

Workshop “From idea to commercialization with Horizon Europe projects”. **Manchester, September 4th, 2026**

From material discovery to demonstration scale

Francisco García Labiano (CSIC) & Jochen Strohle (TUDA)



Flexible chemical looping combustion for combined heat and power production from biogenic residues with negative emissions (Bio-FlexCLC)

- ❖ Grant agreement ID: 101147904
- ❖ Funding Program: HORIZON Europe
- ❖ Call Topic: Development of near zero-emission biomass heat and/or CHP including carbon capture (HORIZON-CL5-2023-D3-02-01)
- ❖ Starting Date: 1 June 2024
- ❖ Duration: 4 years
- ❖ Project Funding: € 3,948,500
- ❖ Coordinator: RISE Research Institutes of Sweden



Bio Methanol Production via Chemical Looping Gasification Coupled with Membrane Reactors (Bio-MeGaFuel)

- ❖ Grant agreement ID: 101147737
- ❖ Funding Program: HORIZON Europe
- ❖ Call Topic: Development of next generation advanced biofuel technologies (HORIZON-CL5-2023-D3-02-07)
- ❖ Starting Date: 1 September 2024
- ❖ Duration: 4 years
- ❖ Project Funding: € 3,797,326
- ❖ Coordinator: RISE Research Institutes of Sweden





Flexible chemical looping combustion for combined heat and power production from biogenic residues with negative emissions (Bio-FlexCLC)

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Workshop

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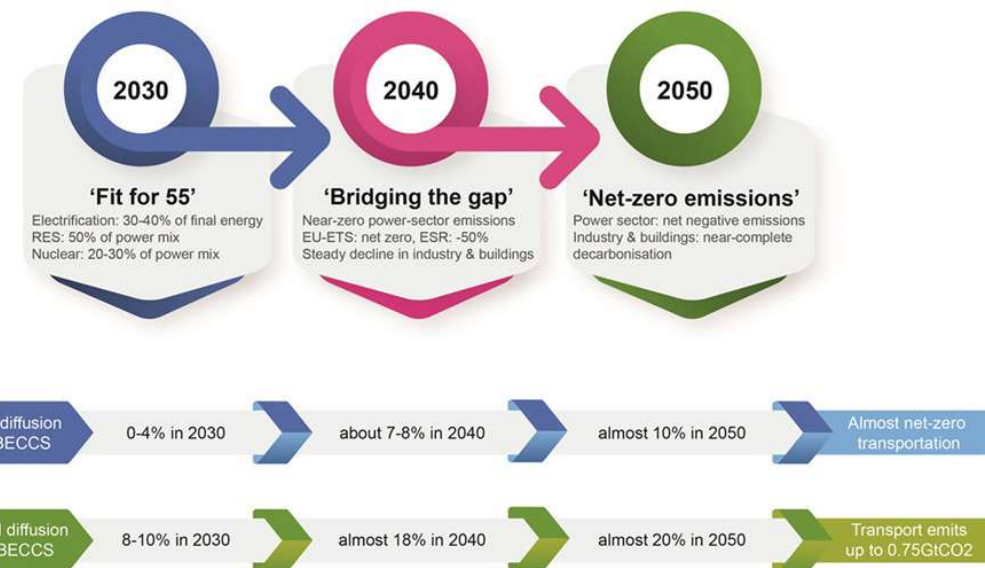
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Motivation

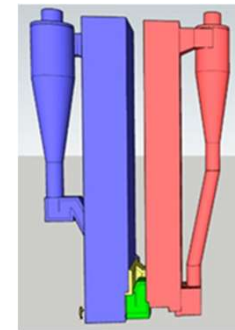
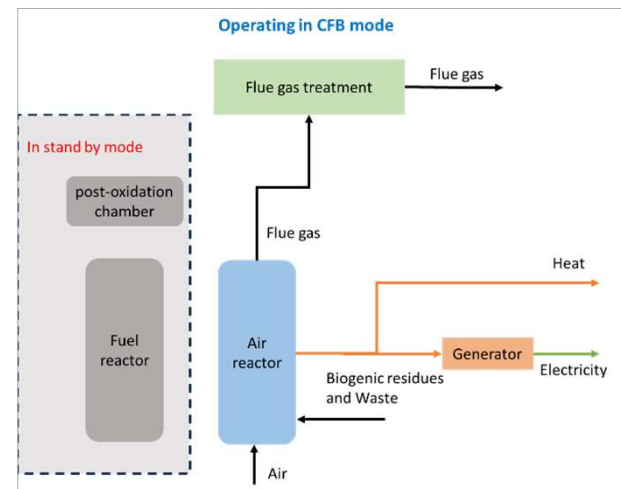
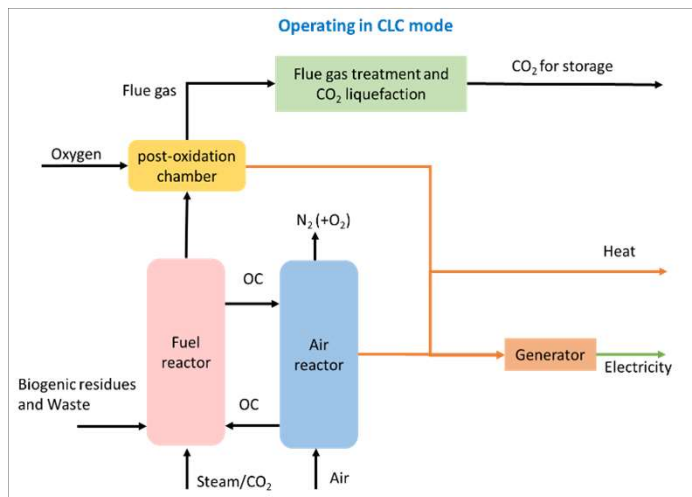
- EU has committed to full decarbonization in less than 30 years and Carbon Dioxide Removal (CDR) including Bio-Energy with Carbon Capture and Storage (BECCS) will be instrumental if this is to be achieved.
- However, the high cost and energy penalties of CCS are considered one of the most important barriers to the implementation of CCS and BECCS.
- Moreover, in light of no policy instruments and economic incentives currently in place for BECCS while at the same time needing rapid and substantial BECCS, it poses a dilemma for end users.

➤ Need to minimize the risks of investment in BECCS

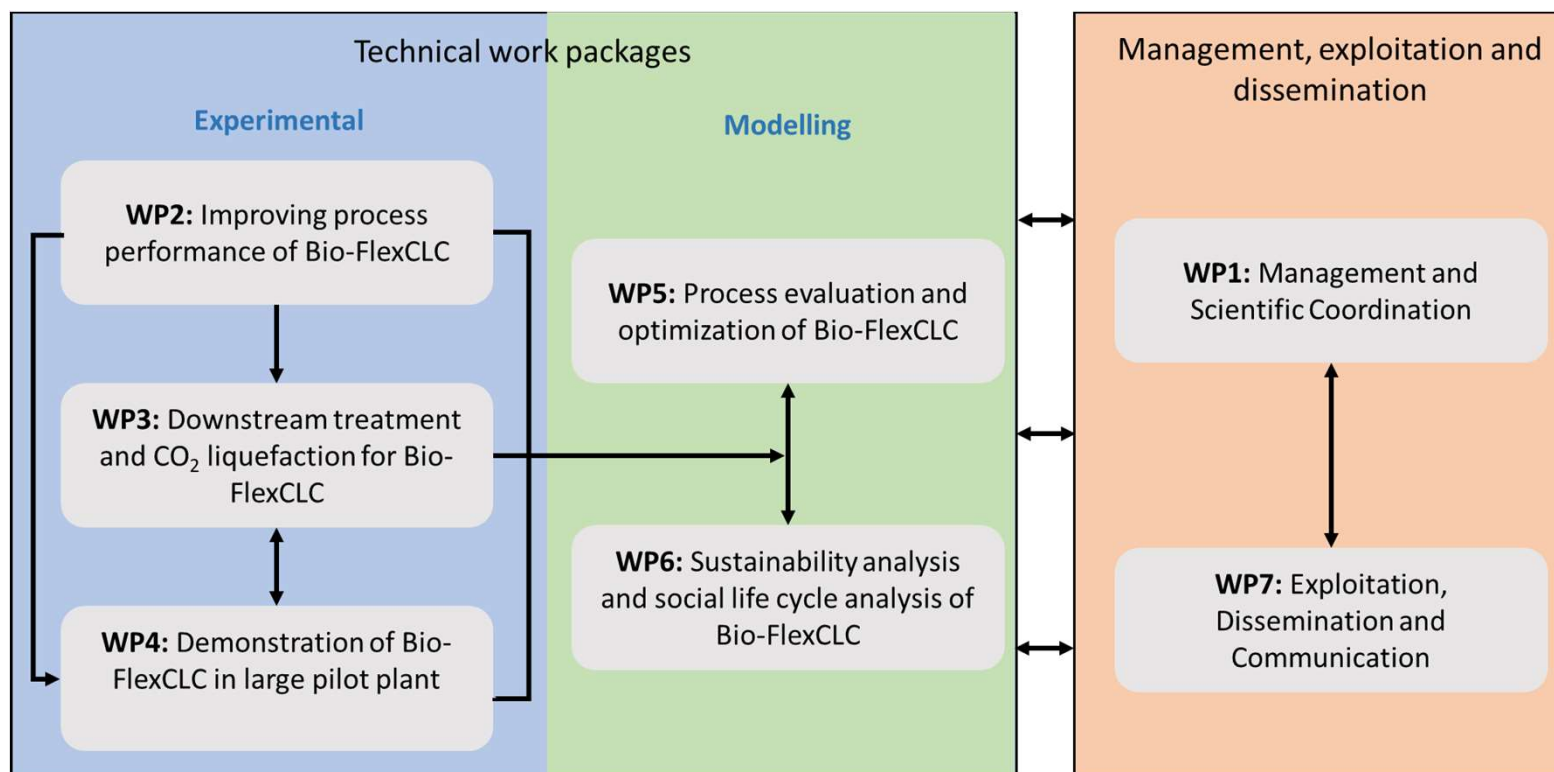


Concept

- 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 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



The overall structure of the work plan in Bio-FlexCLC



Methodology and Execution



To further understand CLC of biogenic residues



CLC operation mode with **four different biogenic residues**, e.g. agricultural and forestry residues, and investigate fate of ash species



To reduce the emissions of harmful gases and particles



Developing the **gas cleaning procedure to reduce SO_x, NO_x**, aromatics, and particle emissions including CO₂ capture and CO₂-Liquifaction unit



portable gas cleaning pilot plant



To improve the conversion of fuel by lab experiments and modelling



Reduce the fraction of unconverted fuel in the fuel reactor (below 10% oxygen demand, or above 90% gas conversion);
Reach >99% conversion in the fuel reactor and post post-oxidation step



10 kW CLC pilot reactor (left) and 20 kW CLC pilot plant (right)

Methodology and Execution



To evaluate the flexibility of Bio-FlexCLC operation



Changing the **thermal input** in the Bio-FlexCLC operation from 100% to 75%, 60% and 50% with a ramp-up/down speed of the boiler load of at least 5 % MCR/min



Develop strategies for optimized operation at **heat-to-power ratio** of 1:1, 2:1, and 3:1



To demonstrate Bio-FlexCLC at MW-scale with downstream treatment and liquefaction



Operate the **1 MW bio-FlexCLC plant** in CLC-CFB modes with downstream gas treatment and liquefaction for at least **200 hours** and reach **>95% CO₂ capture**



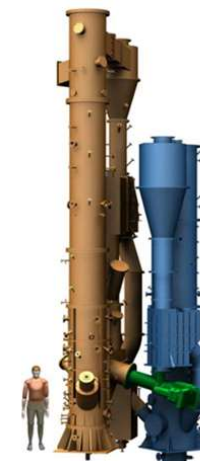
To design a **full chain 100 MW commercial** scale Bio-FlexCLC plant for CHP production from biogenic residues



To evaluate the economic and environmental performance of the process concept



Evaluate the **environmental and economic performance** for at least two locations for adopting Bio-FlexCLC in the regions in transition from fossil fuels



Drawing of TUDA 1MW pilot plant

Bio-FlexCLC partners

10 partners. Universities, Research centers and Companies

Partner	Role
RISE Research Institute Of Sweden	Coordinator, process design and technoeconomic assessment, LCA and sLCA, developing gas cleaning and liquefaction processes
Aichernig Engineering	Designing the process and operating strategies
Götaverken Miljö	Designing gas treatment technologies
Technical University of Darmstadt	Demonstration of Bio-FlexCLC at MW scale; process evaluation and optimization of flexible Bio-FlexCLC
Chalmers University of Technology	Chemical looping and fluidized bed combustion, Improving process performance of flexible Bio-FlexCLC
Spanish National Research Council (CSIC)	Chemical looping and fluidized bed combustion, Improving process performance of flexible Bio-FlexCLC
National Center For Research and Technological Development (CERTH)	CFD modelling of post-oxidation chamber and fuel reactors with packings
1Cube	Exploitation, Dissemination and Communication
Fortum Power and Heat Polska	Providing feedback and data for process and environmental analysis. Utility producer in Poland. Potential end user of the process.
Växjö Energi	Providing feedback and data for process and environmental analysis. Utility producer in Sweden. Potential end user of the process.

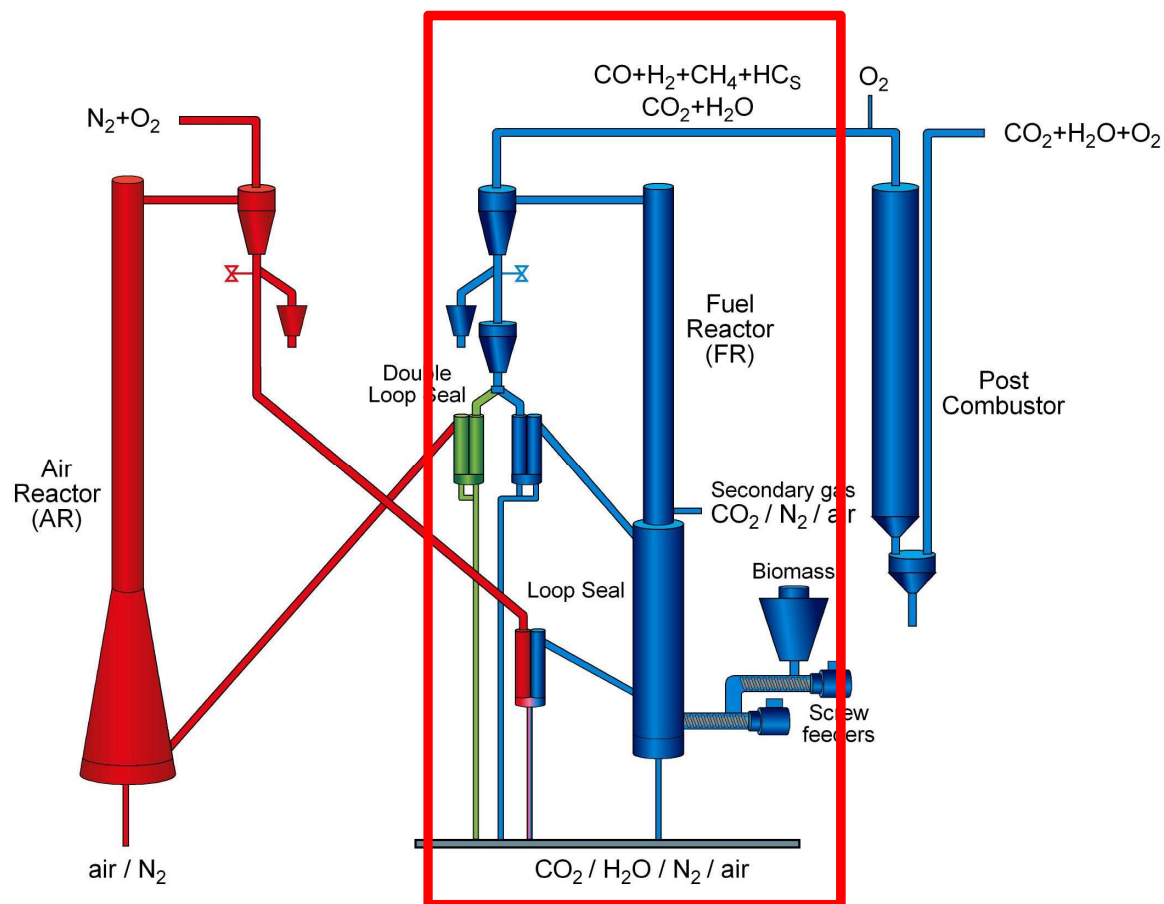


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CLC unit for solid fuels (20 kW_{th})

CFB mode



		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



- Built in 2013 with a nominal capacity of 50 kW_{th} for CLOU and 20 kW_{th} 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.

Thermal power ≈ 20 kW

Reference	Agricultural	Forestry	Biogenic
			
Pine wood pellets	Olive stones	Branches and treetops chips	RDF

Experimental campaigns:

1. Conventional CFB. Sand as bed material.



Agglomeration
(K+Ca)



CFB
Combustion
efficiency > 98%

2. Conventional CFB. Ilmenite as bed material.



CFB
Combustion
efficiency > 98%

3. CLC mode (ilmenite) + post-oxidation chamber.



CLC
Carbon conversion
FR + AR > 98%

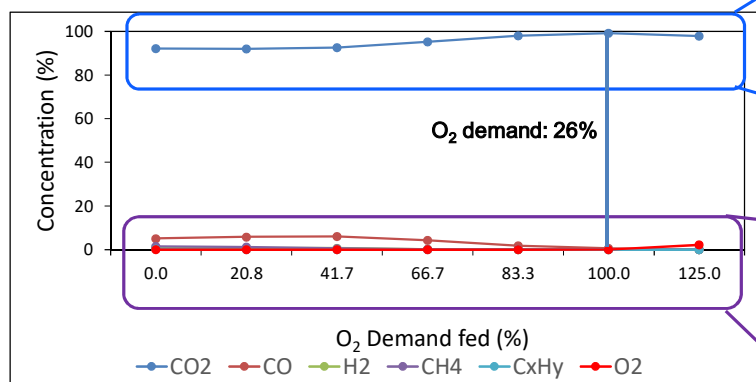
CLC unit for solid fuels (20 kW_{th}) + postcombustor

Temperature: 950 °C

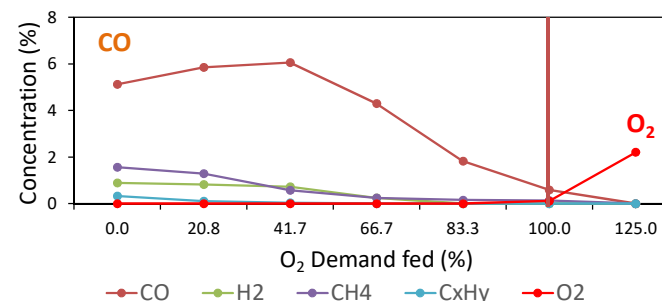
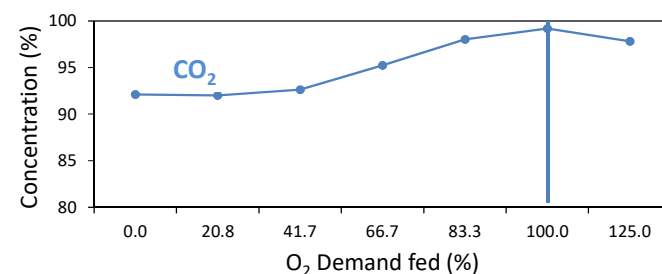
$\Phi = 1.44$

O₂ demand : 26 %

Fuel: Pine wood pellets



O ₂ Demand fed %	0	100	125
CO ₂	92.1	99.18	97.82
CO	5.12	0.58	<0.05
H ₂	0.89	<0.05	<0.05
CH ₄	1.56	0.13	<0.05
C _x H _y	0.32	<0.05	<0.05
O ₂	0	0.11	2.2



CLC unit for solid fuels (10 kW_{th})

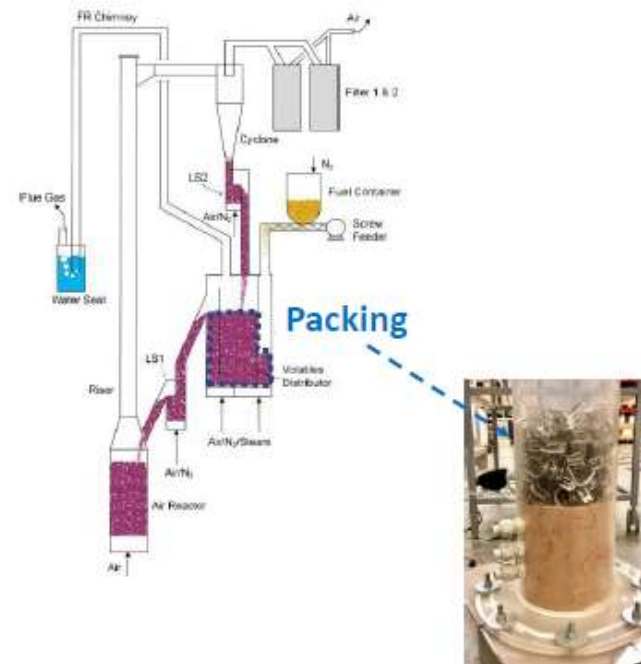
Experiments

- CLC experiments with packings
- ❖ Packing: RMSR 25 mm stainless steel thread saddle rings

Packing	Void factor (-)	Bulk density (kg/m ³)
RMSR	0.96	204



- ❖ Fuel: Black Pellets
- ❖ Oxygen Carrier: Ilmenite concentrate (FeTiO₃, Fe₂TiO₅, Fe₂O₃, TiO₂, Fe₃O₄)



At comparable operating conditions,
Internal packing
increased gas conversion
efficiency



Please follow our project website and our LinkedIn page for the latest news and developments.

Website: <https://www.bioflexclcproject.eu/>

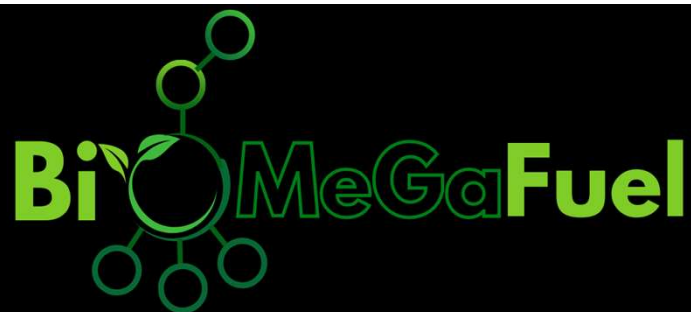
LinkedIn: <https://www.linkedin.com/company/bio-flexclc/>

Website



LinkedIn





Bio Methanol Production via Chemical Looping Gasification
Coupled with Membrane Reactors

From material discovery to demonstration scale

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Background and Motivation



❖ Why Biofuels production?

- ❖ Reduce dependence on fossil fuels.
- ❖ Critical to **decarbonizing hard-to-abate sectors**: aviation, shipping, heavy transport.

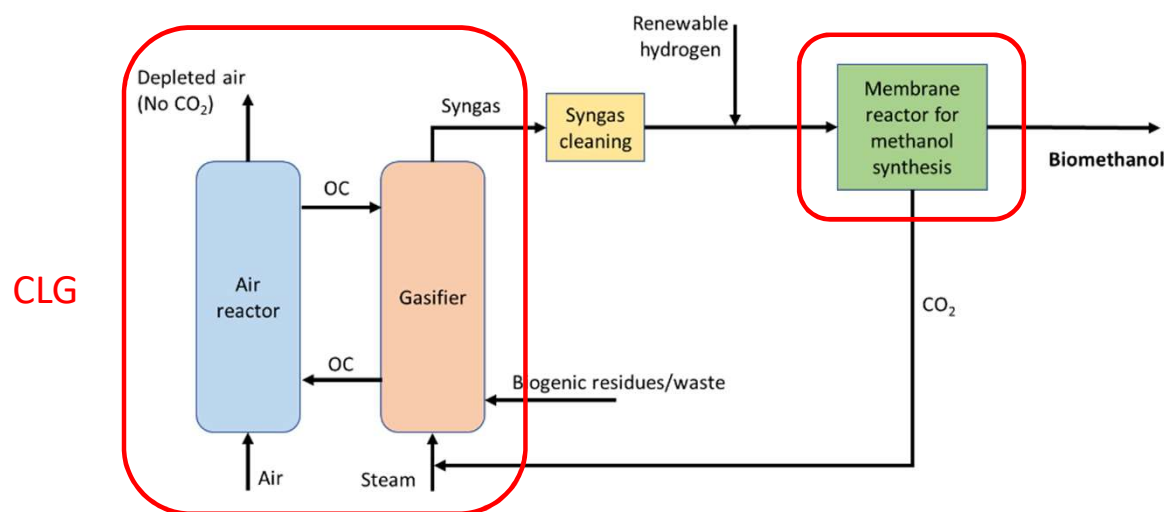
❖ Why Methanol ?

- ❖ Versatile: used in **combustion engines**, blended fuels, fuel cells, and **chemical feedstock**.
- ❖ **Biomethanol** significantly lowers GHG emissions vs fossil methanol.
- ❖ Maritime progress:
 - ❖ **Stena Germanica**: world's 1st methanol-powered vessel → SOx & particle emissions cut by 90%.
 - ❖ **Maersk**: first methanol-powered vessel launched.
- ❖ Methanol in **fuel cells**: higher efficiency, easier storage vs hydrogen.



Overall aim of this project:

Develop a novel **efficient**, and scalable process to convert **low-value biogenic residues** and organic waste to **biomethanol** through chemical looping gasification coupled with membrane reactors



**Bio-MeGaFuel
- CONCEPT -**

Participants

❖ The Bio-MeGaFuel project has an expert consortium. It consists of **9 partners from 5 countries** and includes:

❖ Three Research Institutes:

- ❖ **RISE** Research Institutes of Sweden
- ❖ **IVL** Swedish Environmental Research Institute
- ❖ **CSIC** The Spanish National Research Council

❖ Two Universities:

- ❖ **TUDA** The Technical University of Darmstadt
- ❖ **TU/e** Eindhoven University of Technology

❖ Four Companies:

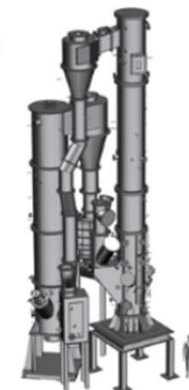
- ❖ **GIDARA Energy**
- ❖ **Perpetual Next**
- ❖ **1Cube**
- ❖ **Blue World Technologies**



Methodology

- ❖ 1: Developing gasification with oxygen carriers to maximize the conversion of biogenic residues and wastes to syngas
 - ❖ Testing at least five different biogenic fuels including microalgae
 - ❖ Operate the 1 MW CLG pilot plant at TUDA in auto-thermal modes to gasify 50-70 tons of biogenic residues (TRL 5)
 - ❖ 80% gasifier cold gas efficiency
 - ❖ 98% carbon conversion in gasifier
 - ❖ <10% of reactive ash species released in air reactor

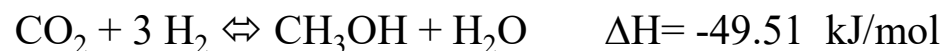
- ❖ 2: Developing membrane reactors for methanol synthesis
 - ❖ Demonstrate membranes at TRL5 in a standalone setup to produce biomethanol
 - ❖ Significantly increase the yield of biomethanol production from syngas by two-fold.
 - ❖ Separating unconverted biogenic CO₂





Methanol synthesis via membrane reactors

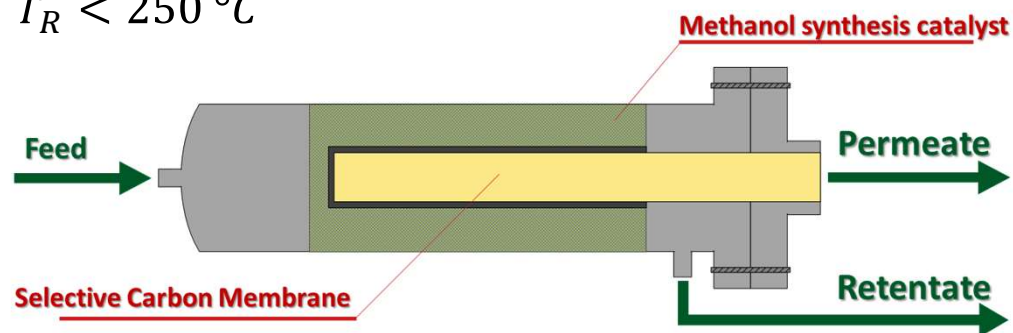
The methanol synthesis is an equilibrium system:



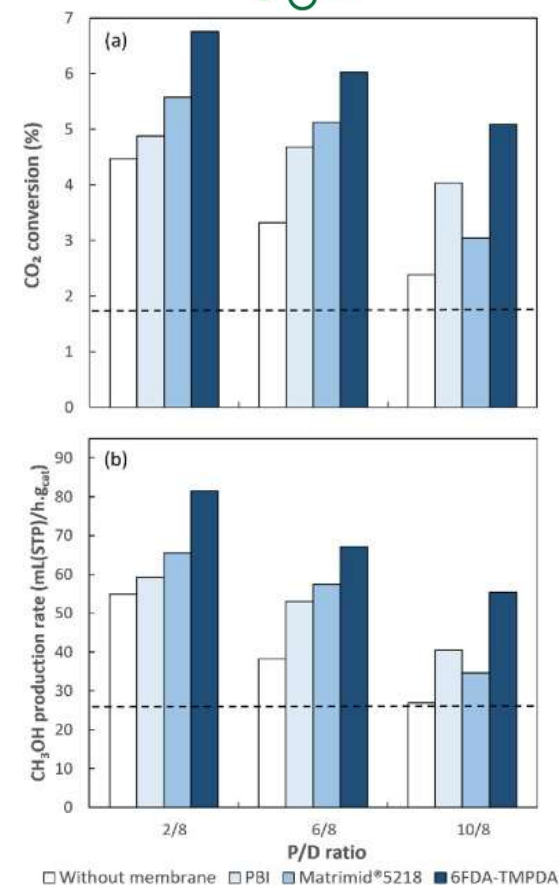
Commercial Cu/ZnO/Al₂O₃ catalyst

$$P_R < 40 \text{ bar}$$

$$T_R < 250 \text{ }^\circ\text{C}$$



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Fuel selection



Biogenic residues

Waste Wood
Type B

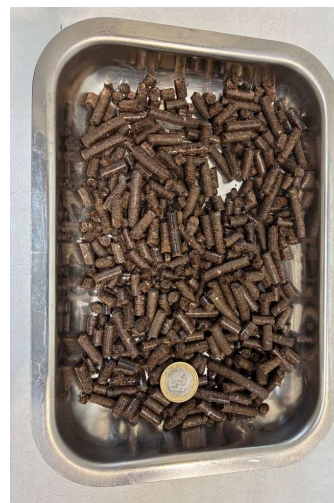


Agricultural residues

Olive pits



Buckwheat
pellets



Woody biomass and
forestry residues

Spruce tree tops
and branches



Algae

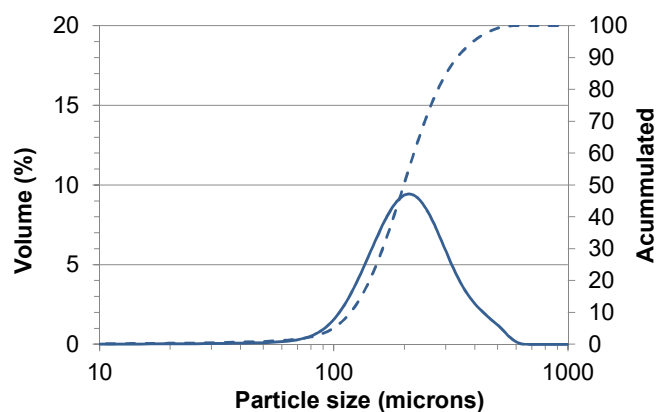
Microalgae



Oxygen carrier : Ilmenite



Fresh ilmenite from Titania, Norway.
Calcination: 950 °C in air for 2 h
Circulated 6 h at 800 °C in air



Calcined ilmenite

Fe_2TiO_5	54.7 wt.%
Fe_2O_3	11.2 wt.%
TiO_2	28.6 wt.%
Inerts	5.5 wt.%

PROPERTIES

	Calcined ilmenite
Particle size (μm)	100-300
True density (kg/m^3)	4100
$R_{O,ilm}$ (%)	4.0
Porosity (%)	1.2
Crushing strength(N)	2.2
XRD (main species)	Fe_2TiO_5 , Fe_2O_3 , TiO_2

20 kW CLG CSIC

1 MW CLG TUD

HTW® TUD



Biogenic residues

Waste Wood Type B



Agricultural residues

Olive pits



Buckwheat pellets



Woody biomass and forestry residues

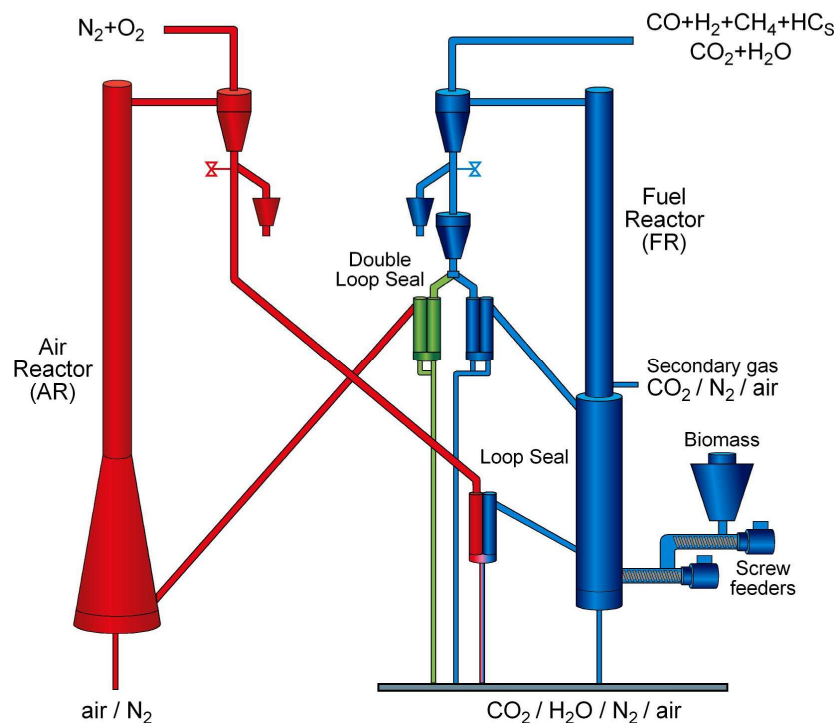
Spruce tree tops and branches



Algae

Microalgae





$$\lambda = \frac{\text{oxygen fed in AR (mol/h)}}{\text{oxygen for full combustion (mol/h)}}$$

FR temperature (T_{FR})

850 – 950 °C

Oxygen-to-fuel ratio (λ)

0.19-0.50

Steam-to-CO₂ ratio (S/CO_2)

25/75, 50/50, 75/25, 100/0

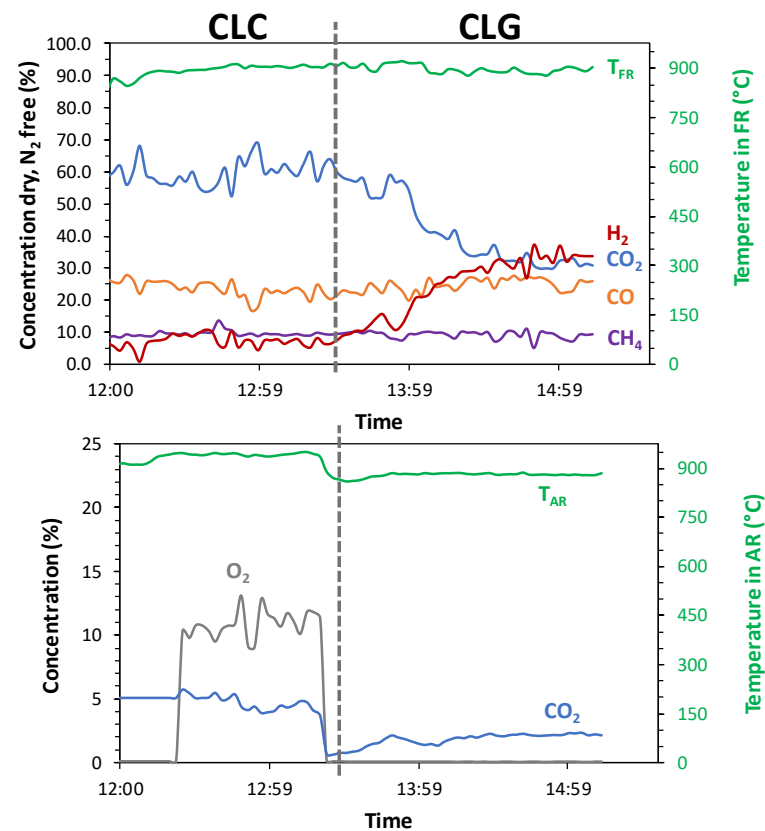
More than 100 h of steady-state operation were accumulated

Small scale continuous CLG gasification tests



Operation in the 20 kW_{th} unit
(Waste Wood Type B)

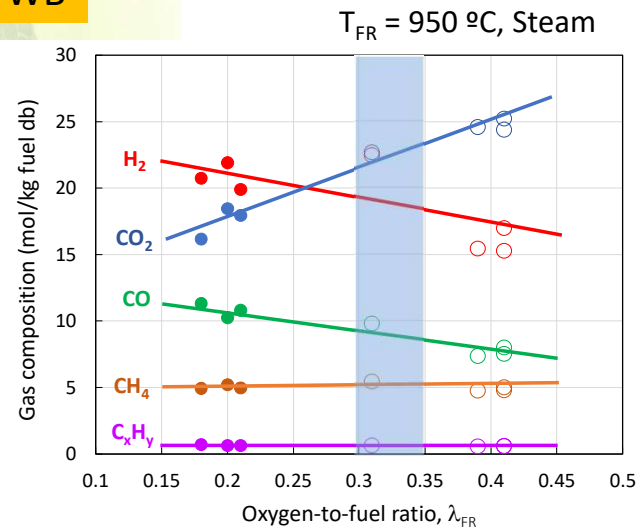
Change from CLC to CLG



Small scale continuous CLG gasification tests

Auothermal conditions

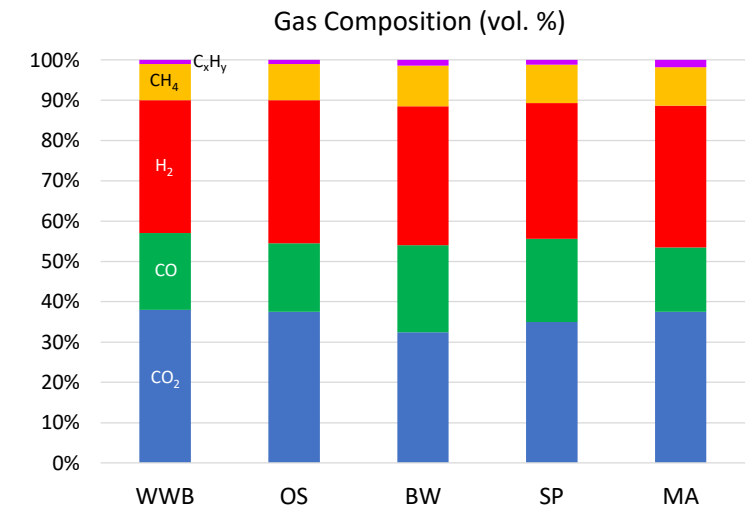
WWB



The syngas produced depends more on λ than on the type of biogenic residue

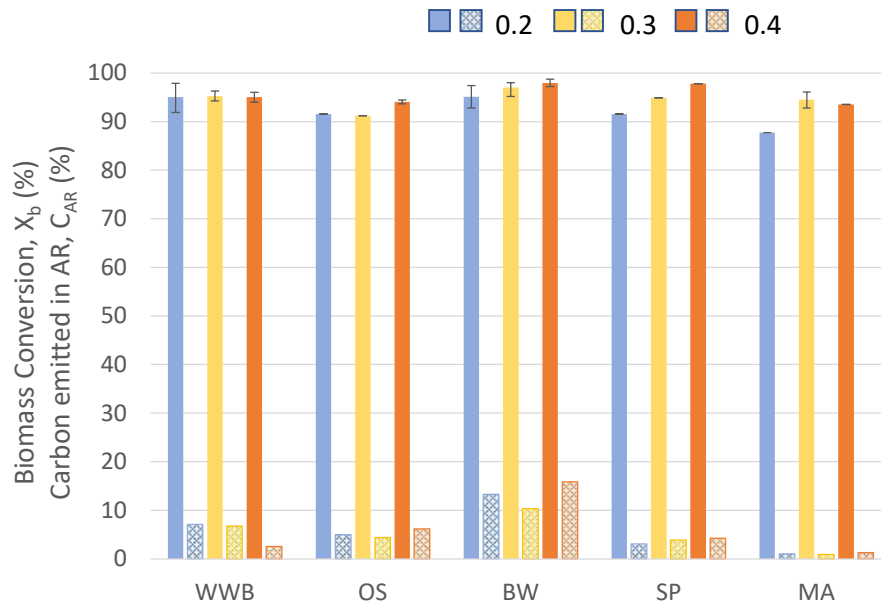
AUTOTHERMAL CONDITIONS

$\lambda = 0.30-0.35$

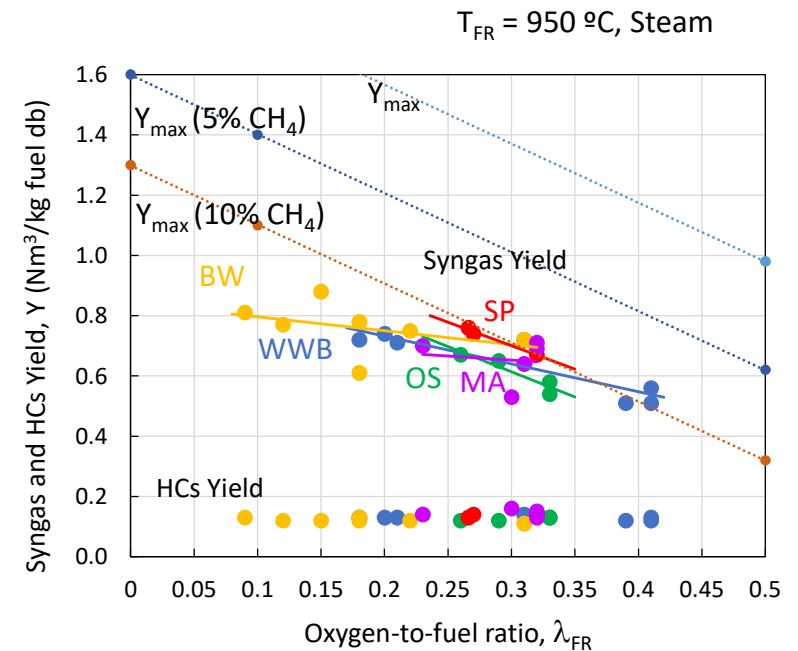


H_2	35 %
CO	19 %
CO_2	36 %
CH_4	9 %
C_2-C_3	1 %

Small scale continuous CLG gasification tests



- Biomass conversion higher than 90% for all fuels
- $C_{AR} < 5\%$ for spruce (SP) and olive stones (OS). Larger values for WWB and BW pellets due to their larger size



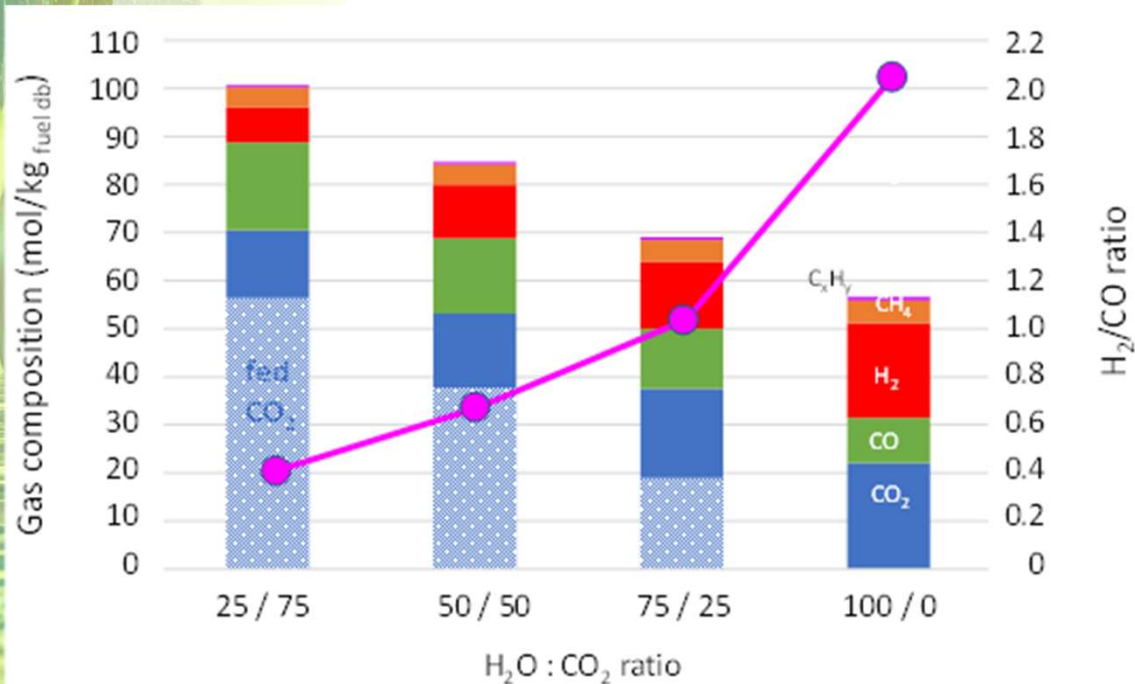
- Syngas yield (Y_g) decreased when increasing λ while hydrocarbon yield (Y_{HC}) was not affected
- No differences for the four biogenic residues

Small scale continuous CLG gasification tests

Effect of gasifying agent (H_2O vs CO_2)

WWB

$T_{FR} = 950\text{ }^{\circ}\text{C}$ and $\lambda \sim 0.3$



- As the S/CO_2 ratio decreased, the amount of CO_2 generated decreased, whereas the CO produced grew moderately
- Only a small fraction of the additional CO_2 supplied was converted into CO via the Boudouard reaction, while most of the fed CO_2 left the fuel reactor unreacted
- The H_2 yield decreased as the steam content was reduced. Thus, the H_2/CO ratio increased with increasing steam fraction in the gasifying agent.

The choice of gasifying agent depends on the intended application

Agglomeration issues

microalgae

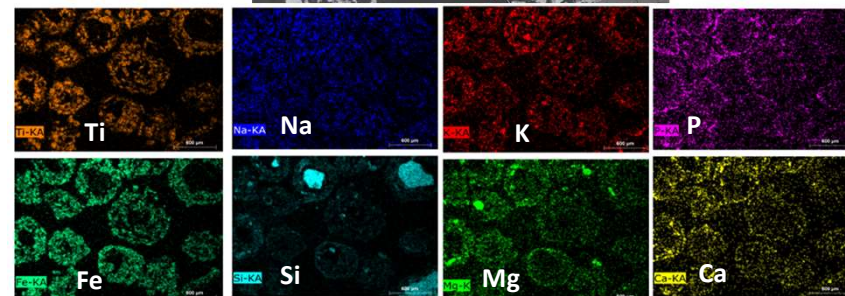
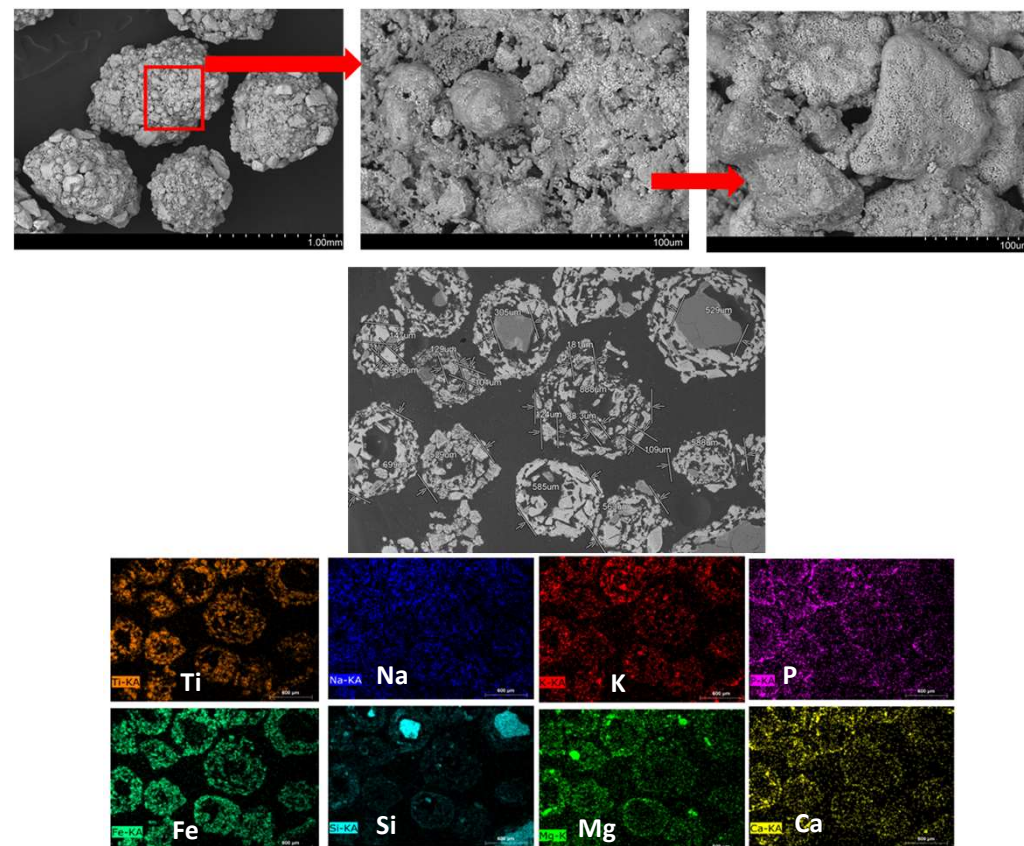
CLG unit after 21 hours of operation



Two possible agglomeration mechanisms were identified:

- 1) Ash components acting as binders between ilmenite particles, mainly K, P, and Mg.
- 2) The presence of Si, either by the presence of silica particles from contamination or by formed from the ashes of the biomass, tend to promote also agglomeration between the ilmenite particles.

Various elements present in the ash of the biogenic residues (Ca, Si, Mg, P, etc.) tend to deposit on the surface of ilmenite particles, while K can diffuse into the particle interior





THANK YOU

QUESTIONS/COMMENTS

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Feedstock analysis



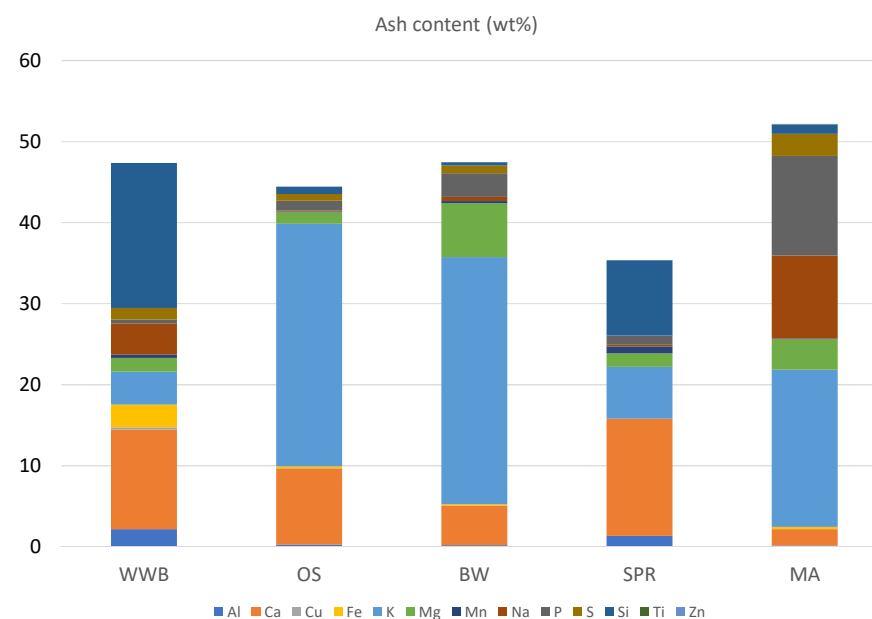
					
ANALYSIS (wt.%)	Waste Wood Type B	Olive pits	Buckwheat pellets	Spruce branches	Microalgae
Moisture	6.8	7.3	9.7	8.0	7.9
Ash	1.7	0.4	2.0	2.5	6.3
Volatiles	74.2	74.9	66.4	72.1	72.9
Fixed carbon	17.3	17.4	21.8	17.5	12.8
C	46.3	47.8	45.0	46.7	44.1
H	5.5	5.3	5.2	5.4	5.7
N	1.1	0.3	0.6	0.4	8.1
S	0	0	<0.1	<0.1	0.7
O(by diff.)	38.6	38.9	37.5	37.0	27.2
LHV (kJ/kg)	16664	17351	16375	16808	17635

Task 2.4. Small scale continuous CLG gasification tests

20 kW tests



Fuel	Units	WWB	Olive Stone	Buckwheat	Spruce	Micro-algae
Proximate analysis						
Moisture	wt%	6.8	7.3	8.8	8.0	7.9
Ashes	wt%	1.7	0.3	1.5	2.5	6.3
Volatiles	wt%	74.2	74.9	66.4	72.1	72.9
Fixed carbon (by dif.)	wt%	17.3	17.4	23.3	17.5	12.8
Ultimate analysis						
C	wt%	46.3	47.8	45.9	46.7	44.1
H *(without H moisture)	wt%	5.5	5.3	5.1	5.4	5.8
N	wt%	1.1	0.2	0.5	0.4	8.2
S	wt%	0.03	0.04	0.04	0.04	0.70
O (by dif)	wt%	38.6	39.0	38.2	37.0	27.1
Ash analysis (wt%)						
Al	wt%	2.17	0.28	0.17	1.32	0.13
Ca	wt%	12.3	9.38	4.93	14.49	2.01
Cu	wt%	0.24	0	0.00	0	0.01
Fe	wt%	2.82	0.23	0.16	0	0.27
K	wt%	4.06	29.97	30.5	6.38	19.44
Mg	wt%	1.71	1.44	6.64	1.67	3.75
Mn	wt%	0.40	0.05	0.25	0.82	0.05
Na	wt%	3.86	0.12	0.54	0.25	10.29
P	wt%	0.48	1.25	2.90	1.14	12.31
S	wt%	1.44	0.82	0.97	0	2.7
Si	wt%	17.89	0.89	0.38	9.29	1.15
Ti	wt%	0	0	0.01	0	0.05
Zn	wt%	0	0	0.06	0	0.04



Task 2.4. Small scale continuous CLG gasification tests

20 kW tests



Fuel	Units	WWB	Olive Stone	Buckwheat	Spruce	Micro-algae
Proximate analysis						
Moisture	wt%	6.8	7.3	8.8	8.0	7.9
Ashes	wt%	1.7	0.3	1.5	2.5	6.3
Volatiles	wt%	74.2	74.9	66.4	72.1	72.9
Fixed carbon (by dif.)	wt%	17.3	17.4	23.3	17.5	12.8
Ultimate analysis						
C	wt%	46.3	47.8	45.9	46.7	44.1
H *(without H moisture)	wt%	5.5	5.3	5.1	5.4	5.8
N	wt%	1.1	0.2	0.5	0.4	8.2
S	wt%	0.03	0.04	0.04	0.04	0.70
O (by dif)	wt%	38.6	39.0	38.2	37.0	27.1
Ash analysis (g/kg db)						
Al	g/kg d.b	0.40	0.01	0.03	0.36	0.09
Ca	g/kg d.b	2.24	0.33	0.80	3.98	1.38
Cu	g/kg d.b	0.04	0.00	0.00	0.00	0.01
Fe	g/kg d.b	0.51	0.01	0.03	0.00	0.19
K	g/kg d.b	0.74	1.07	4.95	1.75	13.34
Mg	g/kg d.b	0.31	0.05	1.08	0.46	2.57
Mn	g/kg d.b	0.07	0.00	0.04	0.23	0.03
Na	g/kg d.b	0.70	0.00	0.09	0.07	7.06
P	g/kg d.b	0.09	0.04	0.47	0.31	8.45
S	g/kg d.b	0.26	0.03	0.16	0.00	1.85
Si	g/kg d.b	3.26	0.03	0.06	2.55	0.79
Ti	g/kg d.b	0.00	0.00	0.00	0.00	0.03
Zn	g/kg d.b	0.00	0.00	0.01	0.00	0.03

