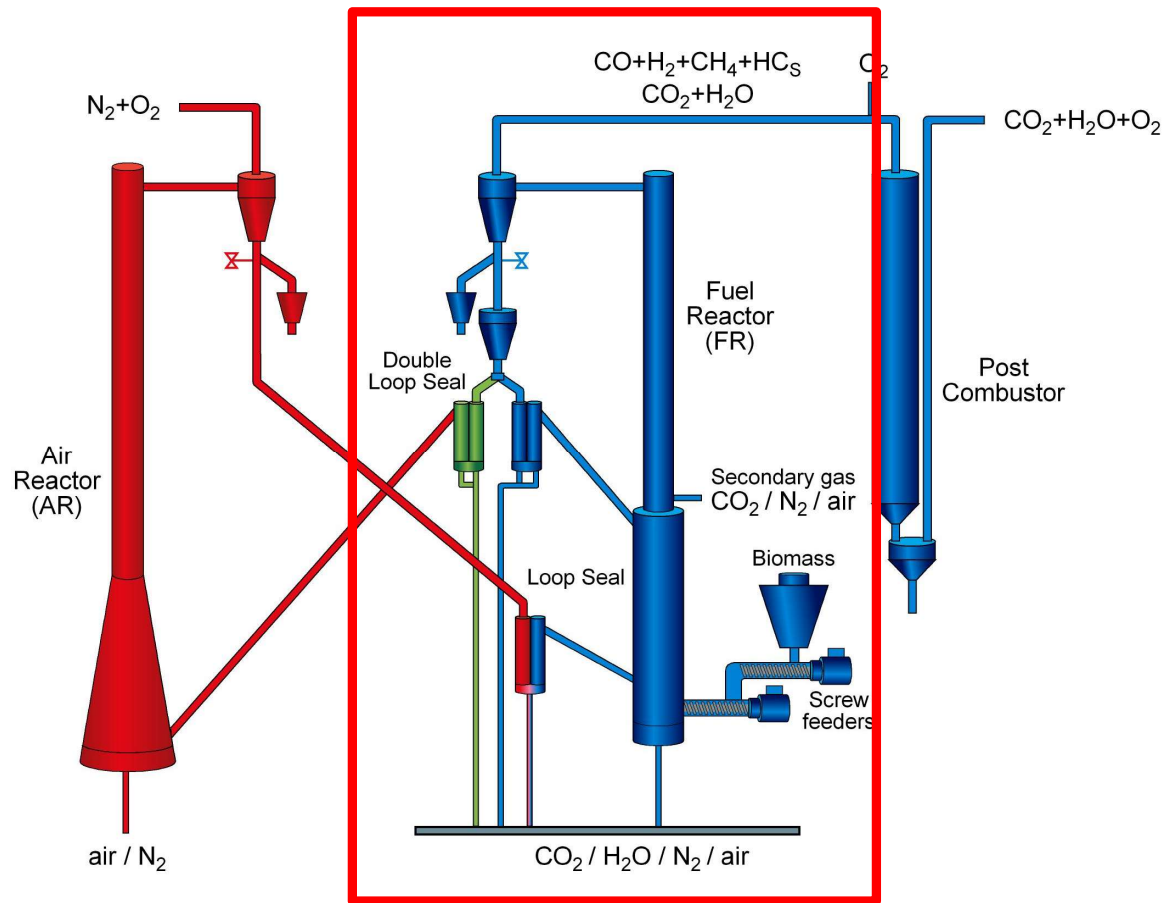
# CLC unit for solid fuels (20 kW<sub>th</sub>)



- Built in 2013 with a nominal capacity of 50 kW<sub>th</sub> for CLOU and 20 kW<sub>th</sub> for iG-CLC.
- Double loop seal allowing the independent variation of the solids inventory, solids circulation rate and fluid-dynamic conditions
- On-line gas analyzers and tar collection system.

|          |     | FR   | AR   | PC   |
|----------|-----|------|------|------|
| Height   | (m) | 4.00 | 4.80 | 2.00 |
| Bottom D | (m) | 0.10 | 0.30 | 0.20 |
| Upper D  | (m) | 0.08 | 0.08 | 0.20 |

# CLC unit for solid fuels (20 kW<sub>th</sub>)



## Three experimental campaigns:

1. Conventional **CFB** combustion without oxygen carriers. **Sand** as bed material.
2. Conventional **CFB** combustion with oxygen carriers. **Ilmenite** as bed material.
3. **CLC** mode. Use of a **post-oxidation chamber**.

# Fuels



| Fuel                      |       | Pine Wood pellets | Olive Stones | Branches and treetops | RDF (pellets) |
|---------------------------|-------|-------------------|--------------|-----------------------|---------------|
| Size                      | mm    | L:5-15, Ø:6       | +0.5-4.0     | +0.5-10.0             | L:5-10, Ø:6   |
| <b>Proximate analysis</b> |       |                   |              |                       |               |
| Moisture                  | wt%   | 7.5               | 7.3          | 8.0                   | 2.8           |
| Ashes                     | wt%   | 0.2               | 0.3          | 2.5                   | 11.8          |
| Volatiles                 | wt%   | 77.1              | 74.9         | 72.1                  | 76.9          |
| Fixed carbon              | wt%   | 15.2              | 17.5         | 17.4                  | 8.5           |
| LHV                       | kJ/kg | 17042             | 17352        | 16808                 | 23211         |
| <b>Ultimate analysis</b>  |       |                   |              |                       |               |
| C                         | wt%   | 47.2              | 47.8         | 46.7                  | 55.0          |
| H                         | wt%   | 5.6               | 5.3          | 5.4                   | 6.6           |
| N                         | wt%   | 0.1               | 0.2          | 0.4                   | 0.9           |
| S                         | wt%   | <0.1              | <0.1         | <0.1                  | 0.3           |
| O (by dif)                | wt%   | 39.4              | 39.1         | 37.0                  | 22.6          |
| Cl                        | g/kg  | -                 | -            | 0.21                  | 9             |
| <b>Ash analysis</b>       |       |                   |              |                       |               |
| Na                        | wt%   | 0.47              | 0.12         | 0.25                  | 2.39          |
| Mg                        | wt%   | 4.35              | 1.44         | 1.67                  | 1.27          |
| Al                        | wt%   | 1.33              | 0.28         | 1.32                  | 6.99          |
| Si                        | wt%   | 3.42              | 0.89         | 9.29                  | 9.37          |
| P                         | wt%   | 1.09              | 1.25         | 1.14                  | 0.36          |
| S                         | wt%   | 1.39              | 0.82         | -                     | 0.60          |
| K                         | wt%   | 15.96             | 29.97        | 6.38                  | 1.67          |
| Ca                        | wt%   | 16.22             | 9.38         | 14.49                 | 16.24         |
| Mn                        | wt%   | 1.06              | 0.05         | 0.82                  | 0.12          |
| Fe                        | wt%   | 1.75              | 0.23         | -                     | 3.38          |

Pine wood pellets  
(Reference)



Olive stones  
(Agricultural)



Branches and treetops chips  
(Forestry)



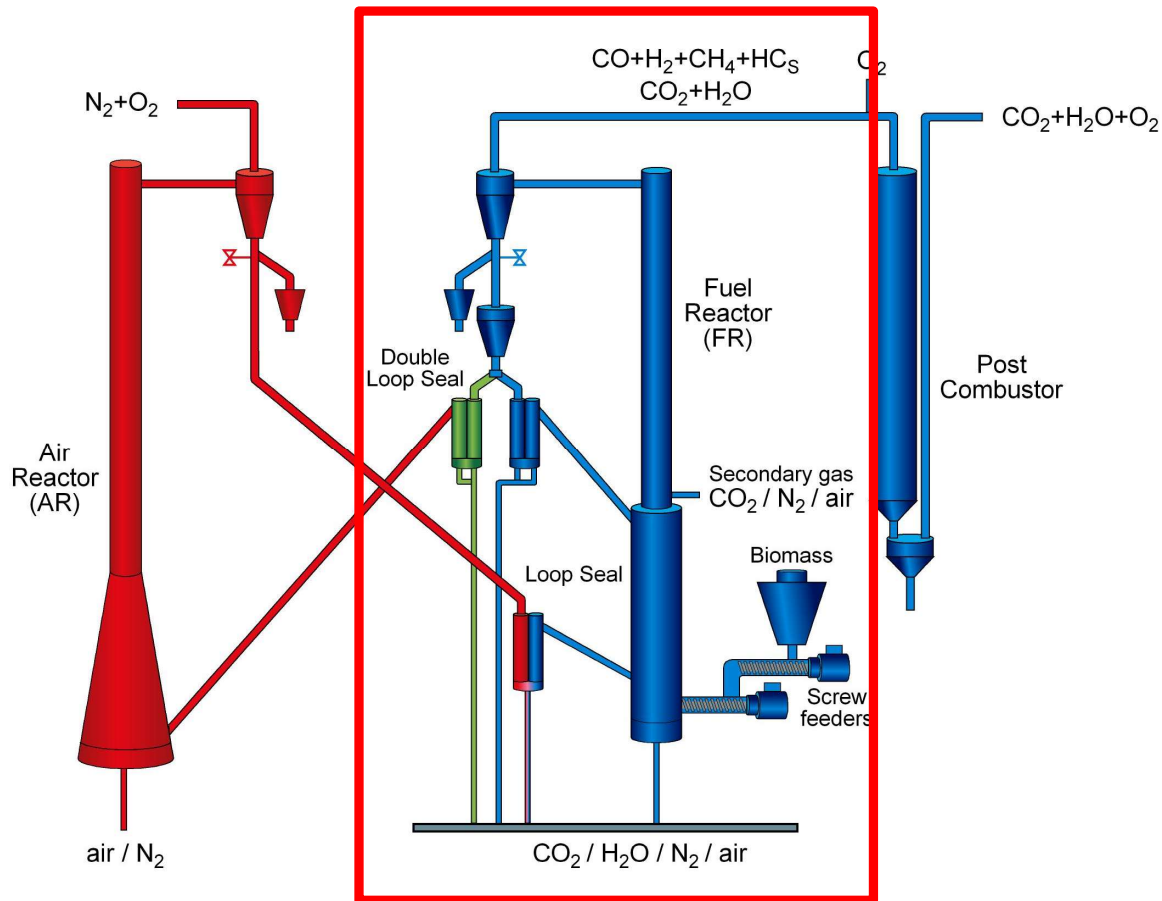
RDF  
(Biogenic)





- Introduction of Chemical Looping combustion
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# Conventional CFB for solid fuels



## 1<sup>st</sup> experimental campaign: CFB

Bed material: **Sand** (Changed by switching the fuel),

$dp = 100 - 500 \mu m$

Reference conditions:

- Temperature: 850 °C
- Excess air: 20 %
- Superficial gas velocity: 2.5 m/s (bottom), 5.0 m/s (top),  
Primary air/total air = 78 %

Solids circulation rate:  $\sim 20 \text{ kg/m}^2 \text{ s}$

### Experimental variables to be analyzed:

- ✓ Temperature: 800 – 900 °C
- ✓ Excess air: 10 – 30 %
- ✓ Superficial gas velocity: variation in the  
secondary/primary air ratio

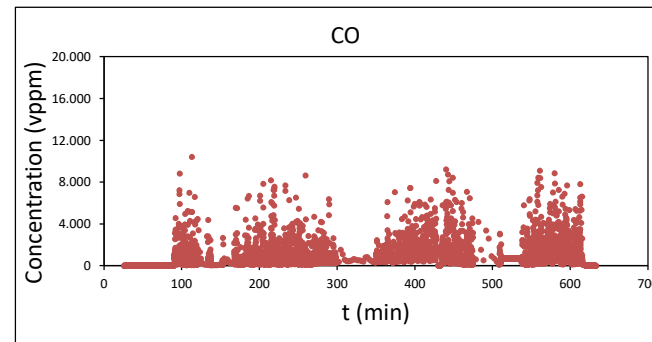
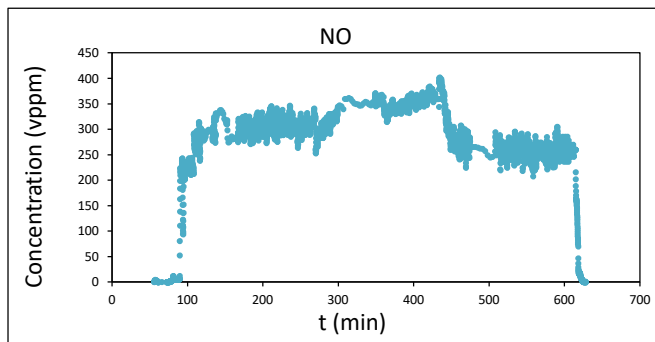
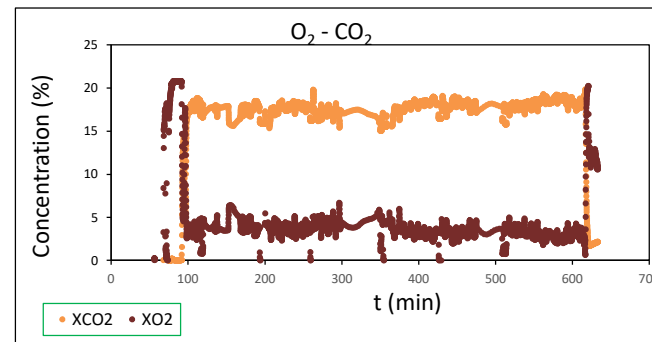
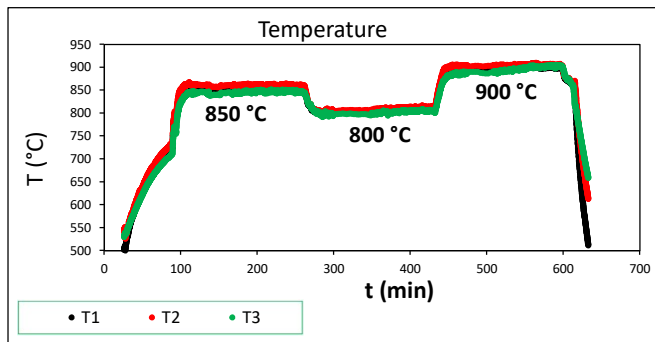
# Results of experimental campaign (Sand)

1<sup>st</sup> experimental campaign: CFB - Sand



Fuel

Branches and treetops chips



# Pine wood pellets

1<sup>st</sup> experimental campaign: **CFB-Sand**



Thermal power  $\approx$  20 kW

Combustion efficiency > 98%

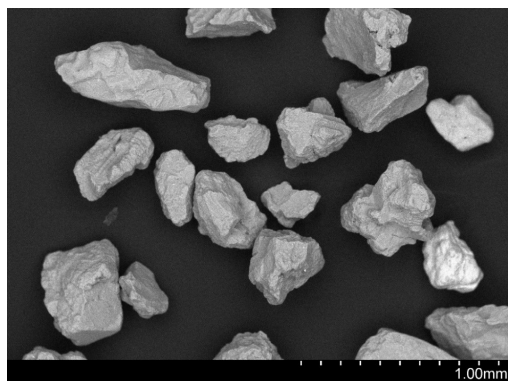
| Test | Temperature (°C) | Excess Air (%) | Primary/total air ratio (%) | CO <sub>2</sub> (%) | O <sub>2</sub> (%) | CO vppm | SO <sub>2</sub> vppm | NO vppm | NO <sub>2</sub> vppm | N <sub>2</sub> O vppm | NH <sub>3</sub> mg/kg bio | Tars g/kg bio (g/m <sup>3</sup> ) |
|------|------------------|----------------|-----------------------------|---------------------|--------------------|---------|----------------------|---------|----------------------|-----------------------|---------------------------|-----------------------------------|
| 1    | 850              | 20             | 78                          | 16.2                | 3.9                | 545     | 0                    | 81      | < 10                 | < 10                  | 0                         | 0.23 (0.043)                      |
| 2    | 800              | 20             | 78                          | 16.2                | 3.9                | 681     | 0                    | 83      | < 10                 | < 10                  | -                         | 0.27 (0.050)                      |
| 3    | 900              | 20             | 78                          | 16.1                | 4.2                | 499     | 0                    | 88      | < 10                 | < 10                  | -                         | -                                 |
| 4    | 850              | 30             | 78                          | 16.8                | 4.7                | 425     | 0                    | 86      | < 10                 | < 10                  | -                         | -                                 |
| 5    | 850              | 10             | 78                          | 18.0                | 1.9                | 1091    | 0                    | 80      | < 10                 | < 10                  | 14.7                      | 0.35 (0.074)                      |
| 6    | 850              | 20             | 62                          | 16.1                | 3.5                | 940     | 0                    | 70      | < 10                 | < 10                  | -                         | -                                 |
| 7    | 850              | 20             | 95                          | 17.4                | 2.8                | 677     | 0                    | 85      | < 10                 | < 10                  | -                         | -                                 |

# Pine wood pellets

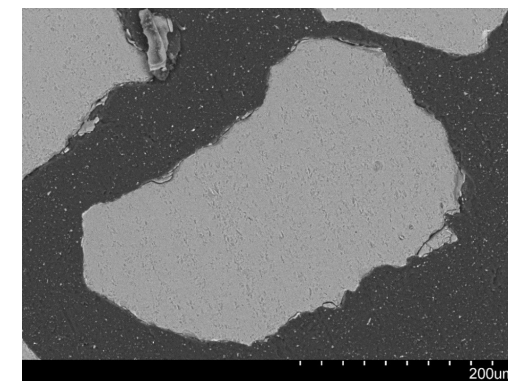
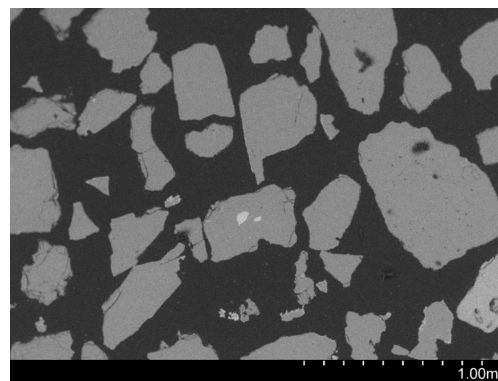
1<sup>st</sup> experimental campaign: CFB - Sand



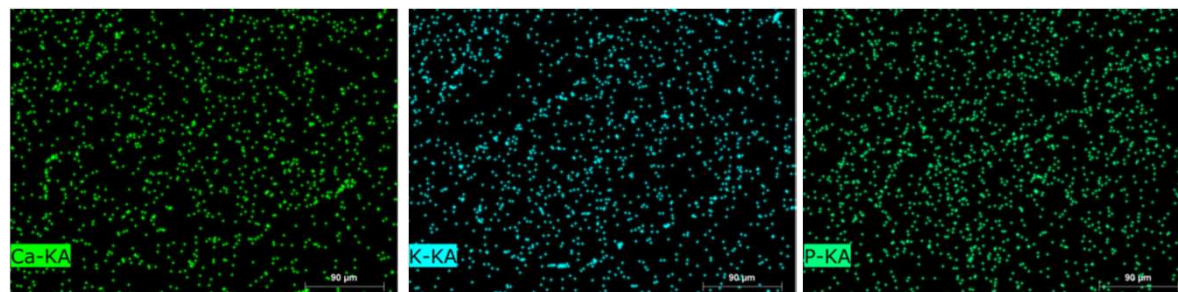
Entire particle



Cross-section



- No ash-sand interaction
- No agglomeration



# Olive stones

1<sup>st</sup> experimental campaign: **CFB - Sand**



Thermal power  $\approx$  20 kW

**Combustion efficiency > 98%**

| Test | Temperature (°C) | Excess Air (%) | CO <sub>2</sub> (%) | O <sub>2</sub> (%) | CO vppm | SO <sub>2</sub> vppm | NO vppm | NO <sub>2</sub> vppm | N <sub>2</sub> O vppm | NH <sub>3</sub> mg/kg bio | Tars g/kg bio (g/m <sup>3</sup> ) |
|------|------------------|----------------|---------------------|--------------------|---------|----------------------|---------|----------------------|-----------------------|---------------------------|-----------------------------------|
| 1    | 850              | 20             | 17.5                | 3.3                | 6910    | 0                    | 140     | < 10                 | < 10                  | 0                         | 0.63 (0.123)                      |
| 2    | 800              | 2              | 17.6                | 3.2                | 7880    | 0                    | 155     | < 10                 | < 10                  | -                         | 0.52 (0.101)                      |
| 3    | 900              | 20             | 17.4                | 3.6                | 6300    | 0                    | 132     | < 10                 | < 10                  | -                         | -                                 |
| 4    | 850              | 10             | 17.2                | 2.2                | 9500    | 0                    | 131     | < 10                 | < 10                  | -                         | -                                 |

# Olive stones

1<sup>st</sup> experimental campaign: CFB - Sand

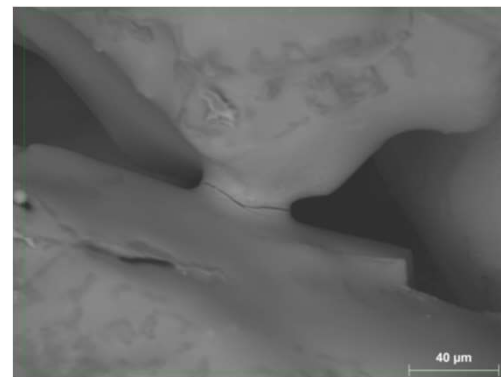
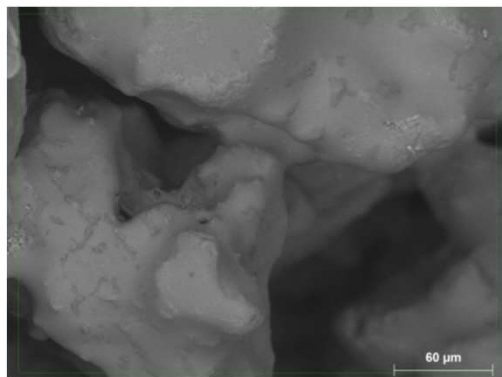
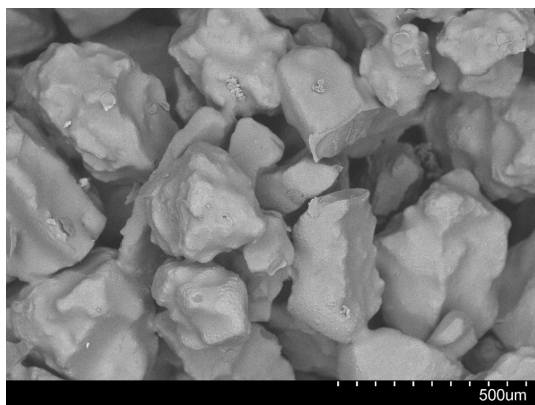
## □ Agglomeration



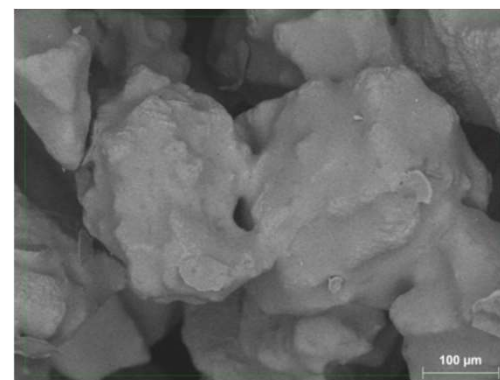
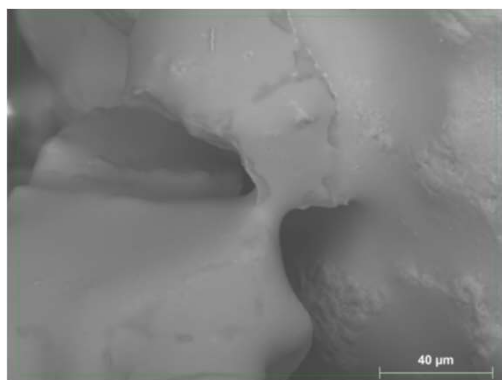
# Olive stones

1<sup>st</sup> experimental campaign: **CFB - Sand**

Entire particles



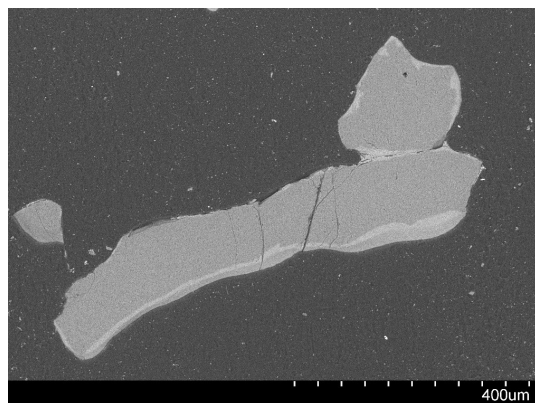
Agglomerated particles



# Olive stones

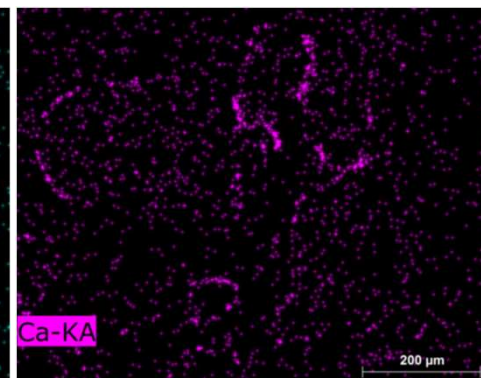
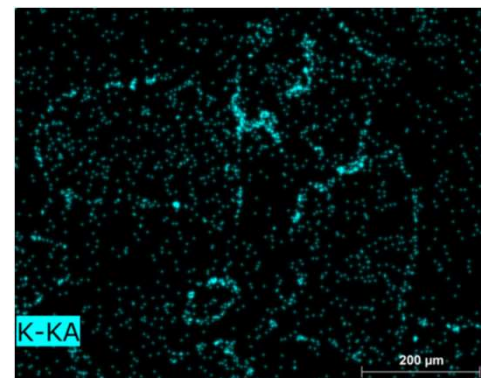
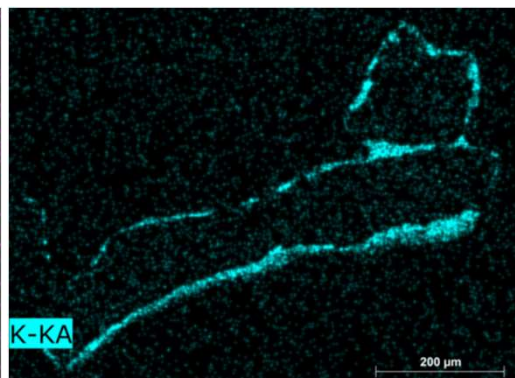
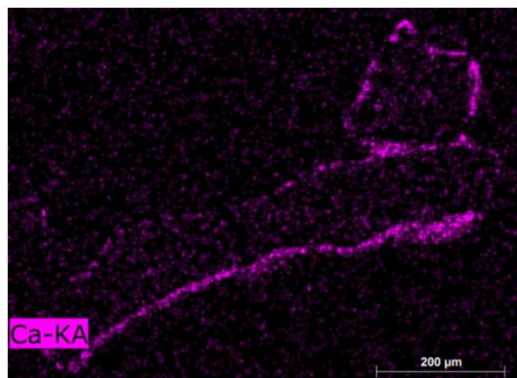
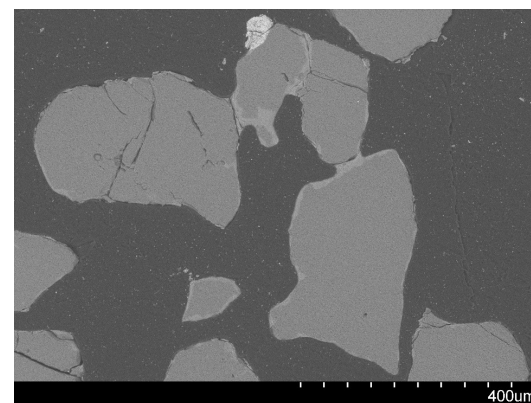
1<sup>st</sup> experimental campaign: CFB - Sand

Cross section



Accumulation of

- K
- Ca



# Chips of spruce branches and treetops

1<sup>st</sup> experimental campaign: **CFB - Sand**



Thermal power  $\approx$  20 kW

Combustion efficiency > 98%

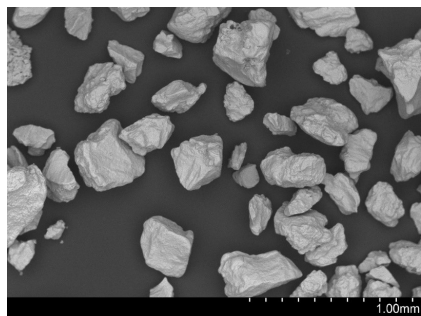
| Test | Temperature (°C) | Excess Air (%) | Primary/total air ratio (%) | CO <sub>2</sub> (%) | O <sub>2</sub> (%) | CO vppm | SO <sub>2</sub> vppm | NO vppm | NO <sub>2</sub> vppm | N <sub>2</sub> O vppm | NH <sub>3</sub> mg/kg bio | Tars g/kg bio (g/m <sup>3</sup> ) |
|------|------------------|----------------|-----------------------------|---------------------|--------------------|---------|----------------------|---------|----------------------|-----------------------|---------------------------|-----------------------------------|
| 1    | 850              | 20             | 78                          | 16.4                | 3.8                | 677     | 0                    | 315     | < 10                 | < 10                  | 0                         | 0.55 (0.104)                      |
| 2    | 800              | 20             | 78                          | 16.8                | 3.4                | 1075    | 0                    | 357     | < 10                 | < 10                  | -                         | 0.45 (0.088)                      |
| 3    | 900              | 20             | 78                          | 17.1                | 3.0                | 915     | 0                    | 248     | < 10                 | < 10                  | -                         | -                                 |
| 4    | 850              | 30             | 78                          | 14.9                | 5.3                | 396     | 0                    | 420     | < 10                 | < 10                  | -                         | -                                 |
| 5    | 850              | 10             | 78                          | 17.9                | 2.1                | 1875    | 0                    | 352     | < 10                 | < 10                  | -                         | -                                 |
| 6    | 850              | 20             | 95                          | 17.4                | 3.4                | 1030    | 0                    | 440     | < 10                 | < 10                  | -                         | -                                 |

# Chips of spruce branches and treetops

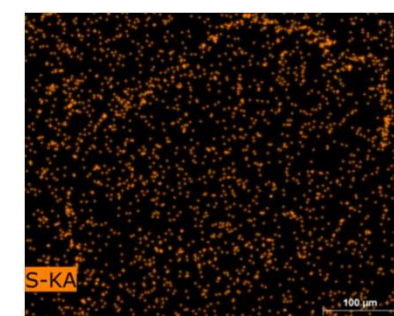
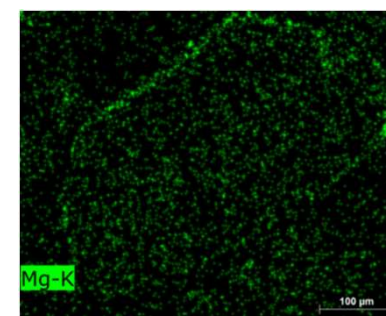
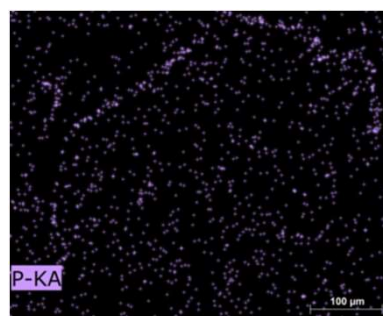
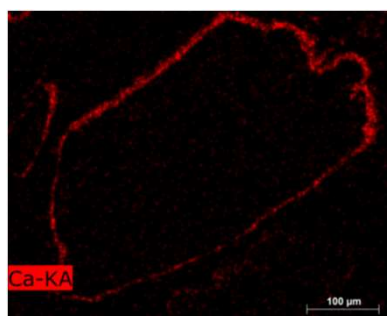
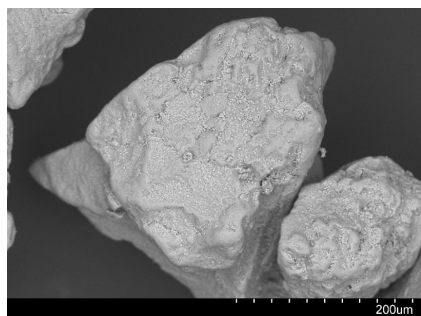
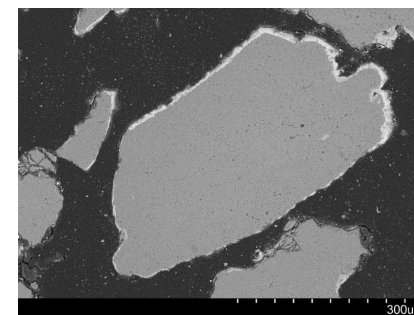
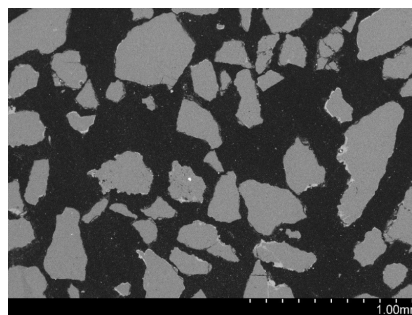
1<sup>st</sup> experimental campaign: CFB - Sand



Entire particles



Cross section



# RDF

1<sup>st</sup> experimental campaign: **CFB - Sand**



Thermal power  $\approx$  20 kW

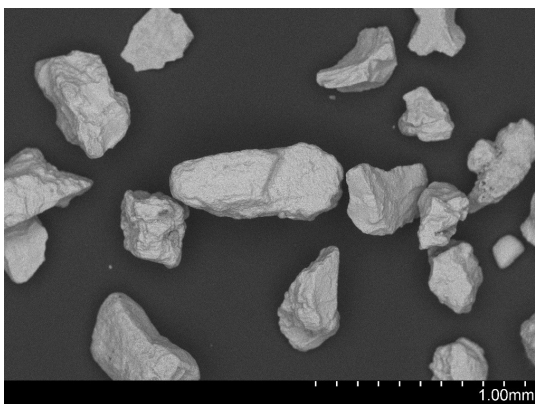
**Combustion efficiency > 98%**

| Test | Temperature (°C) | Excess Air (%) | Primary/total air ratio (%) | CO <sub>2</sub> (%) | O <sub>2</sub> (%) | CO vppm | SO <sub>2</sub> vppm | NO vppm | NO <sub>2</sub> vppm | N <sub>2</sub> O vppm | NH <sub>3</sub> mg/kg bio | Tars g/kg bio (g/m <sup>3</sup> ) |
|------|------------------|----------------|-----------------------------|---------------------|--------------------|---------|----------------------|---------|----------------------|-----------------------|---------------------------|-----------------------------------|
| 1    | 850              | 20             | 78                          | 15.1                | 3.7                | 6980    | 26                   | 239     | 13                   | < 10                  | 35.4                      | 1.10 (0.156)                      |
| 2    | 800              | 20             | 78                          | 15.0                | 3.7                | 8610    | 33                   | 292     | 18                   | < 10                  | -                         | 0.62 (0.090)                      |
| 3    | 900              | 20             | 78                          | 15.6                | 3.0                | 5890    | 14                   | 202     | 12                   | < 10                  | -                         | -                                 |
| 4    | 850              | 30             | 78                          | 13.7                | 5.0                | 5250    | 23                   | 280     | 14                   | < 10                  | -                         | -                                 |
| 5    | 850              | 10             | 78                          | 15.8                | 2.6                | 11090   | 29                   | 260     | 11                   | < 10                  | -                         | -                                 |
| 6    | 850              | 20             | 95                          | 15.3                | 3.3                | 7080    | 31                   | 272     | 13                   | < 10                  | -                         | -                                 |

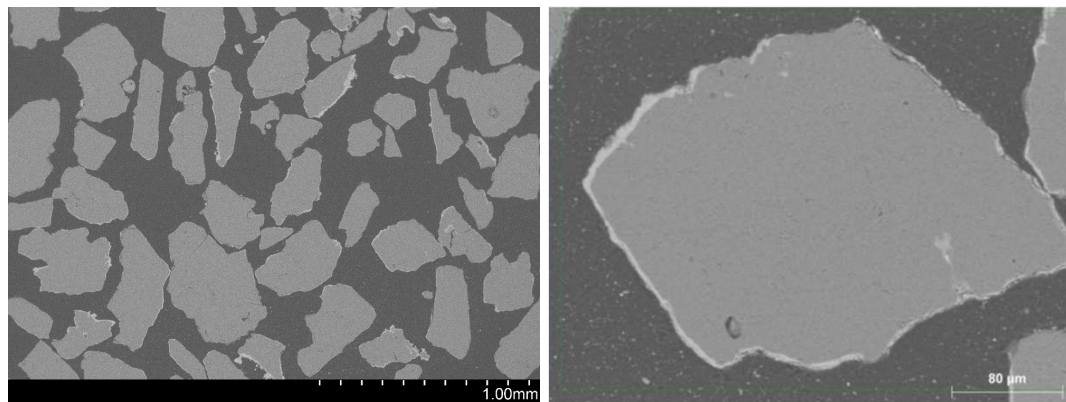
# RDF

1<sup>st</sup> experimental campaign: CFB - Sand

Entire particles

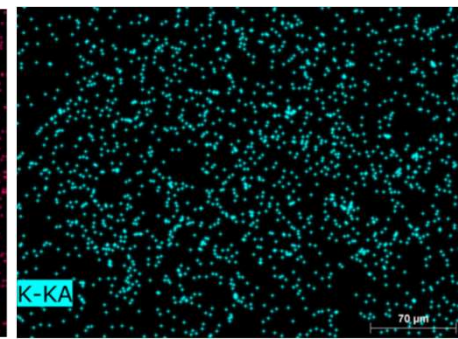
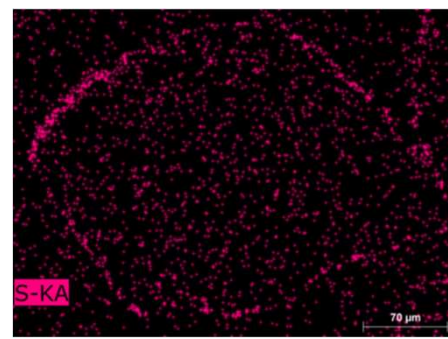
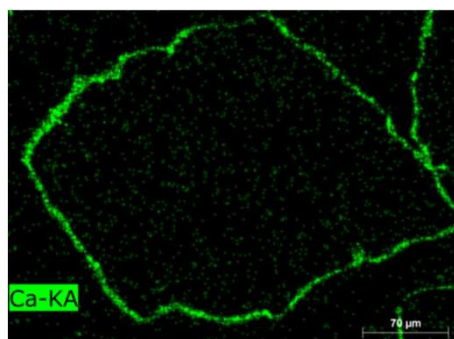


Cross section

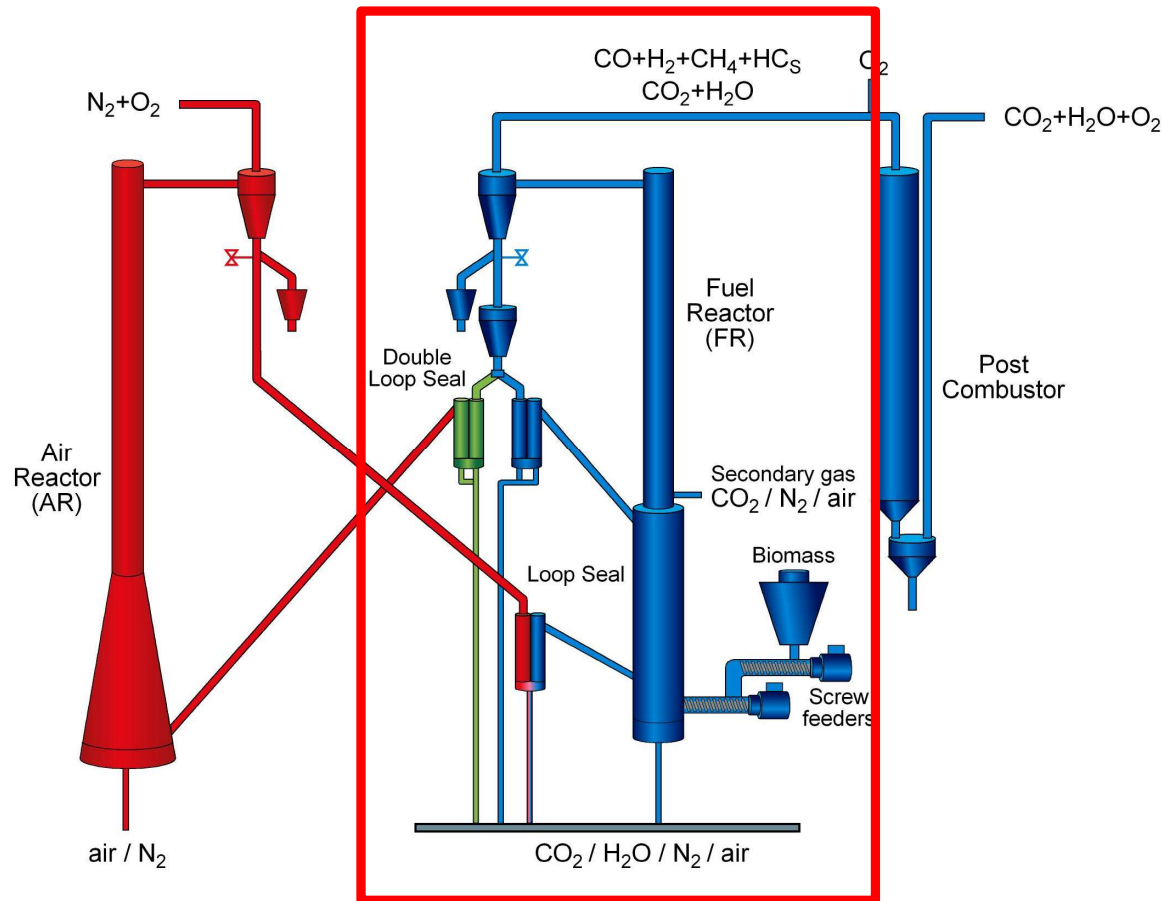


## Accumulation of

- Ca
- S



# Conventional CFB for solid fuels



## 2<sup>nd</sup> experimental campaign: CFB

Bed material: **Ilmenite**,  $d_p = 100 - 300 \mu\text{m}$

Reference conditions:

- Temperature: 850 °C
- Excess air: 20 %
- Superficial gas velocity: 2.5 m/s (bottom), 5.0 m/s (top)

### Experimental variables to be analyzed:

- ✓ Temperature: 800 – 900 °C
- ✓ Excess air: 10 – 30 %
- ✓ Superficial gas velocity: variation in the secondary/primary air ratio

# Pine wood pellets - Olive stones

2<sup>nd</sup> experimental campaign: **CFB - Ilmenite**

| Test | Temperature (°C) | Excess Air (%) | Primary/total air ratio (%) | CO <sub>2</sub> (%) | O <sub>2</sub> (%) | CO vppm | SO <sub>2</sub> vppm | NO vppm | NO <sub>2</sub> vppm | N <sub>2</sub> O vppm | NH <sub>3</sub> mg/kg bio | Tars g/kg bio (g/m³) |
|------|------------------|----------------|-----------------------------|---------------------|--------------------|---------|----------------------|---------|----------------------|-----------------------|---------------------------|----------------------|
| 1    | 850              | 20             | 78                          | 16.5                | 3.9                | 132     | 0                    | 117     | 10                   | < 10                  | 0                         | 0.04                 |
| 2    | 800              | 20             | 78                          | 16.4                | 4.1                | 305     | 0                    | 120     | 11                   | < 10                  | -                         | 0.03                 |
| 3    | 900              | 20             | 78                          | 16.6                | 3.8                | 95      | 0                    | 125     | 13                   | < 10                  | -                         | -                    |
| 4    | 850              | 30             | 78                          | 15.2                | 5.2                | 49      | 0                    | 100     | 10                   | < 10                  | -                         | -                    |
| 5    | 850              | 10             | 78                          | 18.3                | 2.2                | 384     | 0                    | 85      | <10                  | < 10                  | 0                         | 0.02                 |
| 6    | 850              | 20             | 62                          | 16.3                | 4.1                | 45      | 0                    | 101     | <10                  | < 10                  | -                         | -                    |
| 7    | 850              | 20             | 95                          | 16.1                | 4.2                | 191     | 0                    | 112     | 10                   | < 10                  | -                         | -                    |
| 1    | 850              | 20             | 78                          | 17.4                | 3.3                | 4047    | 0                    | 293     | 10                   | < 10                  | 0                         | 0.74                 |
| 2    | 800              | 20             | 78                          | 17.0                | 3.6                | 4570    | 0                    | 218     | 10                   | < 10                  | -                         | 1.36                 |
| 3    | 900              | 20             | 78                          | 17.6                | 3.1                | 3830    | 0                    | 354     | 11                   | < 10                  | -                         | -                    |
| 4    | 850              | 30             | 78                          | 15.7                | 5.0                | 2970    | 0                    | 310     | 10                   | < 10                  | -                         | -                    |
| 5    | 850              | 10             | 78                          | 18.5                | 2.1                | 4325    | 0                    | 313     | 11                   | < 10                  | -                         | -                    |
| 6    | 850              | 20             | 95                          | 17.4                | 3.2                | 6510    | 0                    | 290     | 10                   | < 10                  | -                         | -                    |



Thermal power  $\approx$  20 kW

Combustion efficiency > 98%

- ☐ No agglomeration
- ☐ No interaction ash-ilmenite

# RDF - Chips of spruce branches and treetops

2<sup>nd</sup> experimental campaign: **CFB - Ilmenite**

|                                       | Test | Temperature (°C) | Excess Air (%) | Primary/total air ratio (%) | CO <sub>2</sub> (%) | O <sub>2</sub> (%) | CO vppm | SO <sub>2</sub> vppm | NO vppm | NO <sub>2</sub> vppm | N <sub>2</sub> O vppm | NH <sub>3</sub> mg/kg bio | Tars g/kg bio (g/m <sup>3</sup> ) |
|---------------------------------------|------|------------------|----------------|-----------------------------|---------------------|--------------------|---------|----------------------|---------|----------------------|-----------------------|---------------------------|-----------------------------------|
| RDF                                   | 1    | 850              | 20             | 78                          | 14.9                | 3.6                | 5130    | <10                  | 510     | 21                   | < 10                  | 0                         | 0.15                              |
|                                       | 2    | 800              | 20             | 78                          | 15.4                | 3.0                | 6750    | <10                  | 309     | 14                   | < 10                  | -                         | 0.25                              |
|                                       | 3    | 900              | 20             | 78                          | 15.2                | 3.3                | 4625    | <10                  | 569     | 26                   | < 10                  | -                         | -                                 |
|                                       | 4    | 850              | 30             | 78                          | 14.0                | 4.7                | 2130    | <10                  | 436     | 15                   | < 10                  | -                         | -                                 |
|                                       | 5    | 850              | 10             | 78                          | 16.5                | 1.6                | 7890    | <10                  | 392     | 15                   | < 10                  | -                         | -                                 |
|                                       | 6    | 850              | 20             | 95                          | 15.3                | 3.2                | 5362    | <10                  | 396     | 14                   | < 10                  | -                         | -                                 |
| Chips of spruce branches and treetops | 1    | 850              | 20             | 78                          | 16.4                | 3.9                | 107     | 0                    | 430     | 22                   | < 10                  | 0                         | 0.1                               |
|                                       | 2    | 800              | 20             | 78                          | 16.5                | 4.0                | 267     | 0                    | 380     | 23                   | < 10                  | -                         | 0.3                               |
|                                       | 3    | 900              | 20             | 78                          | 17.1                | 3.3                | 177     | 0                    | 585     | 21                   | < 10                  | -                         | -                                 |
|                                       | 4    | 850              | 30             | 78                          | 15.0                | 5.4                | 106     | 0                    | 466     | 14                   | < 10                  | -                         | -                                 |
|                                       | 5    | 850              | 10             | 78                          | 18.2                | 1.9                | 865     | 0                    | 411     | 10                   | < 10                  | -                         | -                                 |
|                                       | 6    | 850              | 20             | 95                          | 17.0                | 3.3                | 254     | 0                    | 483     | 13                   | < 10                  | -                         | -                                 |



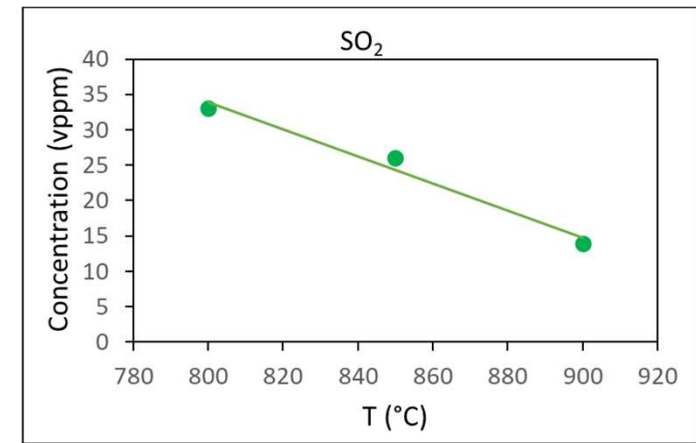
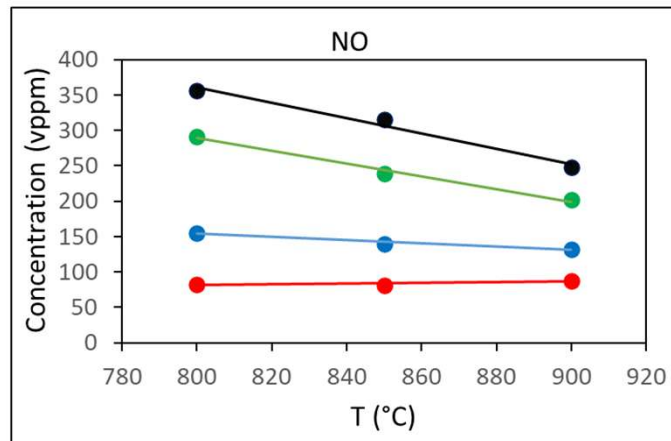
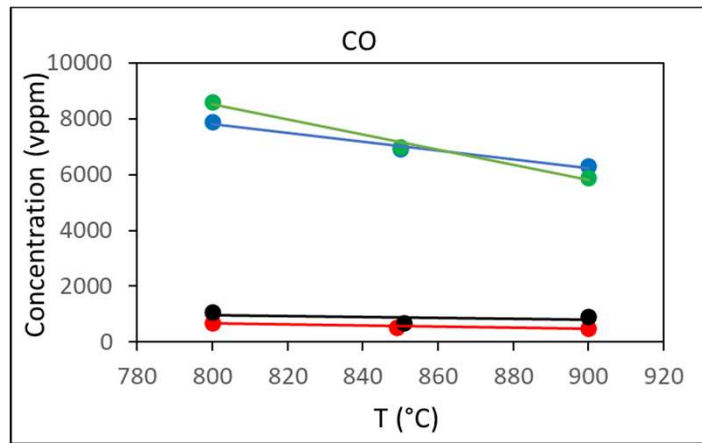
Thermal power  $\approx$  20 kW

Combustion efficiency > 98%

☐ No agglomeration

☐ No interaction ash-ilmenite

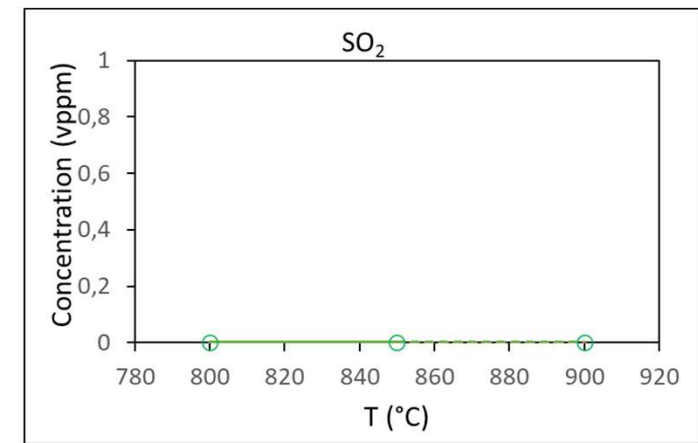
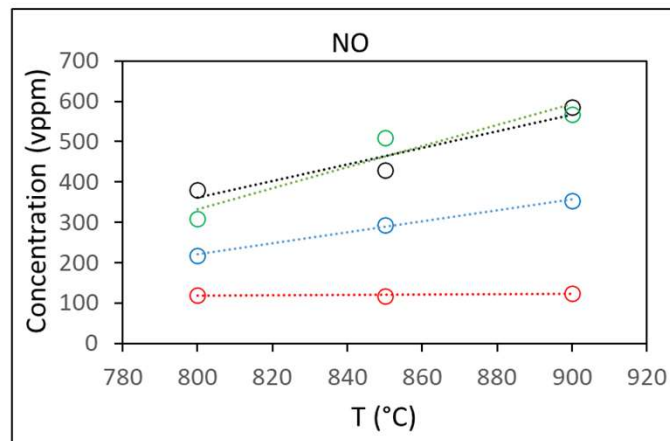
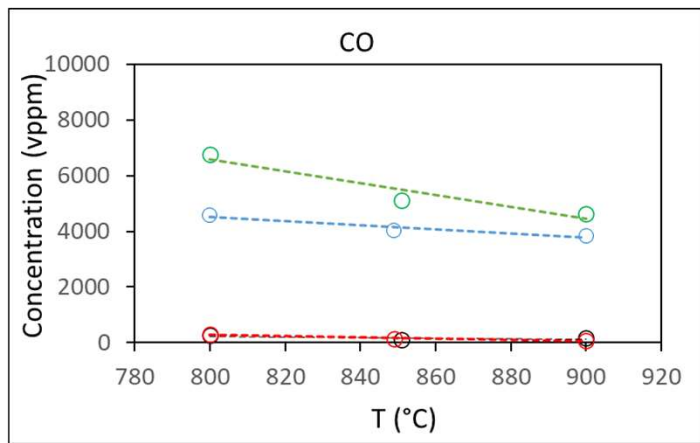
# Comparison of Silica sand and ilmenite results



— Silica sand

● Pine wood ● Olive stones ● Spruce chips ● RDF

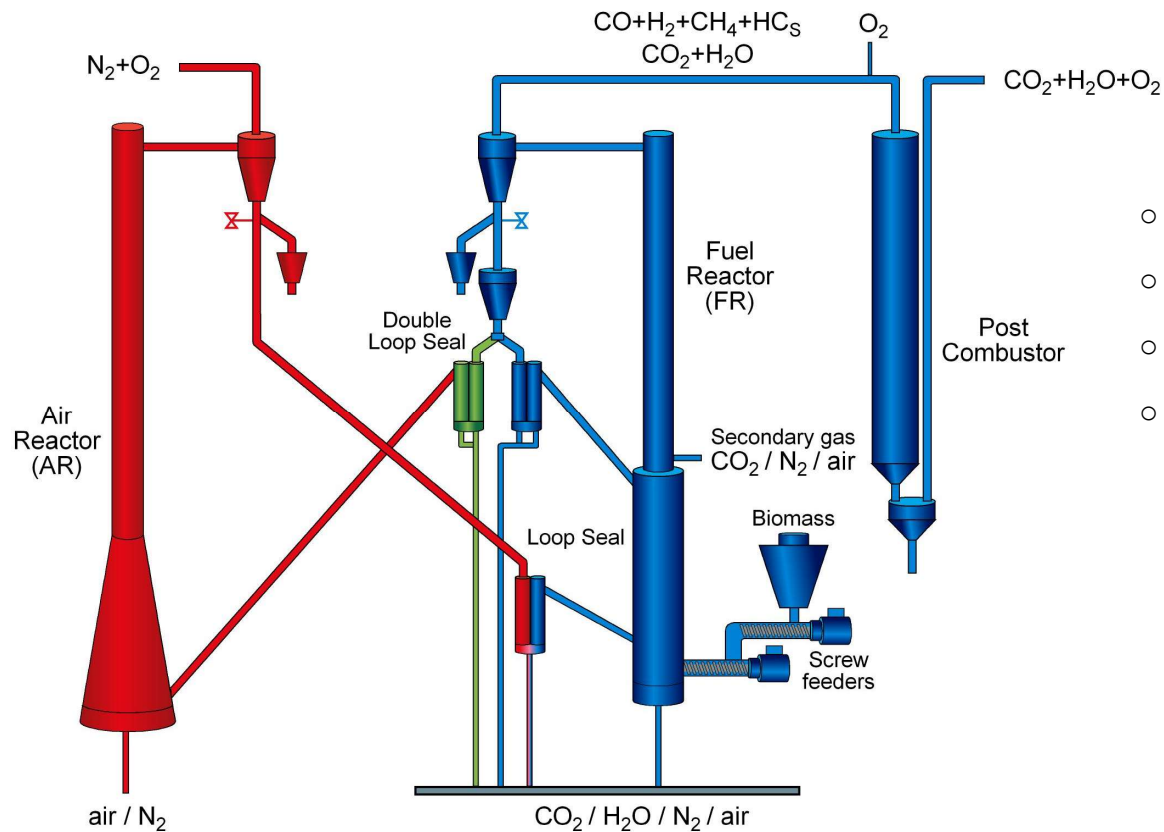
# Comparison of Silica sand and ilmenite results



----- Ilmenite

● Pine wood ● Olive stones ● Spruce chips ● RDF

# CLC for solid fuels equipped with post combustor



## Experimental campaign: CLC

- Bed material: Ilmenite,  $d_p = 100 - 300 \mu m$
- Post-oxidation chamber
- Fuel: Pine wood pellets
- Reference conditions:
  - FR temperature:  $950^\circ C$
  - Excess air: 20 %
  - FR superficial gas velocity:  $\sim 2.3$  m/s (bottom),  $\sim 4.5$  m/s (top)
  - AR superficial gas velocity:  $\sim 0.4$  m/s (bottom),  $\sim 5.3$  m/s (top)

## Experimental variables to be analyzed:

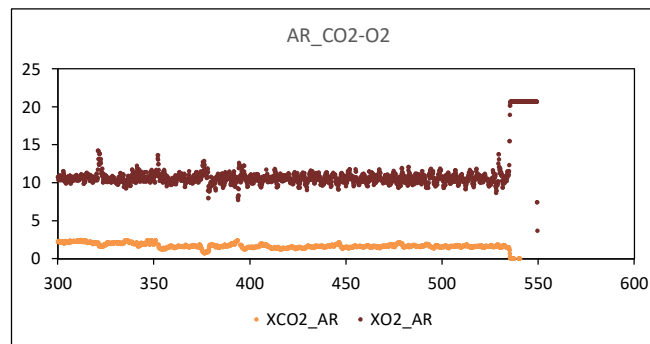
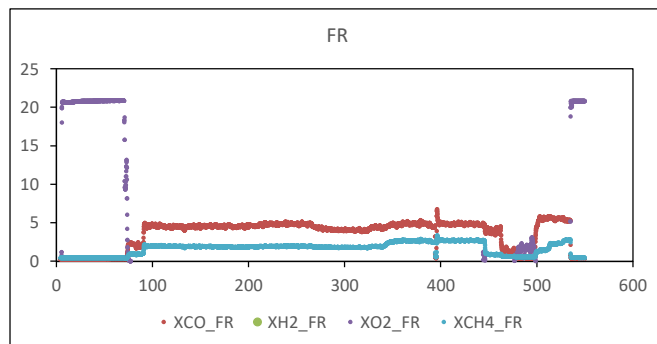
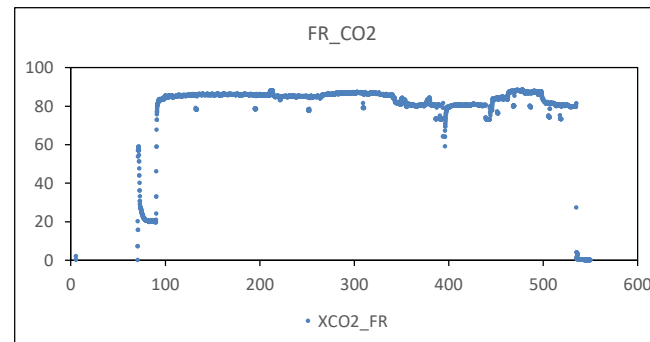
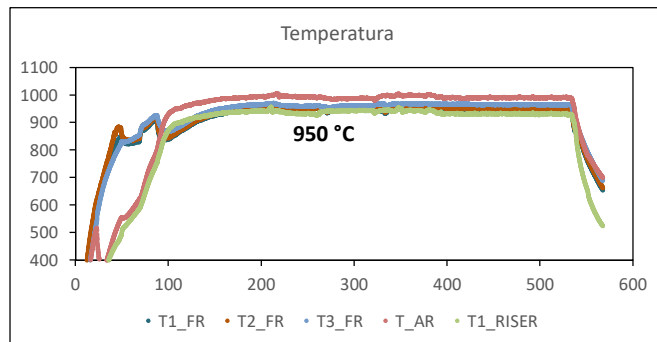
- ✓ Temperature:  $850 - 950^\circ C$
- ✓  $\phi$ : 1 – 2
- ✓ Post oxidation chamber behaviour

# Results of experimental campaign (CLC)

3<sup>rd</sup> experimental campaign: CLC - Ilmenite



Fuel  
Pine wood pellets



# CLC Mode - Effect of Temperature and $\phi$



Thermal power  $\approx 20$  kW

Carbon conversion FR + AR  $> 98\%$

Fuel: Pine wood pellets

Oxygen carrier-to-fuel ratio ( $\phi$ )

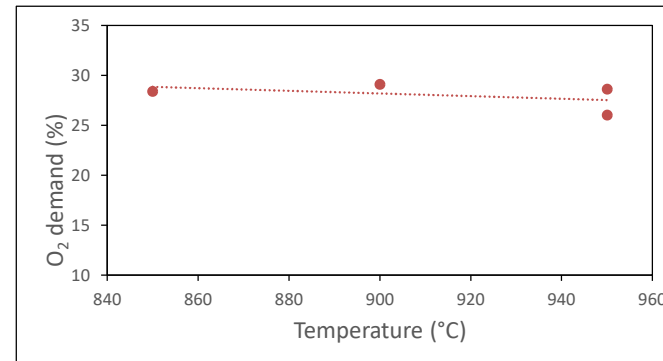
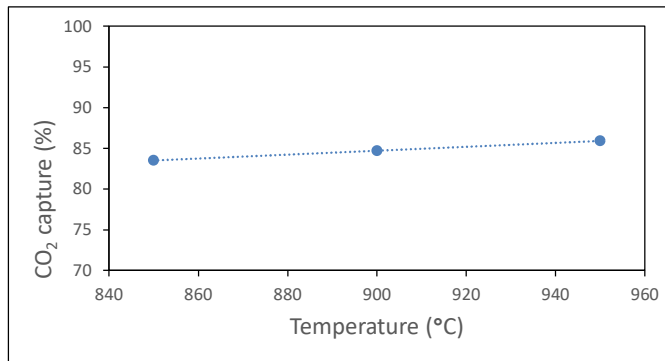
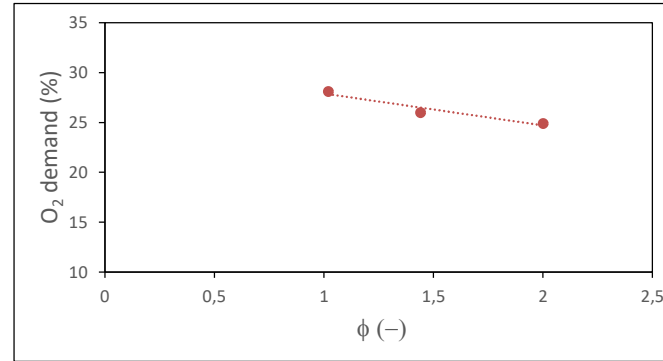
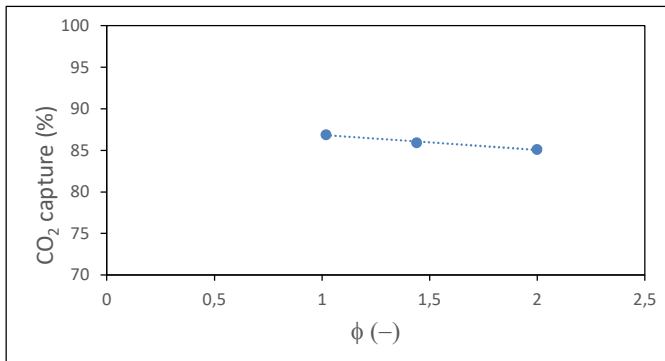
$$\frac{\text{Potential oxygen available in the oxygen carrier}}{\text{Oxygen demanded for the complete combustion of the fuel}}$$

CO<sub>2</sub> capture efficiency ( $\eta_{CC}$ )

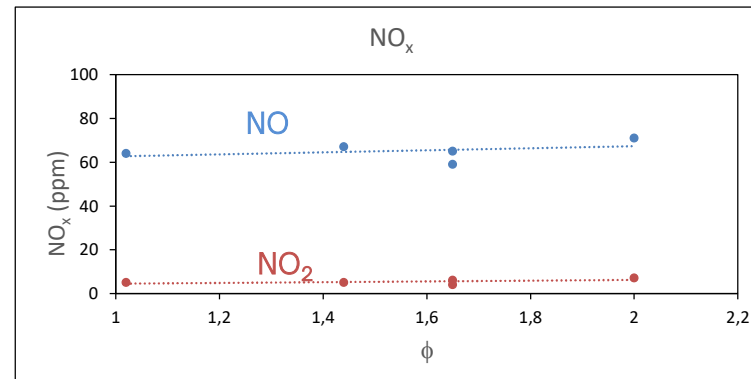
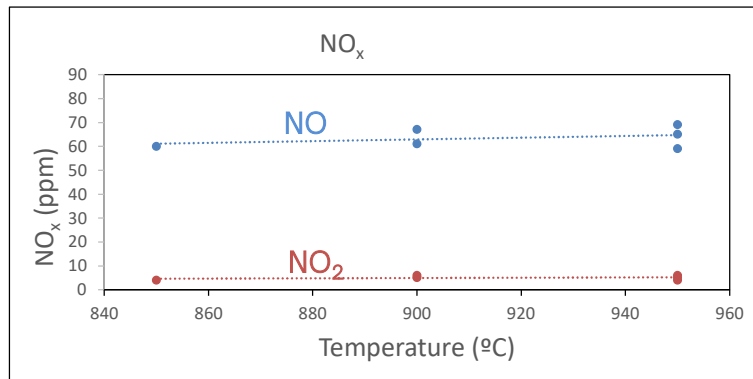
$$\frac{\text{Carbon from fuel in gases from the FR}}{\text{Carbon in the fuel fed}}$$

Total oxygen demand ( $\Omega_{OD}$ )

$$\frac{\text{Oxygen demanded for the complete combustion of gases from the FR}}{\text{Oxygen demanded for the complete combustion of the fuel}}$$



# CLC Mode - Effect of Temperature and $\phi$



❖ Slight increase in  $\text{NO}_x$  due to increase in Temperature as well as oxygen to fuel ratio

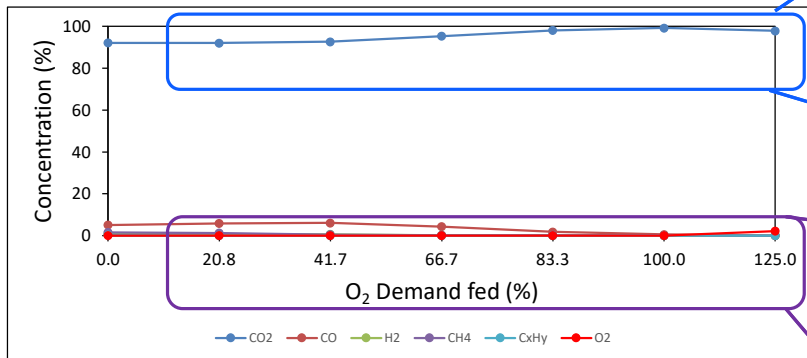
# CLC Mode - Post combustor

Temperature: 950 °C

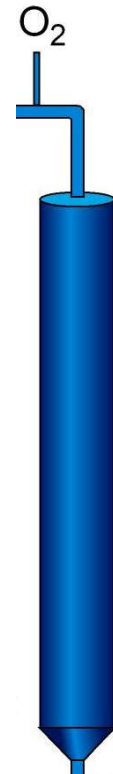
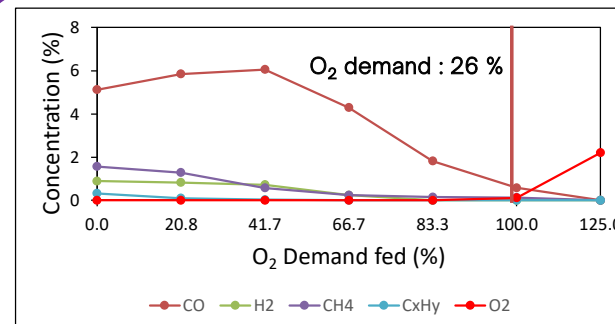
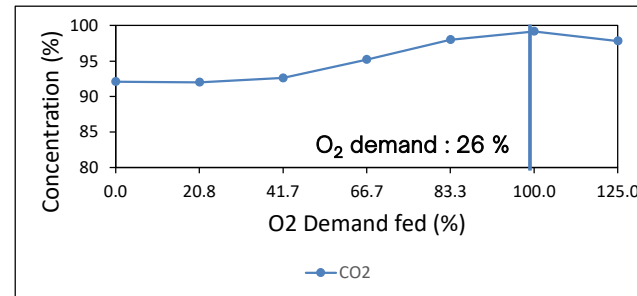
$\Phi = 1.44$

O<sub>2</sub> demand : 26 %

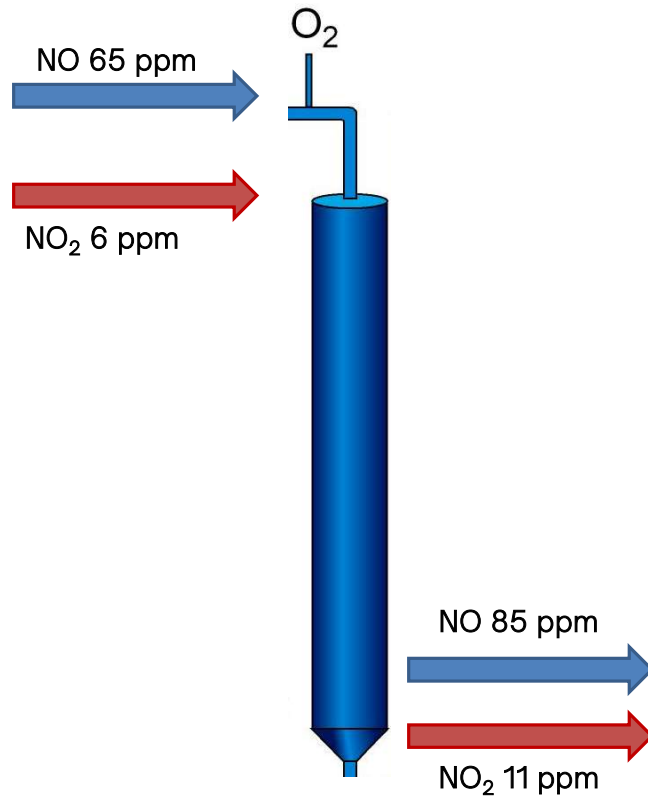
Fuel: Pine wood pellets



| O <sub>2</sub> Demand fed %   | 0    | 100   | 125   |
|-------------------------------|------|-------|-------|
| CO <sub>2</sub>               | 92.1 | 99.18 | 97.82 |
| CO                            | 5.12 | 0.58  | <0.05 |
| H <sub>2</sub>                | 0.89 | <0.05 | <0.05 |
| CH <sub>4</sub>               | 1.56 | 0.13  | <0.05 |
| C <sub>x</sub> H <sub>y</sub> | 0.32 | <0.05 | <0.05 |
| O <sub>2</sub>                | 0    | 0.11  | 2.2   |



# CLC Mode - Post combustor



Thermal power  $\approx$  20 kW

Temperature: 950 °C

$\Phi = 1.44$

Fuel: Pine wood pellets

O<sub>2</sub> demand fed = 125 %

❖ Slight increase in NO<sub>x</sub> due to burn non-combusted components by introducing oxygen in post combustor

# Conclusions



- ❑ **Flexible CFB-CLC operation** demonstrated the technical feasibility of converting biogenic residues into heat and power.
- ❑ Conventional **CFB combustion tests** confirmed stable operation with various biomass fuels across a wide temperature range (800-900 °C), achieving **combustion efficiencies above 98%**.
- ❑ Under CFB combustion conditions with **silica sand** as bed material, **agglomeration** was observed with olive stones. In contrast, **no agglomeration** issues were detected when **ilmenite** was used as the oxygen carrier.
- ❑ **CLC experiments** using ilmenite as the oxygen carrier and pine wood pellets as fuel demonstrated stable operation, with **carbon conversion exceeding 98%**.
- ❑ The incorporation of a **post-oxidation chamber** proved highly effective, ensuring the **complete oxidation of unburned gaseous compounds** and improving overall process performance.

# Thank you for your attention



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Website



LinkedIn



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