Chemical looping gasification for sustainable production of biofuels

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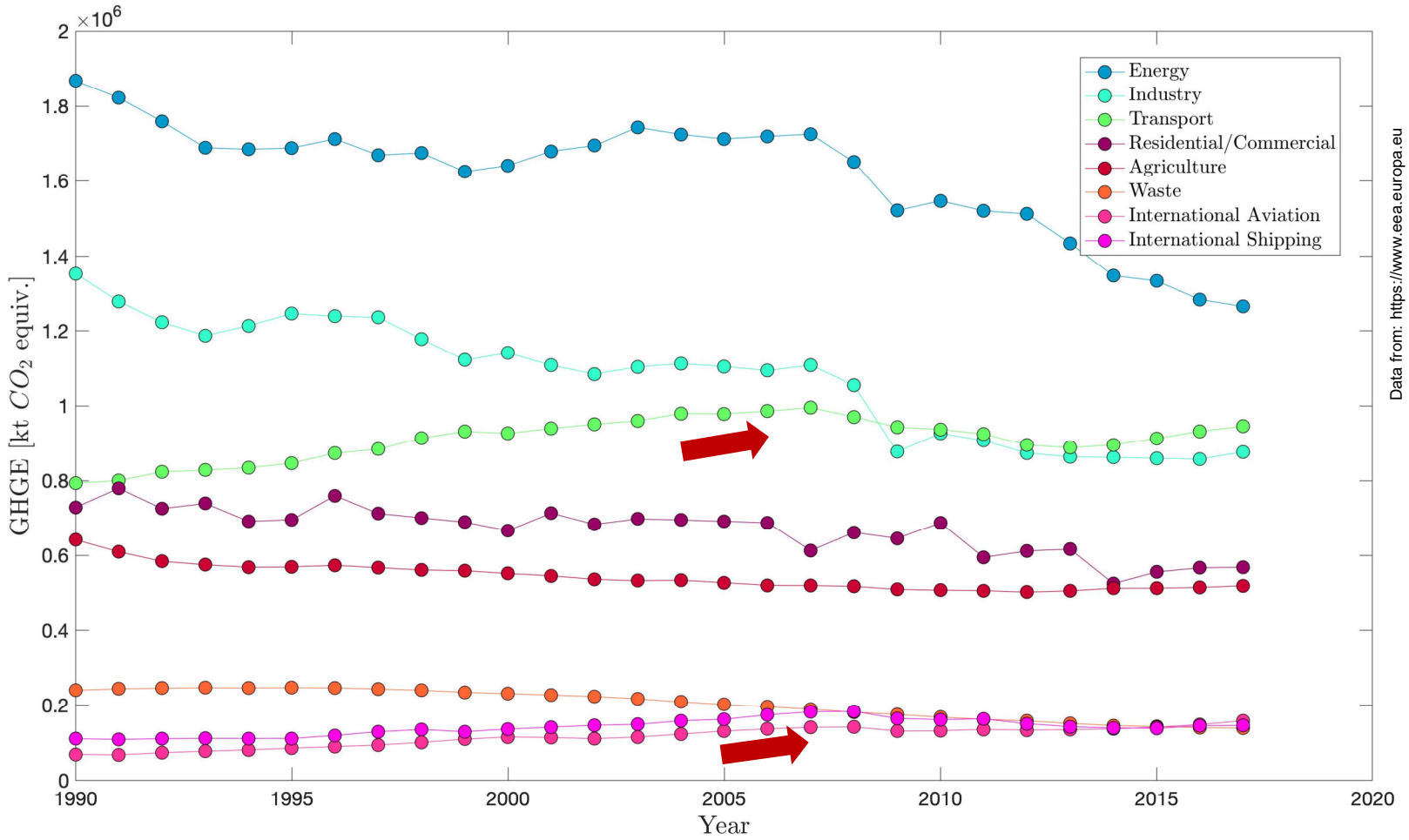
Workshop "**Innovations in Advanced Biofuels Production**"
at TNO in Petten (NL) on 18th May 2022

1 Motivation
GHGE in transport sector



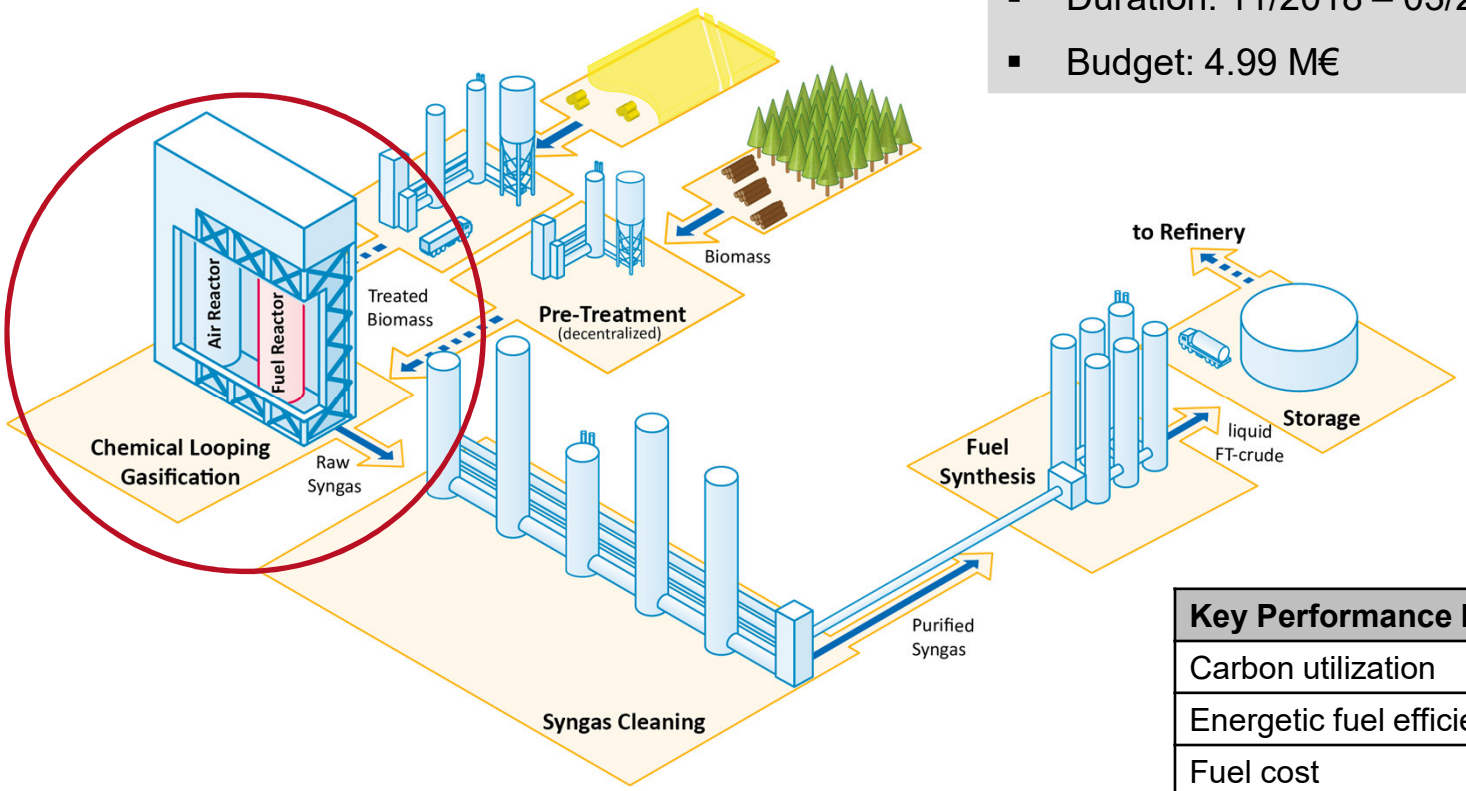
→ 25 % of European GHGE stem from the transport sector[1]

[1]Transport emissions - A European Strategy for low-emission mobility, https://ec.europa.eu/clima/policies/transport_en.

2 CLARA project
Biomass-to-fuel process chain

Novel biomass-to-biofuel process chain for the production of 2nd generation biofuels

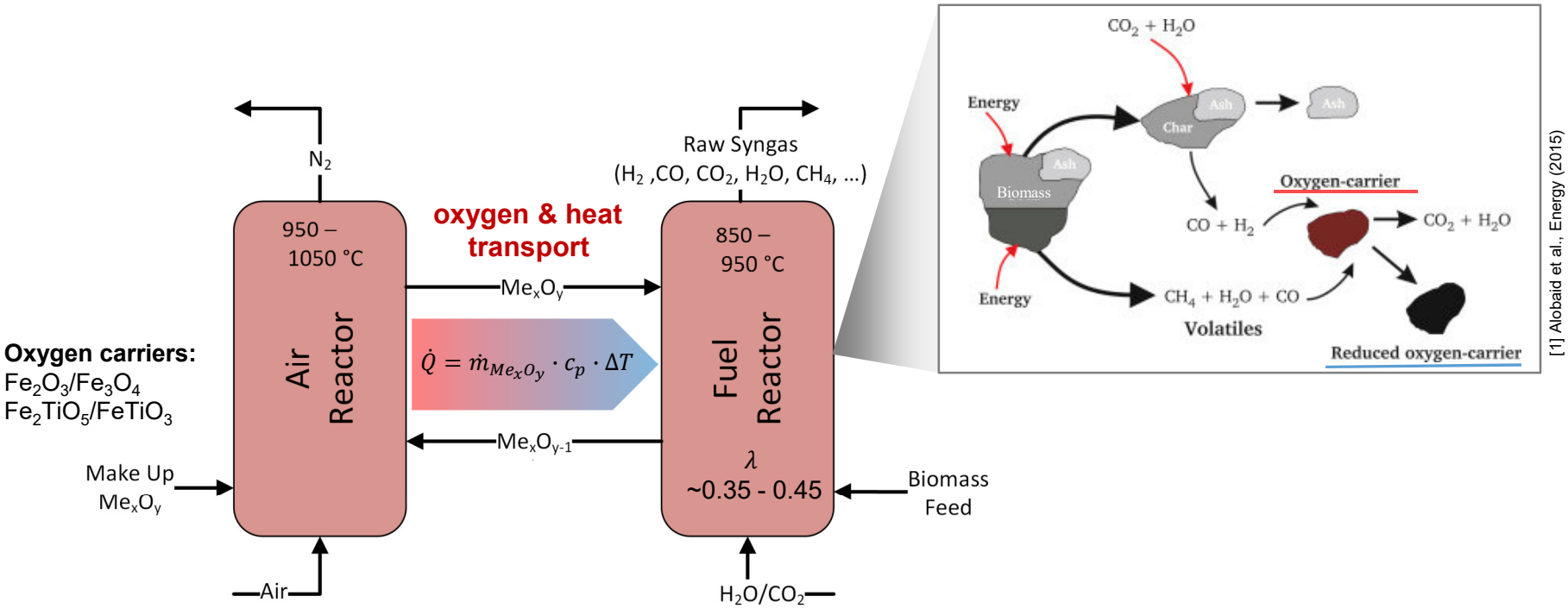
- Duration: 11/2018 – 03/2023
- Budget: 4.99 M€



→ scale-up to a thermal input of 200 MW_{th}

Key Performance Indicators	Target
Carbon utilization	> 33 %
Energetic fuel efficiency	> 55 %
Fuel cost	< 0.7 €/l
CO_2 emissions	< 0
Cold gas efficiency	> 82 %
Carbon conversion	> 98 %

3 Chemical Looping Gasification (CLG) **Concept**



[1] Alobaid et al., Energy (2015)

Advantages:

- No air separation required → cost-efficient
- CO_2 concentrated in syngas → facilitation of net negative CO_2 emissions
- Catalyst for tar cracking/ tar reforming on Me_xO_y surface

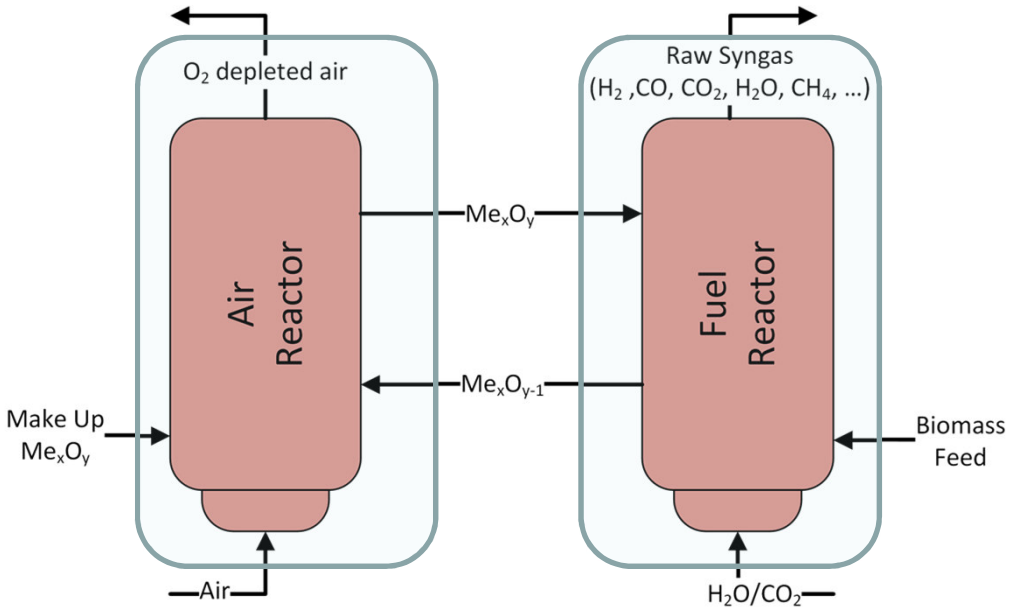
3 Chemical Looping Gasification (CLG) **Reactions**

- **Air Reactor** (T~ 1050 °C)
  - re-oxidation of oxygen carrier

$$Me_xO_{y-1} + 0.5\ O_2 \rightarrow Me_xO_y$$

  - Combustion of unconverted char

$$C + O_2 \rightarrow CO_2$$



- **Fuel Reactor** (T~ 950 °C)
  - Gasification of biomass

$$C + H_2O \rightarrow CO + H_2$$
$$C + CO_2 \rightarrow 2\ CO$$

  - Heterogeneous Me_xO_y – gas reactions

$$4\ Me_xO_y + CH_4 \rightarrow 4\ Me_xO_{y-1} + 2\ H_2O + CO_2$$
$$Me_xO_y + CH_4 \rightarrow Me_xO_{y-1} + 2\ H_2 + CO$$
$$Me_xO_y + CO \rightarrow Me_xO_{y-1} + CO_2$$
$$Me_xO_y + H_2 \rightarrow Me_xO_{y-1} + H_2O$$

  - Tar cracking

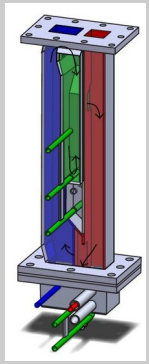
e.g. $C_8H_{18} \rightarrow C_3H_6 + C_5H_{12}$

  - Water gas shift reaction

$$CO + H_2O \leftrightarrow H_2 + CO_2$$

CLG- Technology Development
Overview

Chemical Looping Gasification



300 W

1.5 - 100 kW

1 MW

Lab Scale (300 W)
- Screening of oxygen carrier materials
- Determination of CLG reaction kinetics/mechanisms

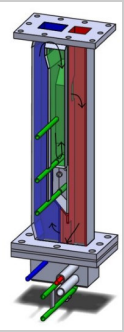
Small Pilots (1.5 – 100 kW)
- Proof of concept
- Parameter studies (e.g. temperature/steam-biomass ratio)
- Optimization

Pilot Scale (1.0 – 1.5 MW)
- Autothermal CLG operation
- Validation in industrial relevant environment
- Basis for up-scaling to industrial size

CLG - Technology Development
Lab Scale

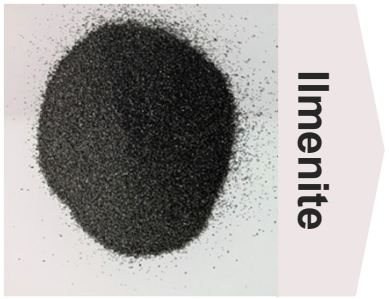
Select oxygen carrier for pilot testing

Investigation of manganese and iron ores



300 W

✓ Two well-suited low-cost oxygen carriers for CLG determined:



Ilmenite

- ✓ High char conversion, syngas yield & cold gas efficiency
- ✓ Decent gas quality (low tar content)
- ✓ Cheap, non-toxic & abundant
- ✓ Excellent mechanical & chemical stability

LD-Slag

✓ Ilmenite selected for pilot testing due to sourcing reasons and existing operational experience

Read more:

A. Hedayati, et al. *„Thermochemical conversion of biomass volatiles via chemical looping: Comparison of ilmenite and steel converter waste materials as oxygen carriers“*

A. Hedayati, et al., *“Experimental Evaluation of Manganese Ores for Chemical Looping Conversion of Synthetic Biomass Volatiles in a 300 W Reactor System”*

4 CLG - Technology Development
Small Pilots

1. **Gain operational experience & deeper process understanding**
2. **Determine operational strategy for large-scale implementation**

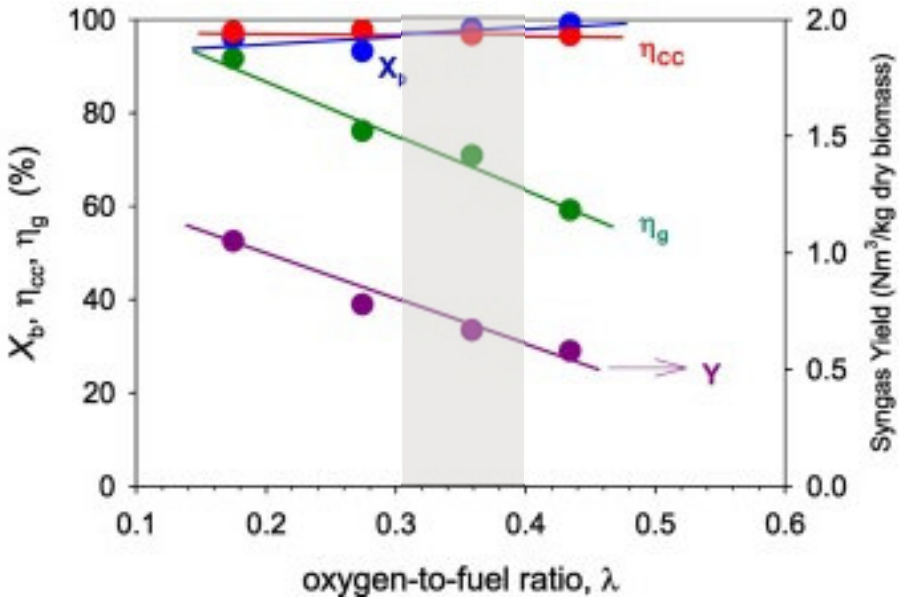
→ Investigation of CLG in three different small pilots

- 1.5 kW_{th} CLG unit (CSIC)
- 50 kW_{th} CLG unit (CSIC)
- 100 kW_{th} CLG unit (CTH)

1.5 - 100 kW

✓ Process control concept successfully tested

✓ Effect of most crucial operating variable evaluated



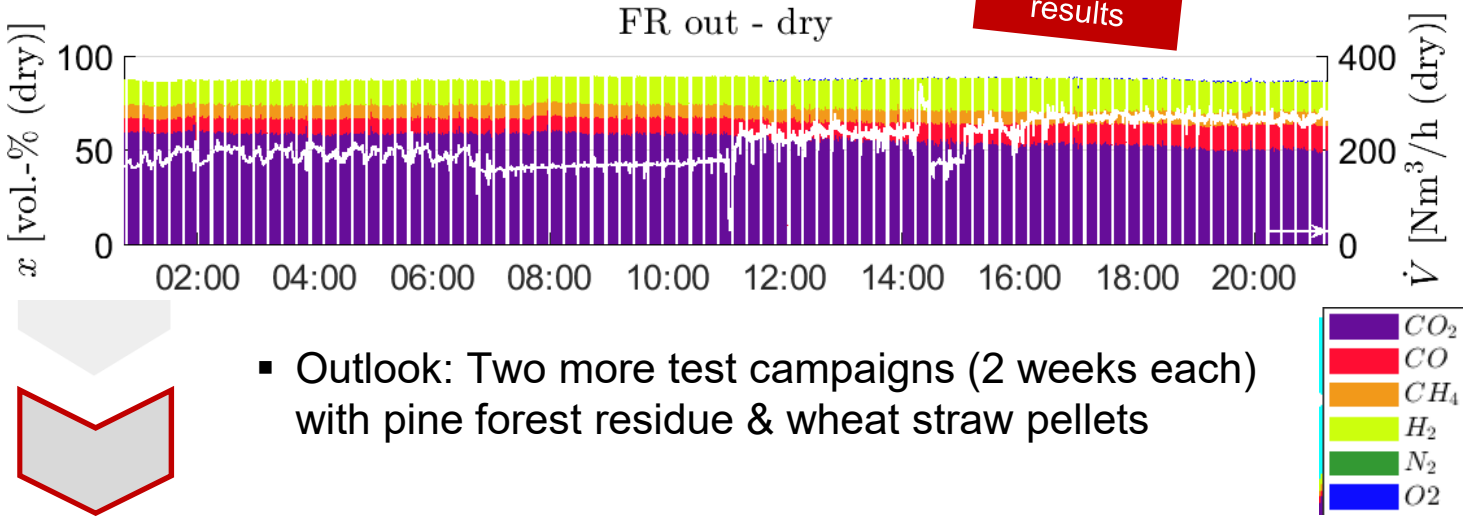
Read more:
O. Condori et al., *"Biomass Chemical Looping Gasification for syngas production using LD slag as oxygen carrier in a 1.5 kWth unit"*
Oscar Condori et al. "*Biomass Chemical Looping Gasification for syngas production using ilmenite as oxygen carrier in a 1.5 kWth unit*"

4 CLG - Technology Development
Pilot Scale

Investigate CLG in an industrially relevant environment & demonstrate autothermal CLG operation

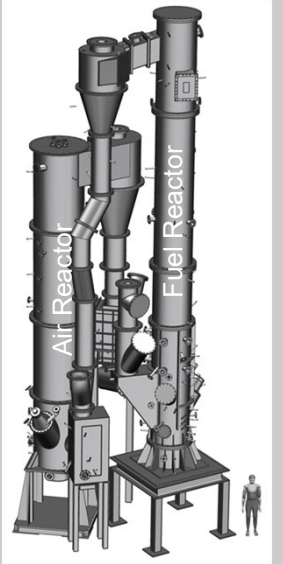
- ✓ Redesign of existing pilot plant for 1 MW_{th} CLG operation
- ✓ Multiple-day stable CLG operation (> 70 h)
  - → Demonstration of autothermal CLG operation at 1.1 MW_{th}
  - → Successful validation of novel process control concept

preliminary results



- Outlook: Two more test campaigns (2 weeks each) with pine forest residue & wheat straw pellets

1 MW



Read more:
Falko Marx et al.,*"Design of a 1 MWth Pilot Plant for Chemical Looping Gasification of Biogenic Residues"*
P. Dieringer et al. *"Process Control Strategies in Chemical Looping Gasification—A Novel Process for the Production of Biofuels Allowing for Net Negative CO2 Emissions"*

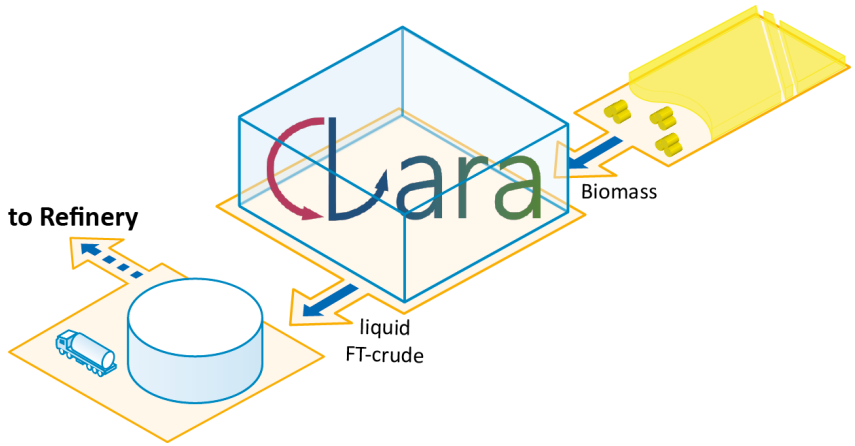
5 Summary & Outlook

Novel Biomass-to-Liquid (BtL) process chain based on chemical looping gasification

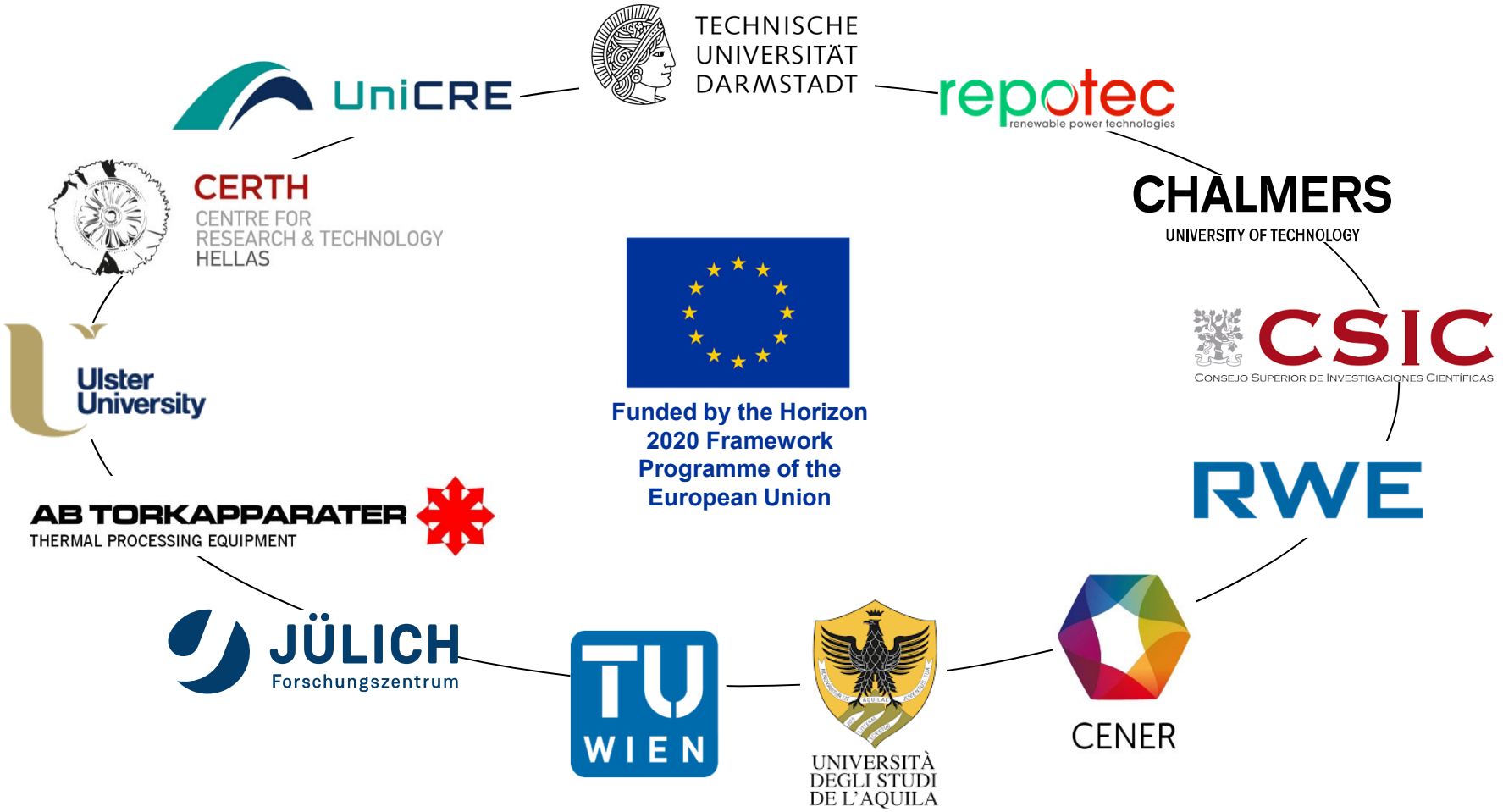
✓ Individual technologies have been analyzed in lab & pilot scale

✓ First 1 MW_{th} Chemical Looping test campaign operated in April 2022

- **Full-chain test campaigns** in Q2/Q3 2022
- **Upscaling** of all relevant technologies by Q4 2022
- **Techno-economic** assessment of entire BtL chain by Q1 2023
- **Techno-socio-economic** risk evaluation of all technologies by Q1 2023



5 Consortium & Funding



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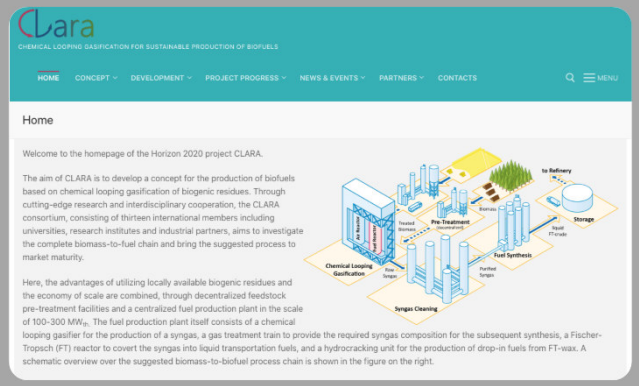

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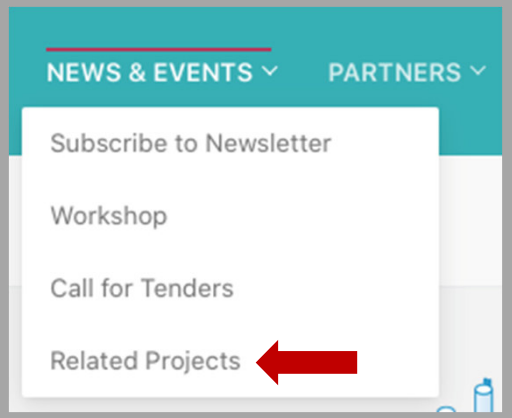

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