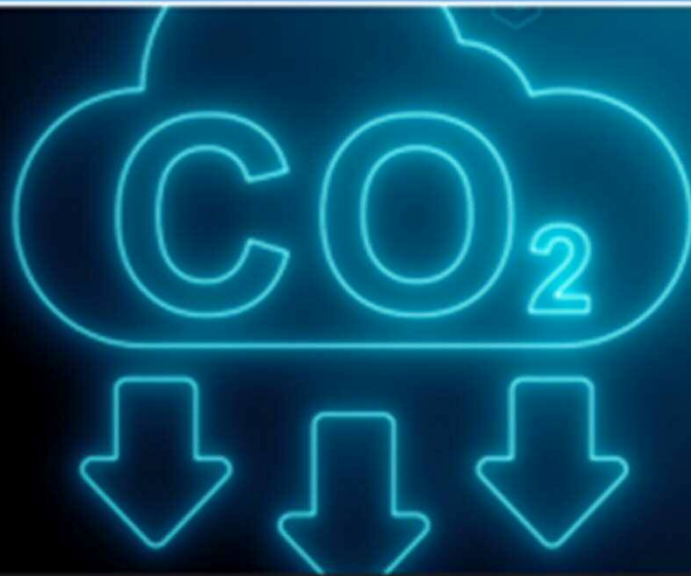


# GERG CCUS WORKING GROUP



# Advances, Applications and Opportunities of Chemical Looping Technologies for Carbon Capture

*María Teresa Izquierdo*

*Instituto de Carboquímica (ICB)*

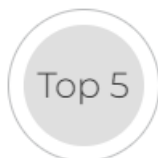
*Consejo Superior de Investigaciones Científicas (CSIC)/ Spanish National Research Council*



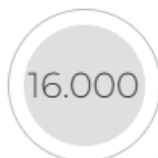
# CSIC: Spanish National Research Council



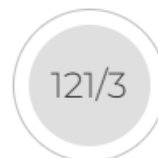
Public research institution at global scale



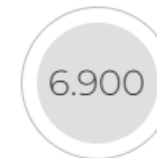
European institution by number of actions H2020v



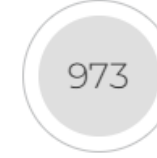
People



Institutes, centres, units



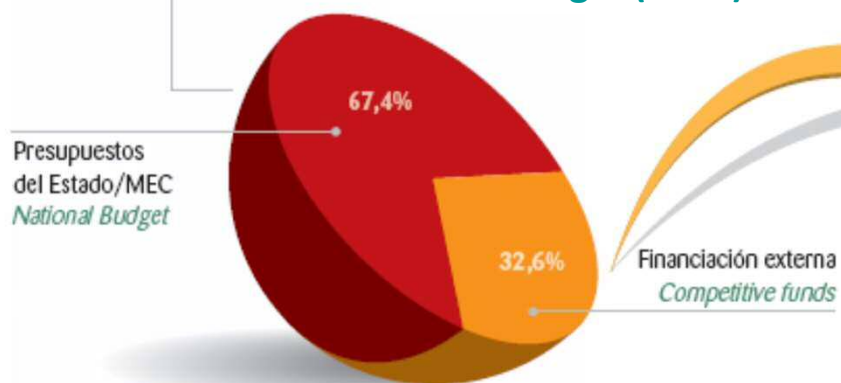
Ongoing projects



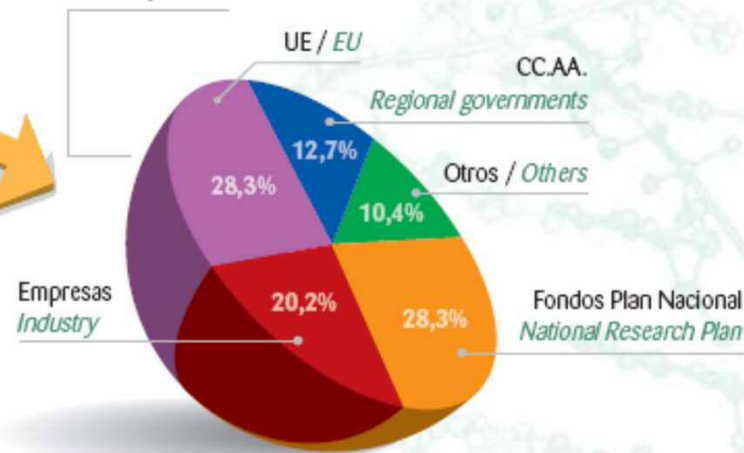
Protected technologies

## Origen de los recursos económicos *Origin of economic resources*

Total budget (2023) : 1394 M€



## Financiación externa *Competitive funds*



# CSIC: Spanish National Research Council



covers all fields of knowledge, from basic research to technological development



- Humanities and Social Sciences



- Biology and Biomedicine
- Natural Resources
- Agricultural Sciences
- Food Sciences and Technology



- Physical Sciences and Technologies
- **Chemical Sciences and Technologies**
- Material Sciences and Technologies



# Instituto de Carboquímica (ICB-CSIC)



## RESEARCH LINES:

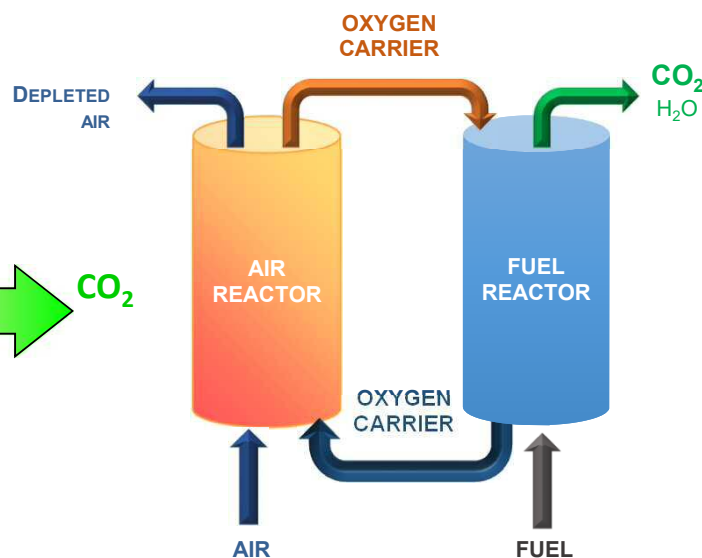
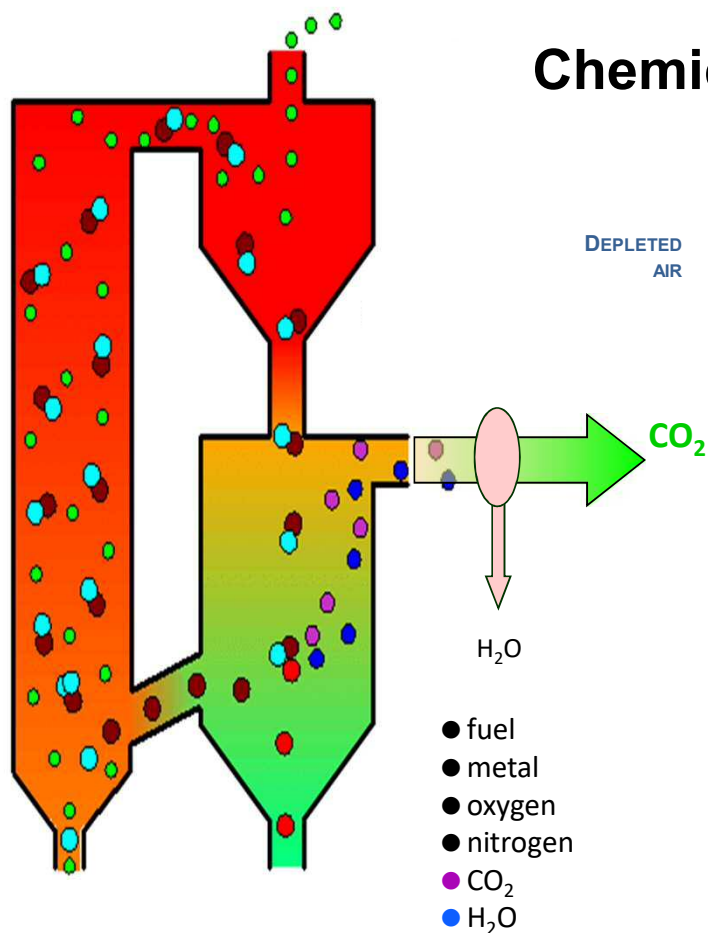
- Combustion & Gasification: Renewable fuels (biogas, biomass, waste) in fluidized bed reactors
- CO<sub>2</sub> capture
  - Chemical Looping Combustion (CLC)
  - Oxi-combustion in fluidized beds
- Syngas / H<sub>2</sub> production with CO<sub>2</sub> capture
  - Chemical Looping Reforming (CLR)
  - Sorption Enhanced CLR (SE-CLR)
  - Chemical Looping Gasification (CLG)



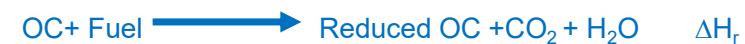
## STAFF:

Permanent position: 9  
PhD students: 7  
Technicians: 3

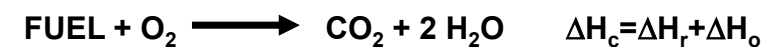
# Chemical Looping Combustion



## FUEL REACTOR:



## AIR REACTOR:

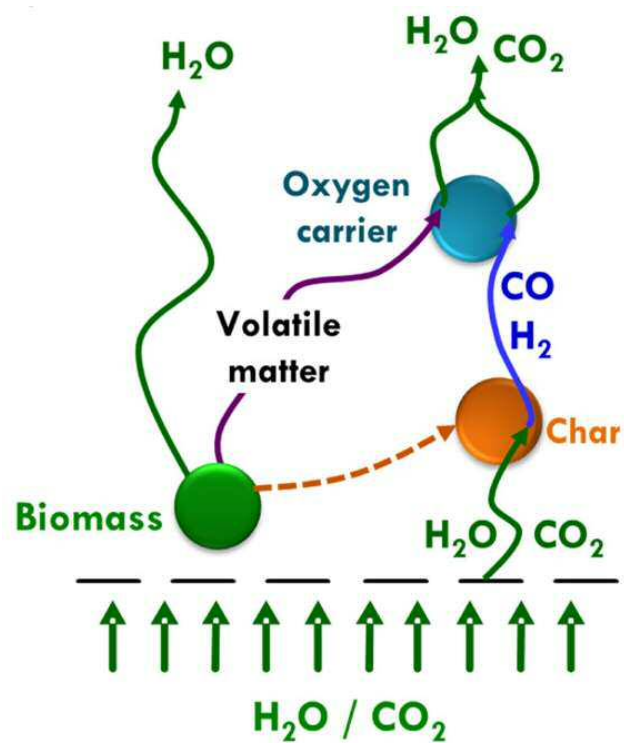


## KEY: The oxygen carrier

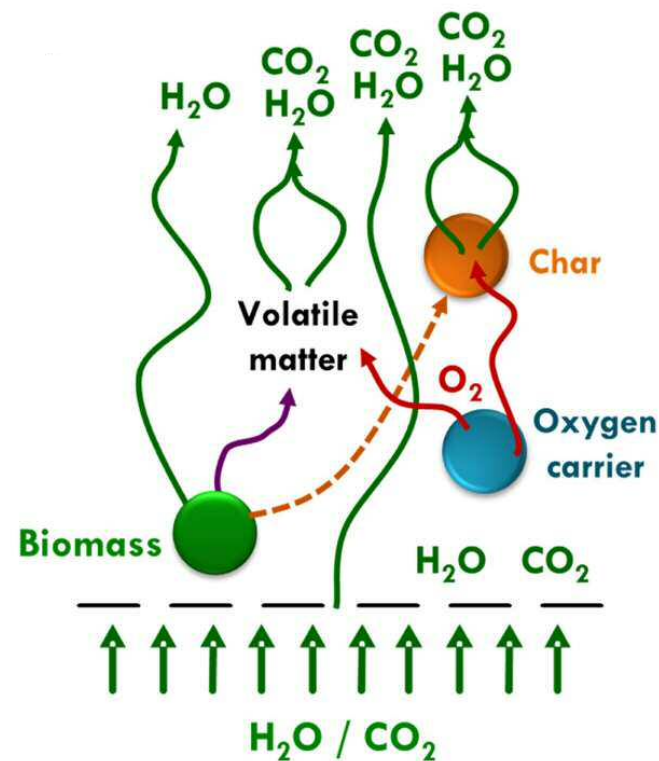
- High selectivity towards CO<sub>2</sub> y H<sub>2</sub>O
- Enough oxygen transport capacity
- Chemical and mechanical stability along cycles
- Adequate particle size for fluidization
- Environmental friendly
- Low cost

# Chemical Looping Combustion

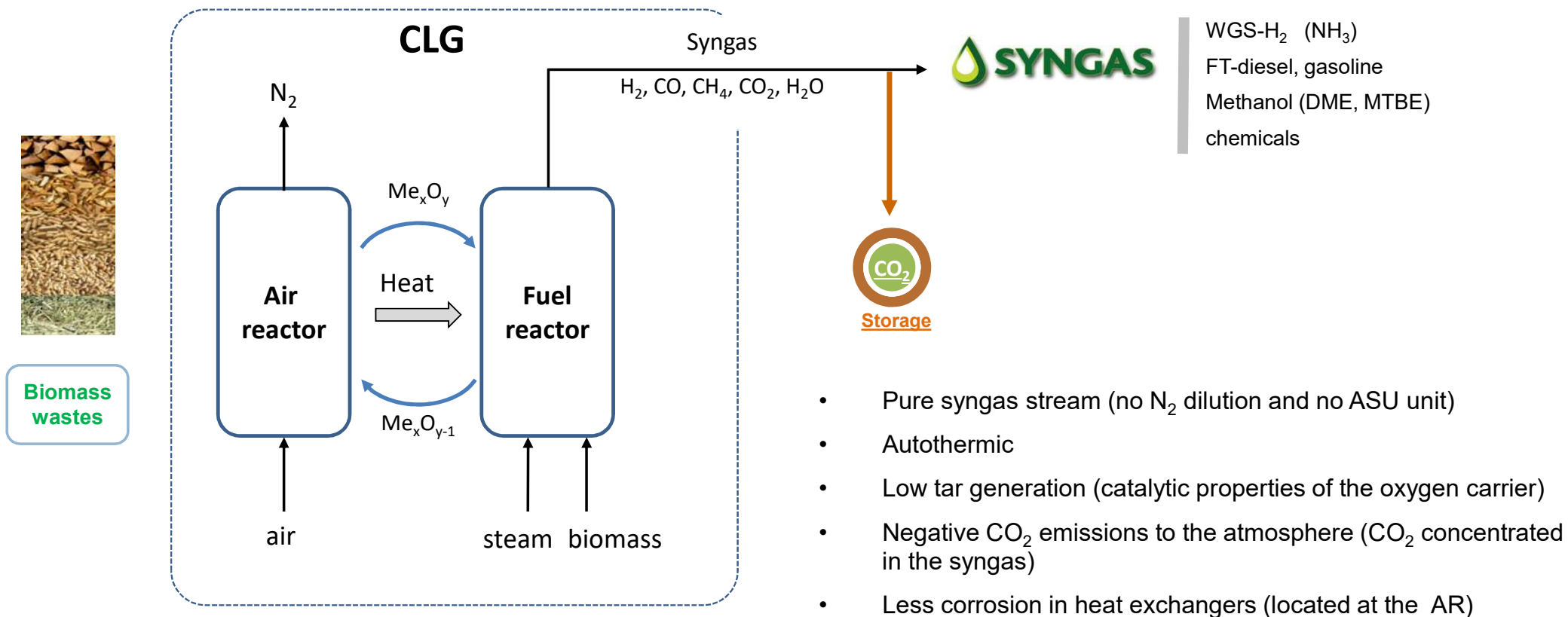
*in situ* gasification CLC (iG-CLC)



chemical looping with oxygen uncoupling (CLOU)

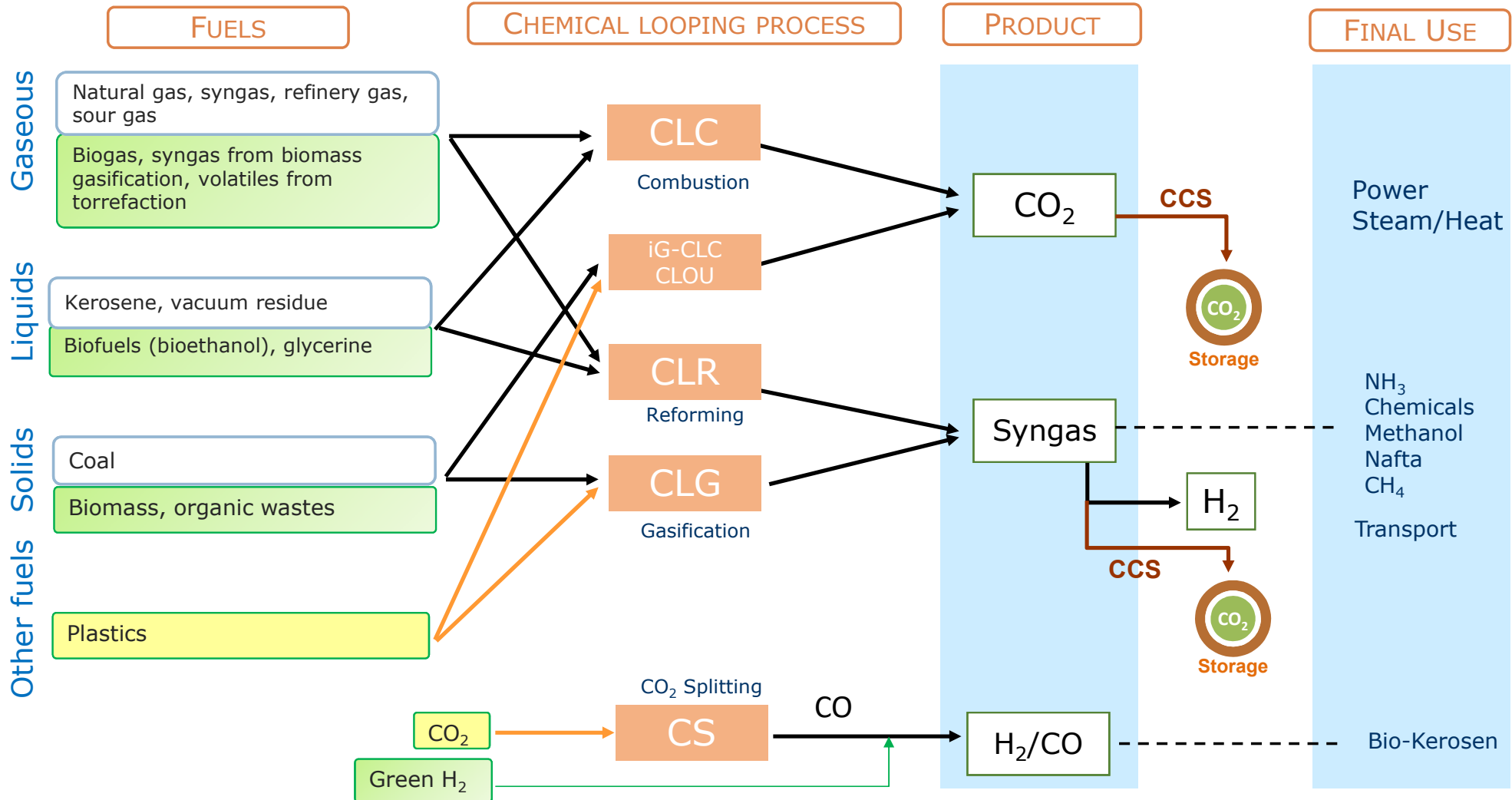


# Chemical Looping Gasification

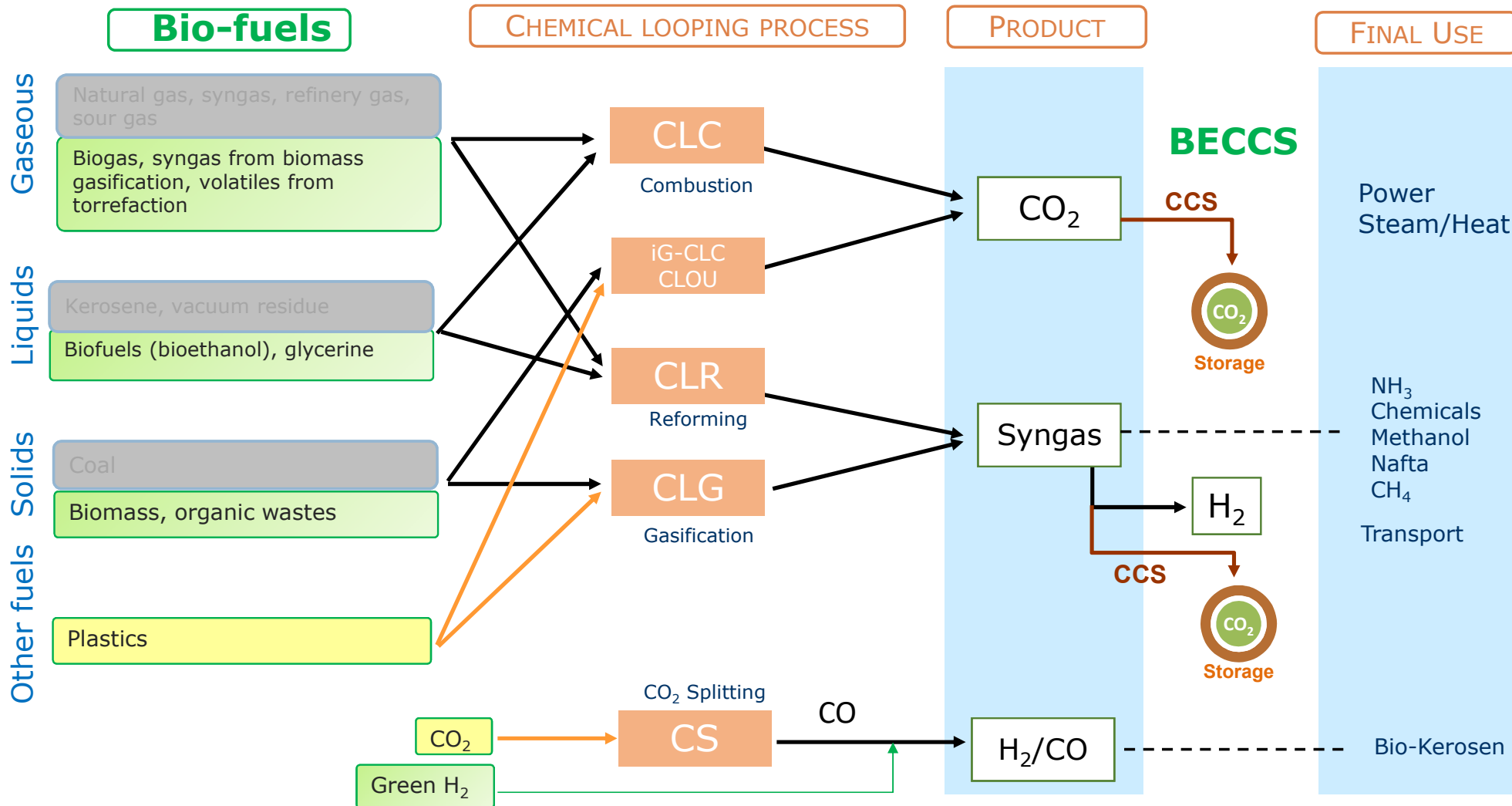


- Pure syngas stream (no  $N_2$  dilution and no ASU unit)
- Autothermic
- Low tar generation (catalytic properties of the oxygen carrier)
- Negative  $CO_2$  emissions to the atmosphere ( $CO_2$  concentrated in the syngas)
- Less corrosion in heat exchangers (located at the AR)

# Chemical Looping Technologies



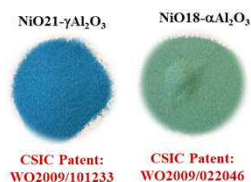
# BIO-FUEL Chemical Looping Technologies



# ICB-CSIC milestones in Chemical Looping



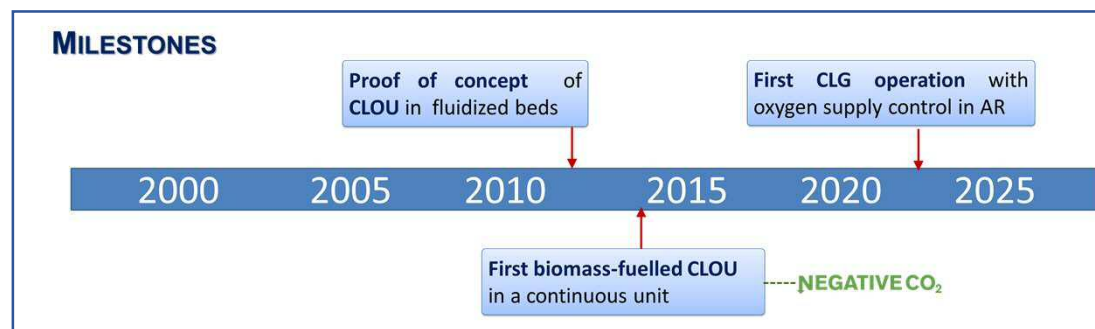
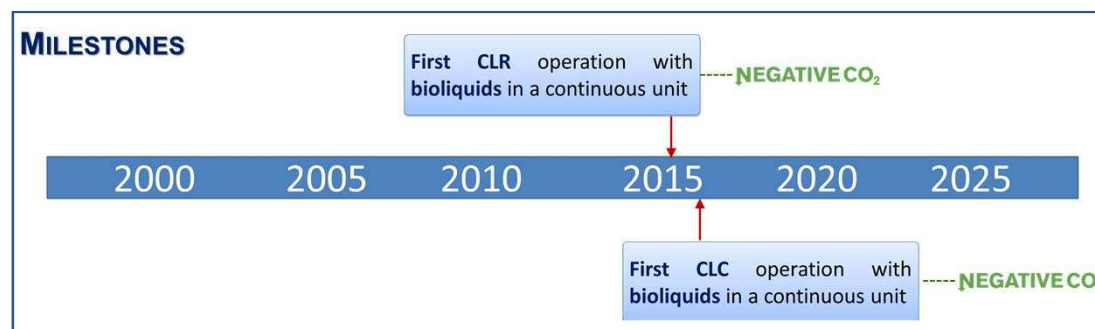
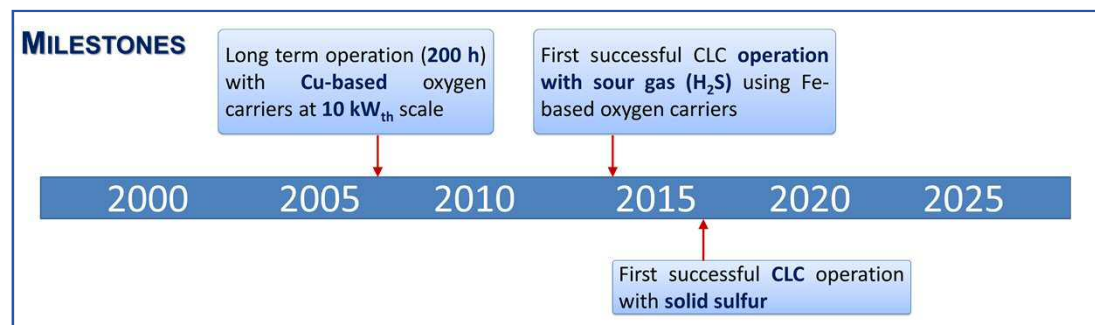
- **2000 h** continuous operation
- Special mention: use of fuels containing S compounds



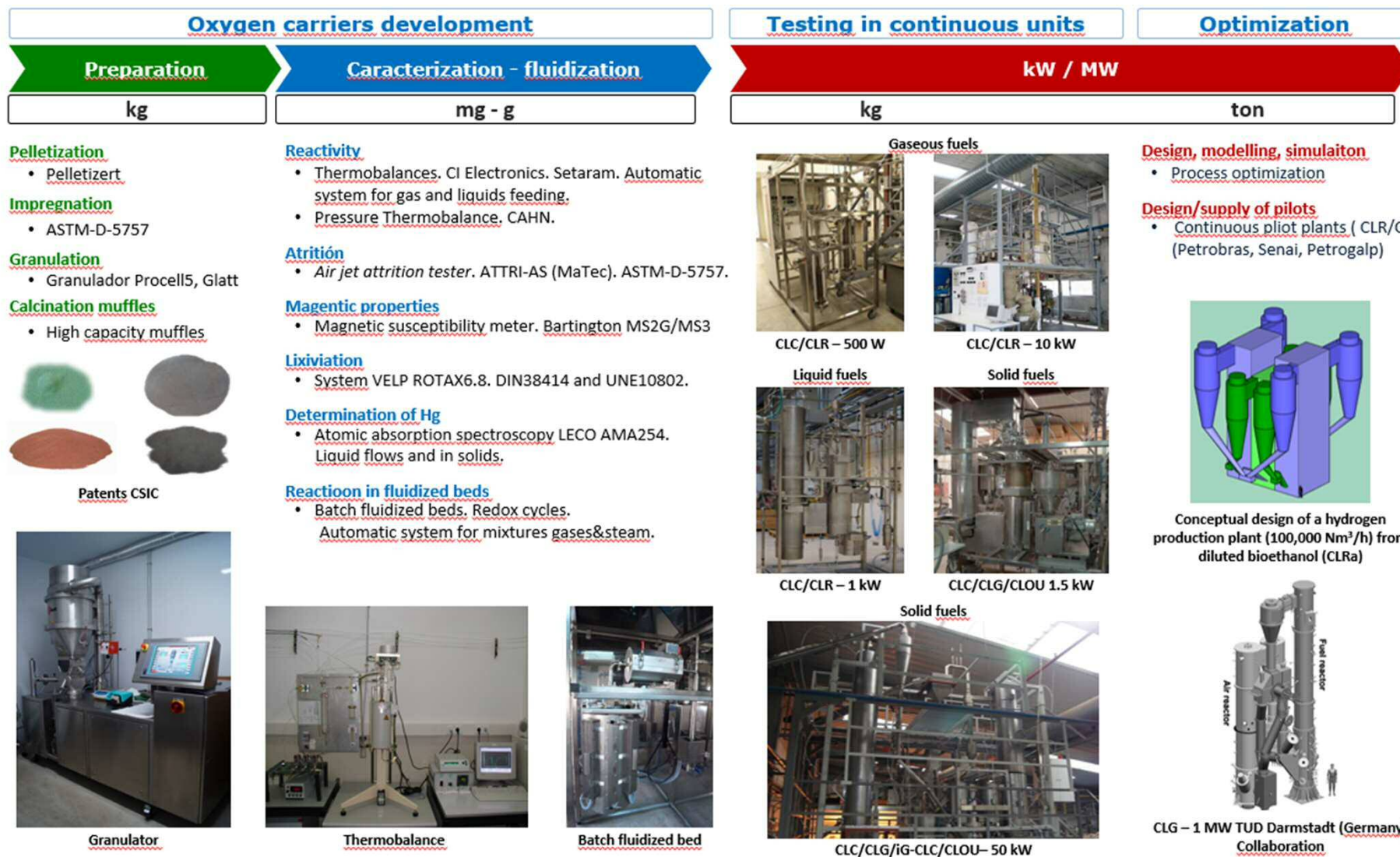
- **500 h** continuous operation



- **+2000 h** continuous operation  
Combustion and Gasification



# ICB-CSIC facilities for Chemical Looping development

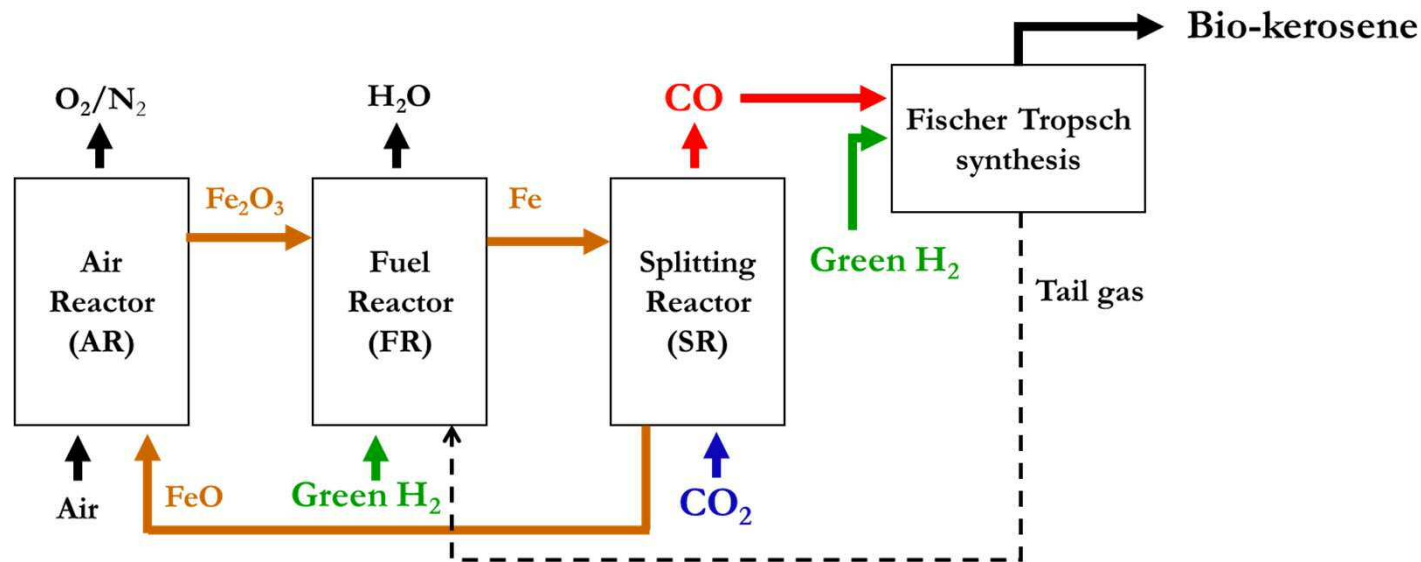
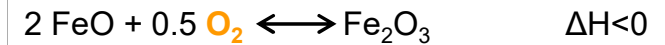
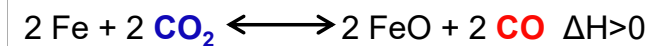
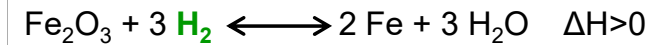


# ICB-CSIC main Chemical Looping on-going national projects

## New chemical looping process to obtain pure CO from CO<sub>2</sub> and green H<sub>2</sub> as a route for aviation biofuel production (CO<sub>2</sub>SPLIT)

The **CO<sub>2</sub>SPLIT process** uses **three reactors** instead of two commonly used in CLC.

- Fuel Reactor (FR), the OC is reduced with green H<sub>2</sub> that is oxidized to H<sub>2</sub>O.
- The reduced OC goes to the Splitting Reactor (SR) where it is partially oxidized by CO<sub>2</sub>, generating CO.
- Air Reactor (AR), the OC is fully oxidized, being again prepared for a new cycle



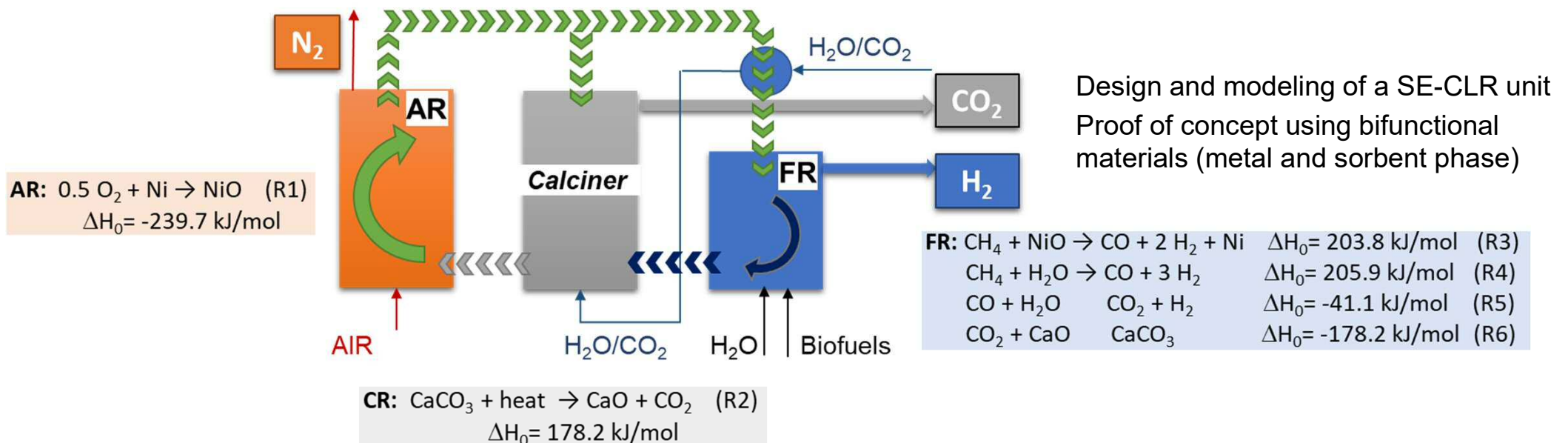
1 kWth CO<sub>2</sub>SPLIT unit

# ICB-CSIC main Chemical Looping on-going national projects

Hydrogen production with CO<sub>2</sub> capture by one-step and fuel-flexible sorption enhanced chemical looping reforming (HYSERLOOP).

The Sorption Enhanced Chemical Looping Reforming, SE-CLR, is a combination of the aCLR and Sorption Enhanced Reforming (SER) processes that allows obtaining separate streams of hydrogen and CO<sub>2</sub>.

- Elimination of the subsequent H<sub>2</sub> purification stages needed in the aCLR process
- Elimination of external energy supply for the regeneration of the sorbent needed in the SER process



# ICB-CSIC main Chemical Looping on-going EU projects



HORIZON-No. 101147904

June 2024 – June 2028

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

EU funding: €3,948,500.00



## Flexible Chemical Looping Combustion for combined heat and power production from biogenic residues with negative emission

**Main objective:** Develop and demonstrate a flexible combined heat and power (CHP) plant based upon the chemical looping combustion concept.

**Value proposition:** Compared to current CFB boilers, Bio-FlexCLC will reduce the risk of implementation by developing and demonstrating CLC-CFB concept, decreasing cost and energy penalty of CO<sub>2</sub> capture, utilizing the biogenic residues and wastes as a fuel, and developing the gas cleaning and CO<sub>2</sub> liquefaction.



HORIZON-No. 101147737

Sep 2024 – Aug 2028

<https://www.biomegafuelproject.eu/>

EU funding: € 3,797,326.25



## Bio Methanol Production via Chemical Looping Gasification Coupled with Membrane Reactors

**Main objective:** 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 by using renewable H<sub>2</sub>

**Value proposition:** Compared to the most common oxygen-driven gasification technologies, MeGaBiofuel will avoid expensive and energy-consuming ASU, which significantly reduces the total investment and the electricity consumption of a biomass-to-liquid (BtL) plant.



# ICB-CSIC main Chemical Looping on-going EU projects



Flexible chemical looping combustion for combined heat and power production from biogenic residues with negative emission

10 consortium partners from 7 EU countries

Partner	Role
RISE	Project coordination, process design and techno-economic 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>	<b>Chemical looping and fluidized bed combustion</b>
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.





# ICB-CSIC main Chemical Looping on-going EU projects



## Flexible chemical looping combustion for combined heat and power production from biogenic residues with negative emission

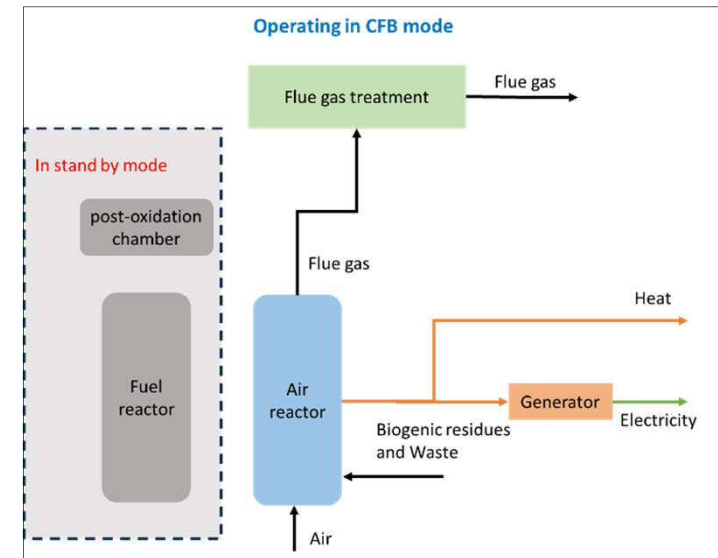
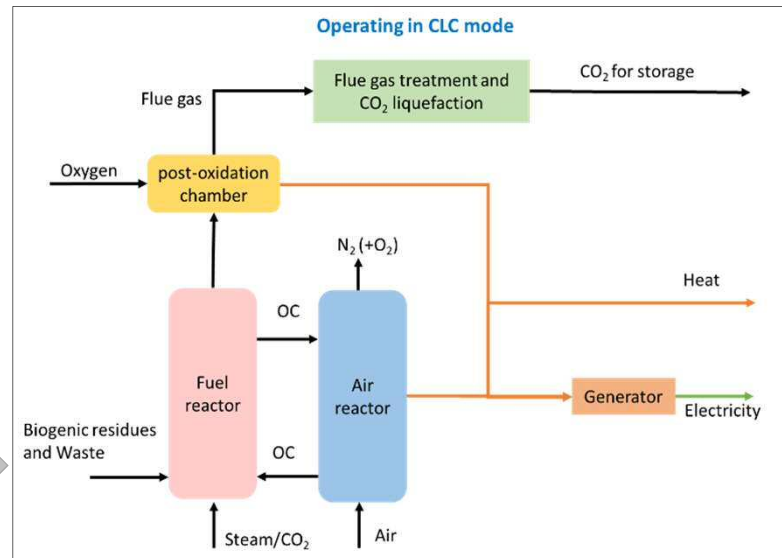
The concept is based on dual Circulating Fluidized Bed (CFB) reactors, which can operate in Chemical Looping Combustion (CLC) mode while both reactors are in use or switch to conventional CFB operation when only one reactor is in use.

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



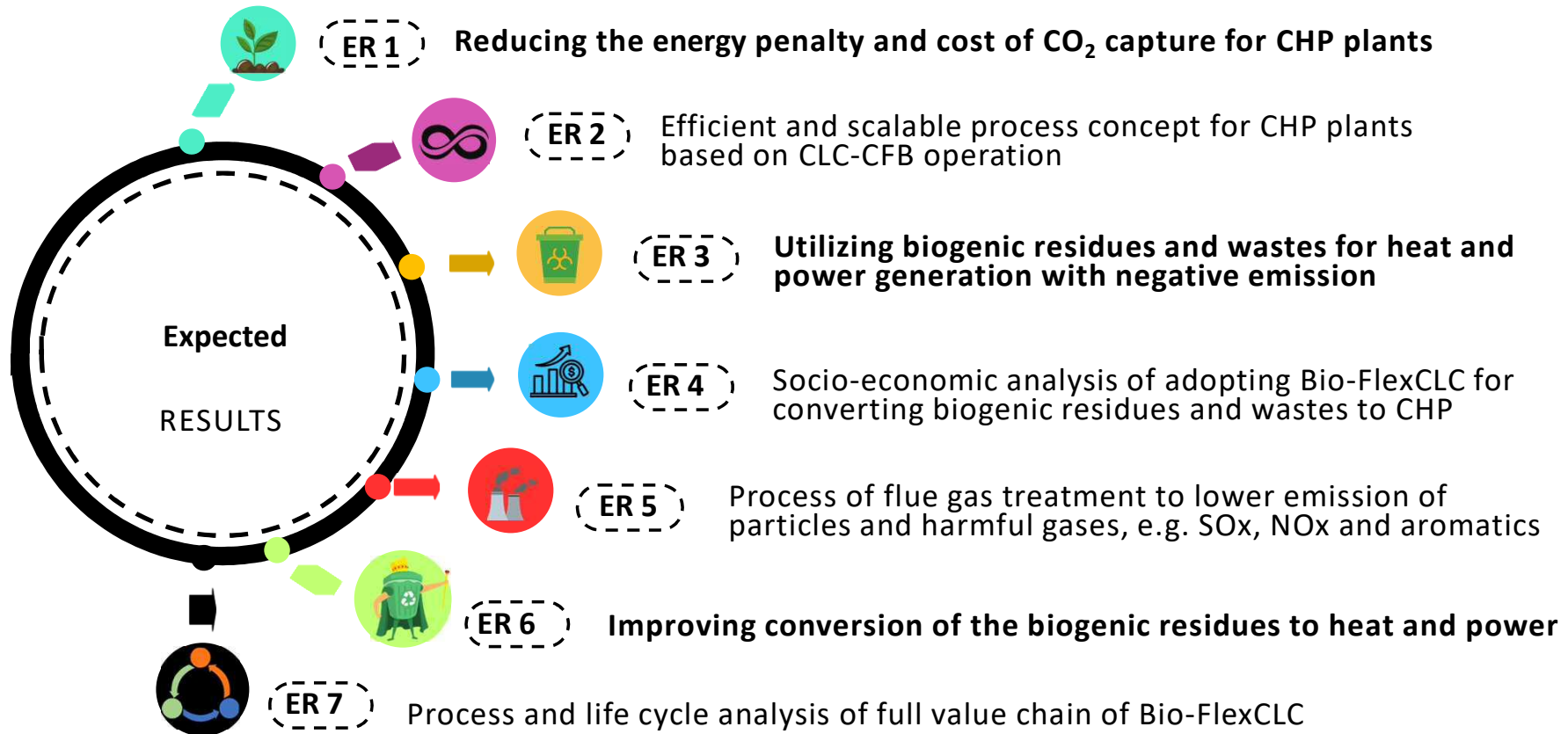
Biogenic waste as feedstock





# ICB-CSIC main Chemical Looping on-going EU projects

Flexible chemical looping combustion for combined heat and power production from biogenic residues with negative emission





# ICB-CSIC main Chemical Looping on-going EU projects



**Flexible chemical looping combustion for combined heat and power production from biogenic residues with negative emission**



To further understand CLC of biogenic residues



CLC operation mode with **four different biogenic residues**

## Preselection of biomass

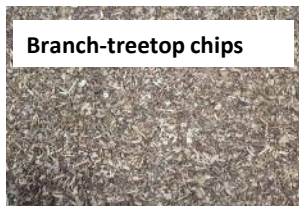
- Relevance for industries in Europe
- Relevance for energy companies of consortium
- Composition with respect to reactive ash species
- Availability at scales and sizes needed for testing



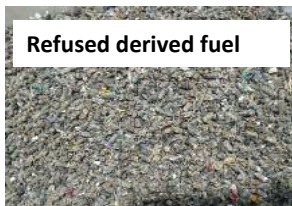
Pine wood pellets



Olive stones



Branch-treetop chips



Refused derived fuel



To improve the conversion of fuel by CLC experiments



Developing strategies for improving fuel conversion: packings and a post oxidation chamber

## Key Performance Indicators

- 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

## Evaluation in a TLR4 CLC unit at ICB-CSIC

Oxygen carrier: Ilmenite (natural ore)



After calcination:

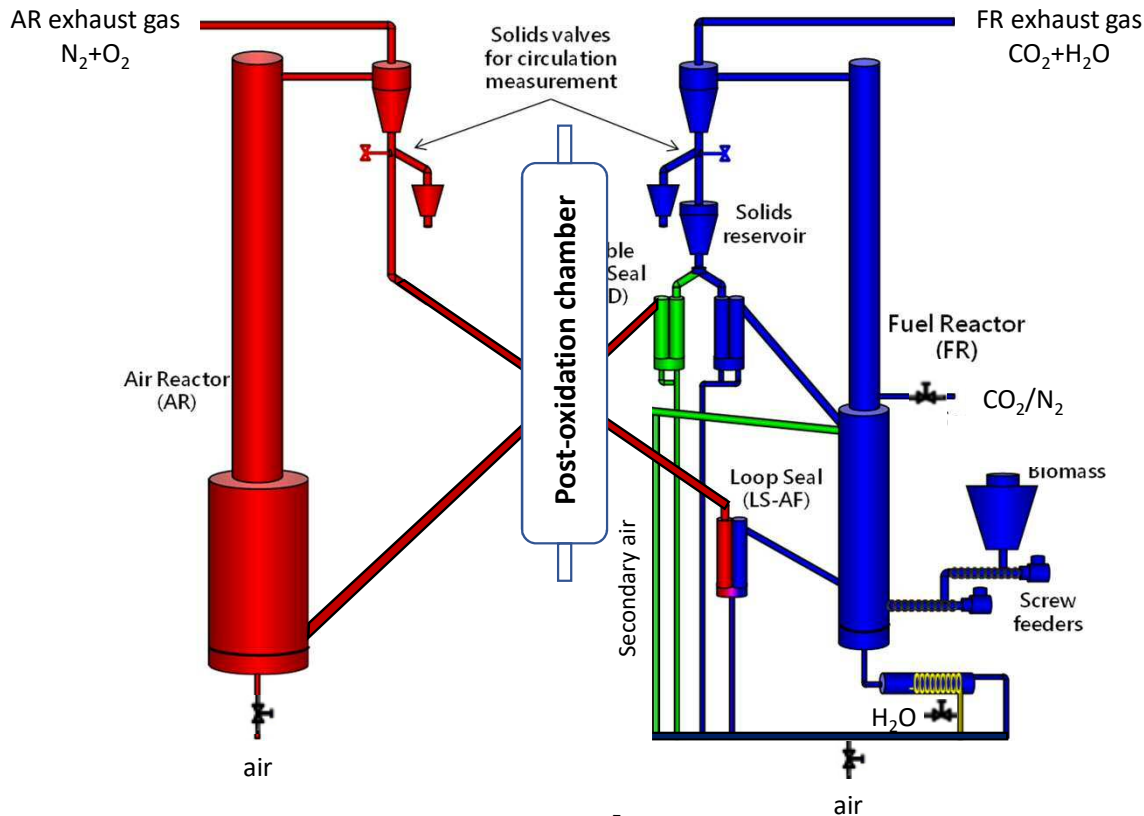
$\text{Fe}_2\text{TiO}_5$ ,  $\text{Fe}_2\text{O}_3$ ,  $\text{TiO}_2$ , inerts (about 5 wt%)

Oxygen transport capacity: 4 %



# ICB-CSIC main Chemical Looping on-going EU projects

Flexible chemical looping combustion for combined heat and power production from biogenic residues with negative emission



## CLC unit for solid fuels

- 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.

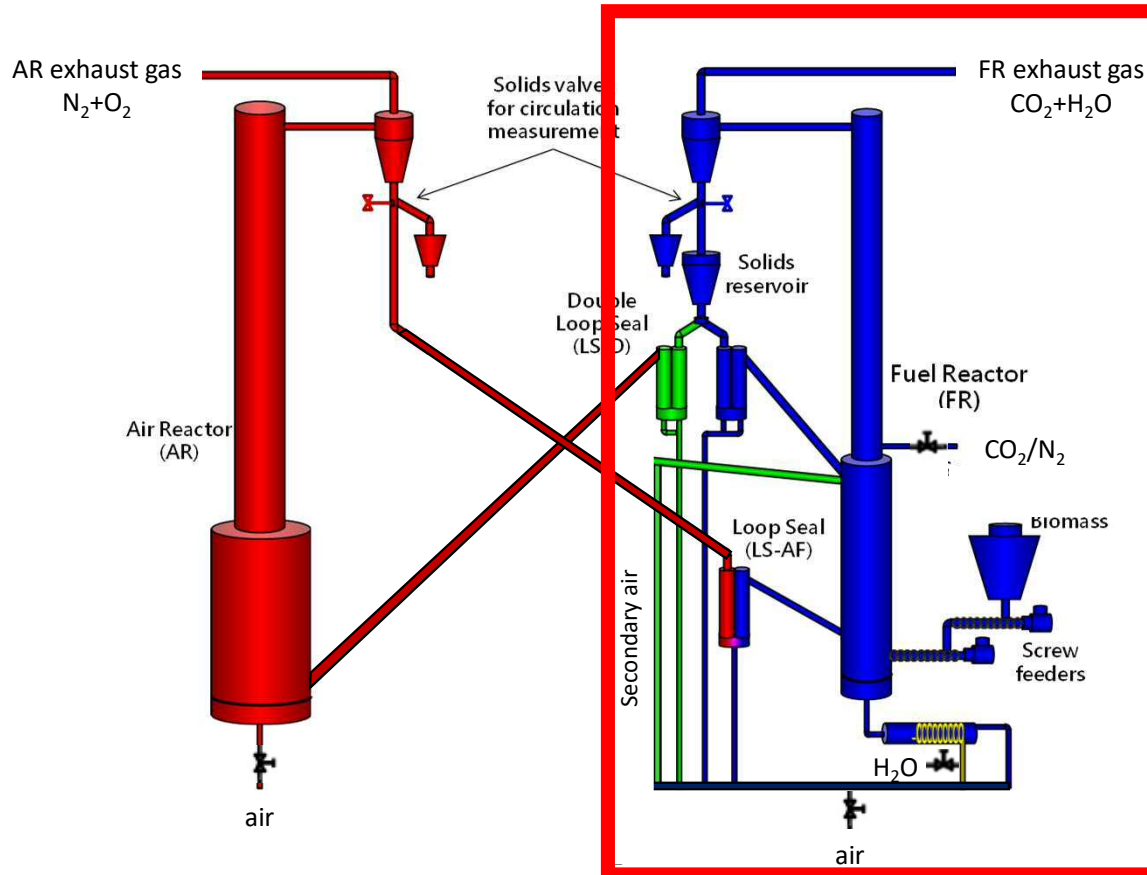
## Modifications for this project

- Post-oxidation chamber: design modelled by CETH (now under commissioning)

		FR	AR	CS
Height	(m)	4.00	4.80	0.70
Bottom D	(m)	0.10	0.30	0.15
Upper D	(m)	0.08	0.08	-
Solids inventory	(kg)	45		

# ICB-CSIC main Chemical Looping on-going EU projects

Flexible chemical looping combustion for combined heat and power production from biogenic residues with negative emission



20 kW<sub>th</sub> unit for iG-CLC

### First experimental campaign

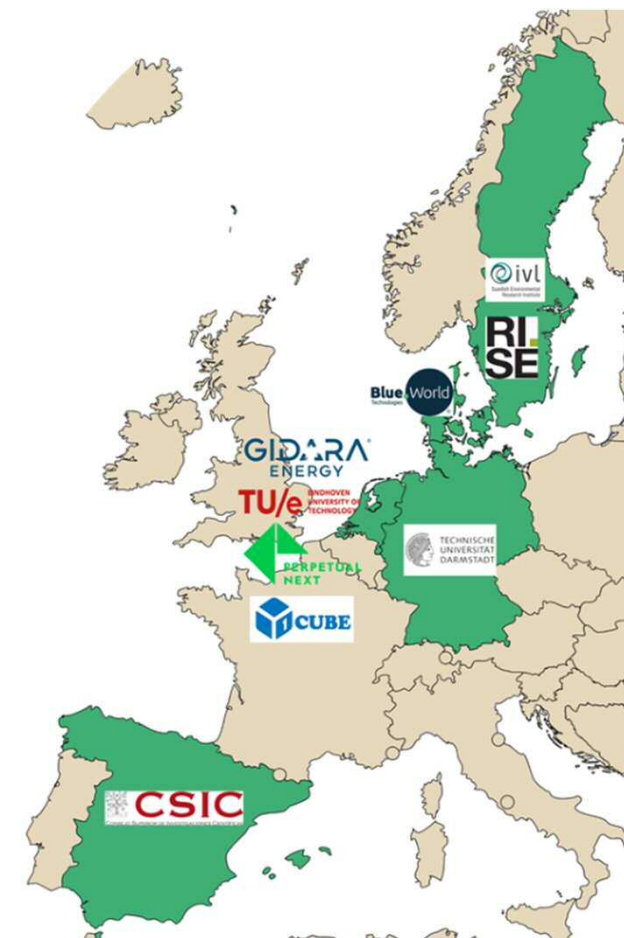
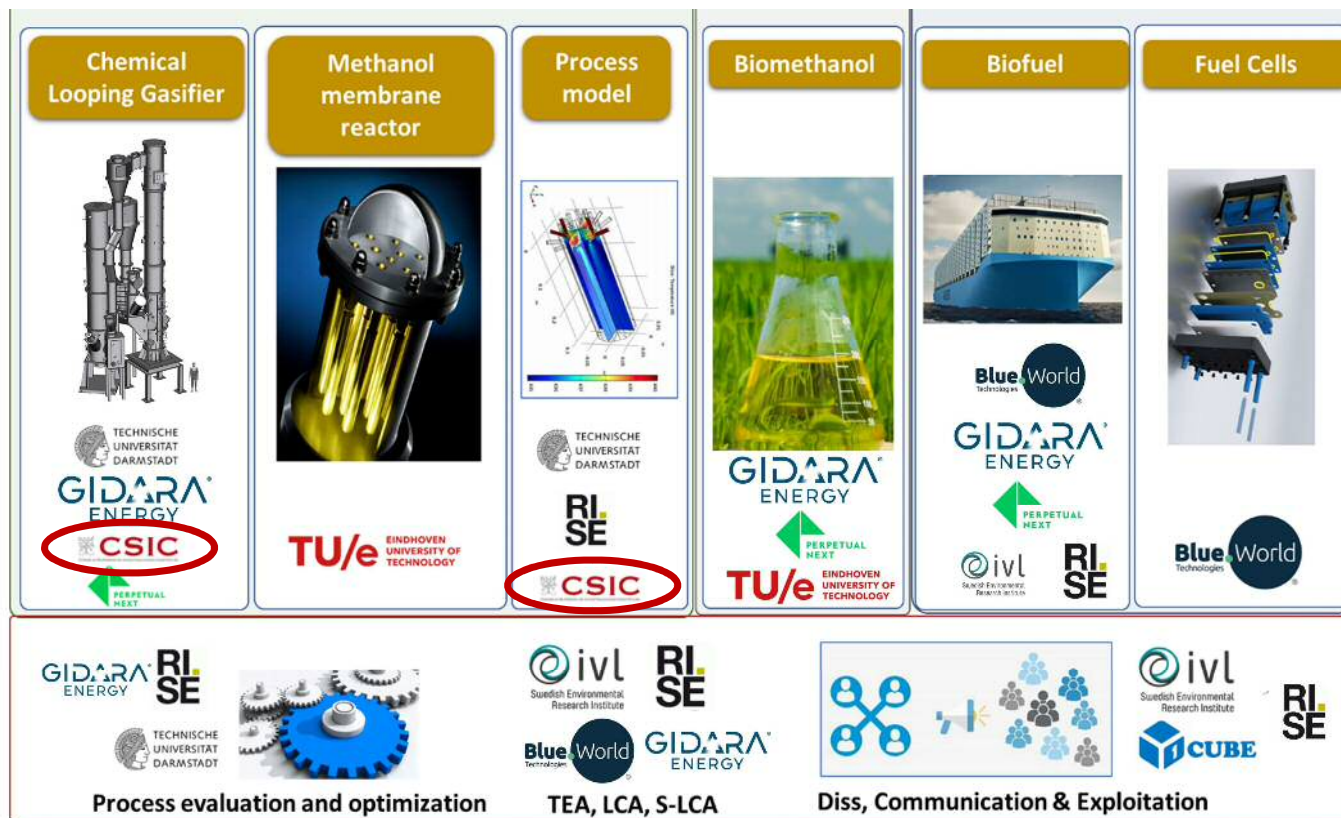
- Use only one reactor of CLC unit, the other in standby.
- Oxygen Carrier: ilmenite
- Four selected biomasses
- Evaluating performance at different temperatures, air excess and secondary/primary air ratio

Near 50 h of operation

# ICB-CSIC main Chemical Looping on-going EU projects

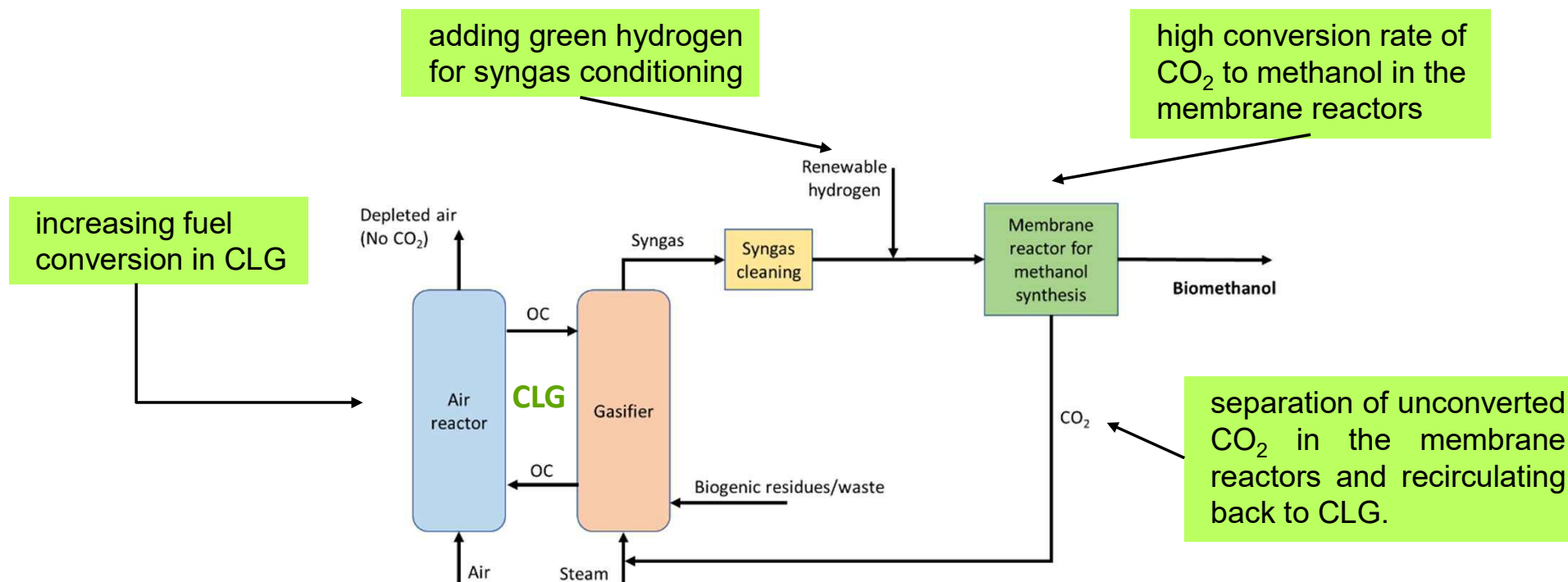
## Bio Methanol Production via Chemical Looping Gasification Coupled with Membrane Reactors

9 consortium partners (4 companies, 3 research institutes, 2 universities) from 5 EU countries

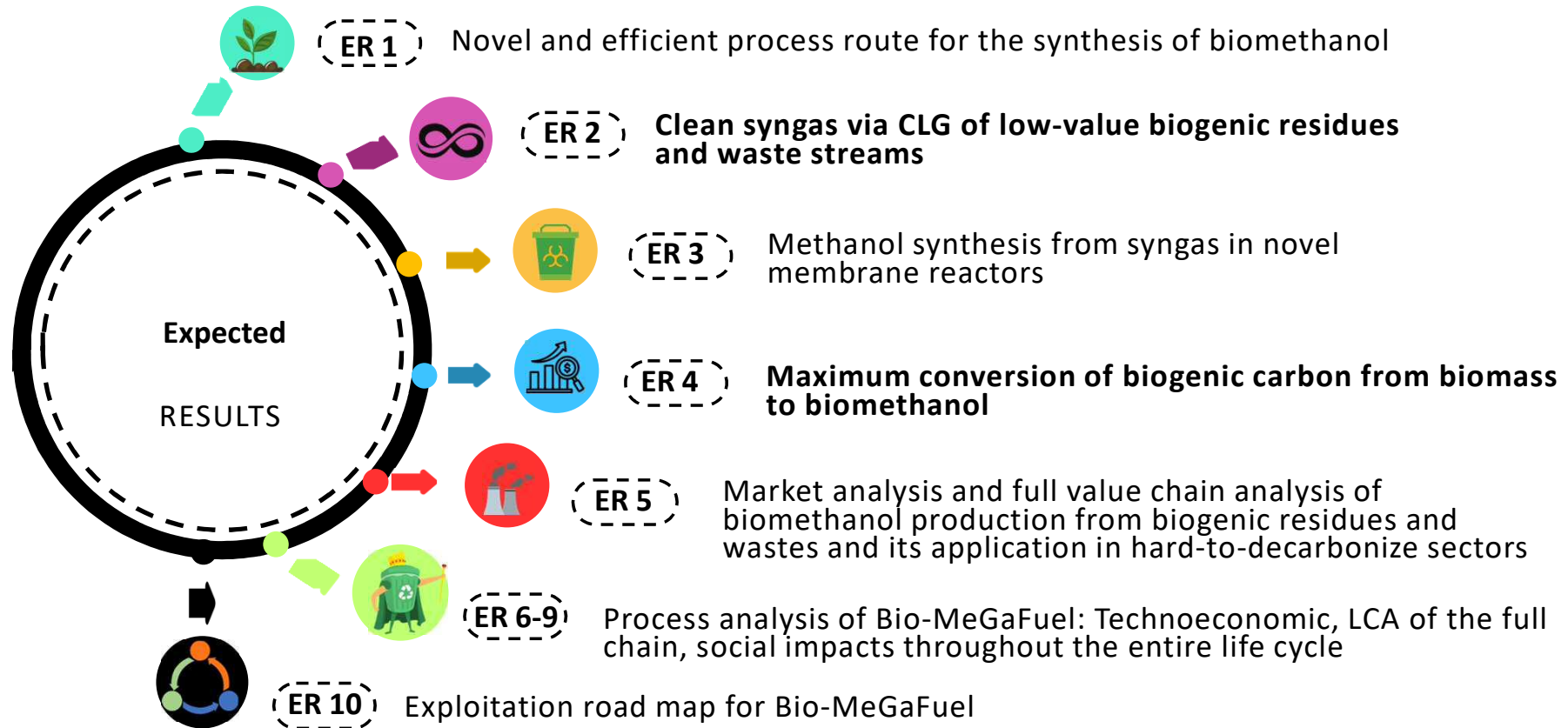


## Bio Methanol Production via Chemical Looping Gasification Coupled with Membrane Reactors

Aims to demonstrate a biomethanol production route at TRL-5 with lower production cost with potential net zero emission (significantly reducing GHG emissions): Maximizing the biomass and biogenic carbon utilization to biomethanol through...



## Bio Methanol Production via Chemical Looping Gasification Coupled with Membrane Reactors



# ICB-CSIC main Chemical Looping on-going EU projects






## Bio Methanol Production via Chemical Looping Gasification Coupled with Membrane Reactors

**To further understand CLG of biogenic residues**

CLG operation mode with **five different biogenic residues**

**Increasing fuel conversion in CLG**

Operating strategies of a chemical looping gasifier for high syngas yield by conversion of bio-residue

<b>Biogenic residues</b>	Waste Wood	
<b>Agricultural residues</b>	Olive pits	
	Buckwheat pellets	
<b>Woody biomass and forestry residues</b>	Spruce	
<b>Algae</b>	Microalgae	

### KEY PERFORMANCE INDICATORS

- *80% gasifier cold gas efficiency*
- *98% carbon conversion in gasifier*

**Evaluation in a TLR4 CLG unit at ICB-CSIC**  
**Oxygen carrier: Ilmenite (natural ore)**

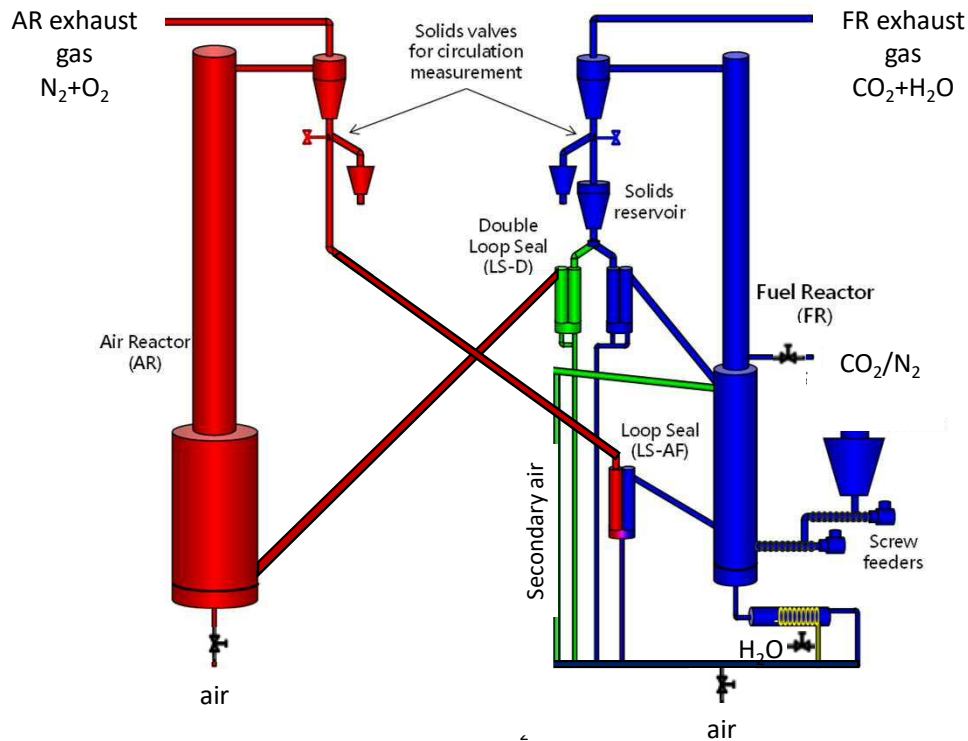


After calcination:  
 $\text{Fe}_2\text{TiO}_5$ ,  $\text{Fe}_2\text{O}_3$ ,  $\text{TiO}_2$ , inerts (about 5 wt%)  
 Oxygen transport capacity: 4 %

# ICB-CSIC main Chemical Looping on-going EU projects

## Bio Methanol Production via Chemical Looping Gasification Coupled with Membrane Reactors

three selected biomasses at 20 kWth CLG scale



- Control of the oxygen transported between reactors to control the degree of oxidation of the fuel

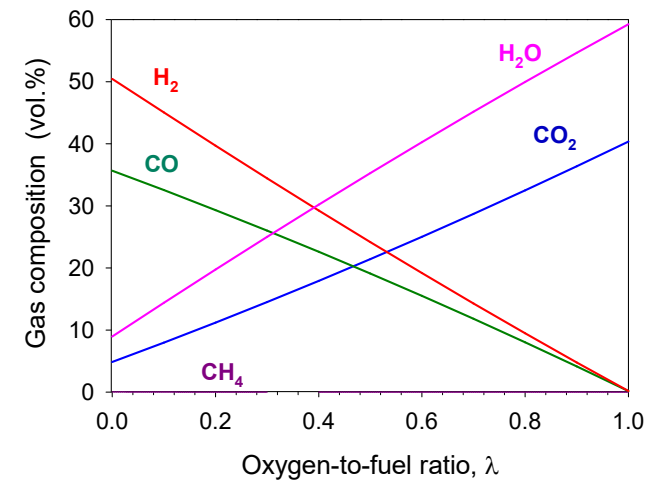
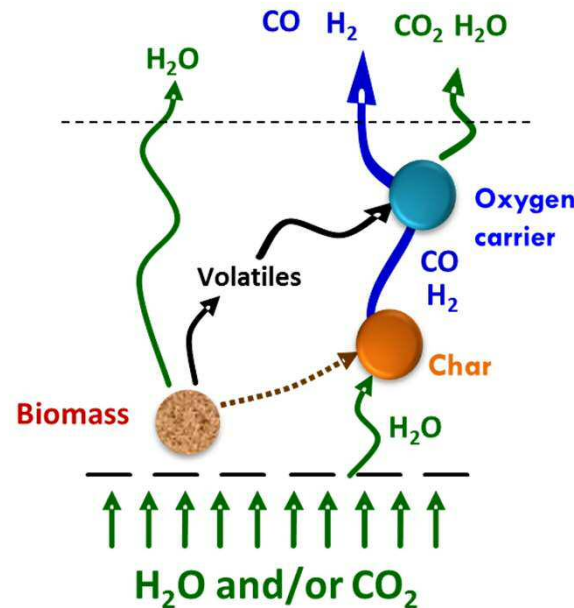
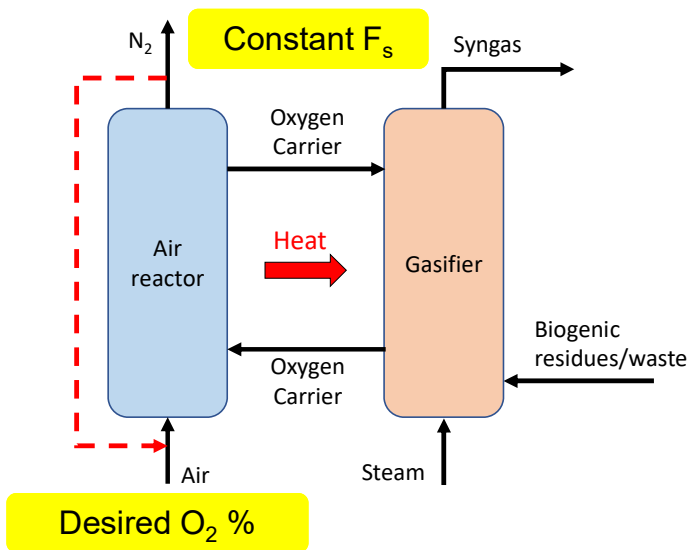
		FR	AR
Height	(m)	4.00	4.80
Bottom D	(m)	0.10	0.30
Upper D	(m)	0.08	0.08
Solids inventory	(kg)	45	

# ICB-CSIC main Chemical Looping on-going EU projects

## Bio Methanol Production via Chemical Looping Gasification Coupled with Membrane Reactors

### BY VARYING THE O<sub>2</sub> FED IN THE AIR REACTOR

- Allows operation at different  $\Delta T$  and solid circulation rate ( $F_s$ ) with any OC
- Allows production of pure N<sub>2</sub>
- Allows higher syngas yield at autothermal conditions





# Advances, Applications and Opportunities of Chemical Looping Technologies for Carbon Capture



Funded by  
the European Union

*"Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Climate, Infrastructure and Environment Executive Agency (CINEA). Neither the European Union nor CINEA can be held responsible for them."*