Newsletter VII, February 2023

CLara

Chemical Looping Gasification for Sustainable Production of Biofuels

What is CLARA?

CLARA is a Horizon 2020 project, funded by the EU, involving 13 partners from across Europe, which aims at developing an efficient technology for the production of 2nd generation liquid biofuels based on chemical looping gasification (CLG) of biogenic residues.

H2020 Research and Innovation action
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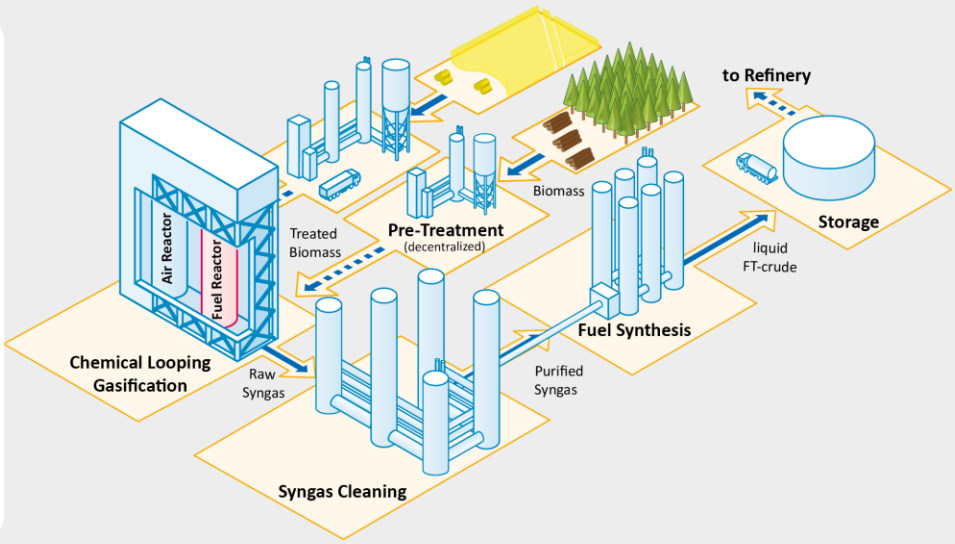
About the Project

The **de-carbonization of the transport sector** is a key factor to achieve **significant reductions** in greenhouse gas emissions that are required to **prevent a surge in global average temperatures**, exceeding the 1.5 °C Paris Agreement threshold. To tackle this issue, the **large-scale deployment of biofuels**, in addition to electrification and the increased deployment of rail transport, is necessary. Therefore**, substantial advances in renewable fuel generation**, not affecting food availability and prices, are required. One route to achieve these objectives is **the synthesis of advanced biofuels through thermochemical conversion** of biomass-based residues. Within the scope of CLARA, an efficient technology for the **production of liquid fuels based on chemical looping gasification (CLG) of biogenic residues** is being developed. The major objective is to further investigate and test CLG up to 1 MW_{th} scale in an industrially relevant environment, elevating the process to market maturity. Furthermore, the project aims at devising and optimizing innovative, cost-efficient technologies for biomass pre-treatment and syngas cleaning. These novel process steps will be supplemented by established fuel synthesis technologies (e.g. Fischer-Tropsch process), yielding the full biomass-to-biofuel process chain.

On the Inside



Project Highlights

- The final pre-treatment chain, allowing for the utilization of wheat straw in CLG, has been defined.
- The Innovative gas cleaning process with alternative agent has been filed for patenting. It includes the use of $KMnO_4$ (instead of formerly mentioned H_2O_2) to convert H_2S into pure sulfur from sour gas after its desorption from loaded amine solution.
- CLG has successfully been tested in the 1 MW_{th} scale. >200 hours of CLG operation with three biomass feedstocks was achieved.
- Moreover, the entire process chain (i.e. from biomass to FT-syncrude) was investigated in full-chain tests in 1 MW_{th} scale.
- A layout for a full-scale (200 MW_{th}) biomass-to-liquid plant, incld. pre-treatment, CLG, gas cleaning and fuel synthesis was developed.
- Technical, environmental, economic and societal risks of the entire process chain were evaluated, showing that large-scale implementation of the biomass-to-liquid process chain is feasible.
- Techno-economic assessments show that favorable syncrude prices are attainable via the suggested method. Especially if CO_2 credits are considered, with syncrude prices ~0.7 €/l being achievable in this environment.

For more information on the project progress visit: https://clara-h2020.eu/.

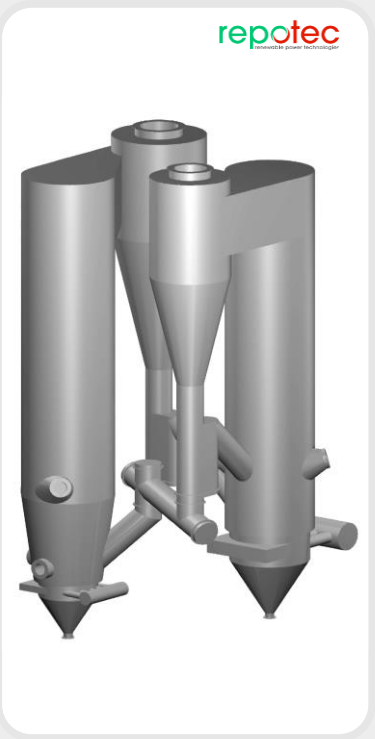
In case you want to receive regular updates on the project, you can subscribe to the biannual newsletter.

Project Progress

Since the beginning of last year progress was made in terms of *Full-Chain Process Development*, *Technology Development* (*Concept for Pre-Treatment of Straw*, *Chemical Looping Gasification*, & *Novel Gas Cleaning Concept)*, and the *Demonstration of the Full Process Chain*. Moreover, major advances in the field of *Risk Assessment* and *Techno- & Socio-Economic and Environmental Assessment* were made. The progress is briefly summarized in the following.

Full-Chain Process Development

- Building on the basic definition of the Biomass-to-Liquid (BtL) process chain, a more sophisticated process layout was devised.
- Subsequently, the BtL chain was optimized, to enhance the overall plant efficiency and hence maximize biofuel yields. To allow for basic engineering of the individual components as well as the estimation of their costs' structures, heat and mass balances were calculated for all sub-units for this optimized process layout.
- Based on these calculations and using the expertise of the CLARA consortium, the layouts for the pre-treatment unit, the chemical looping gasifier, the gas treatment unit, as well as the fuel synthesis unit were specified for a thermal load of 200 MW_{th}.
- E.g. Aichernig Engineering designed a final layout for the full-scale 200 MW_{th} chemical looping gasifier, consisting of two circulating fluidized bed reactors, with diameters of 4-5 m and a height of approx. 26 m (see right).



Development of a Concept for Pre-Treatment of Straw

- The final pre-treatment chain for wheat straw has been defined based on pelleting and additivation. Here, focus was not only placed on technical, but also economic criteria, to obtain a competitive product, relying solely on drying, pelleting and additivation.
- Based on the suggested layout, heat and mass balances for an industrial pre-treatment unit were calculated, before the economics of the pre-treatment process were evaluated.

Development of Chemical Looping Gasification

- Building on the findings made during lab-scale testing, CLG has been investigated small pilots (50 & 100 kW_{th}). Here, extensive parameter studies were carried out, laying the foundation in deriving a new process control concept, allowing for an efficient implementation and control in industrial size.
- Moreover, important insights with regard to material selection, process requirements, operability, & process efficiency were obtained
- The experimental endeavors, aiming towards elevating CLG towards market maturity, were accompanied by simulation and modelling efforts for validation of the experimental findings and deeper optimization through sensitivity analyses, amongst others.

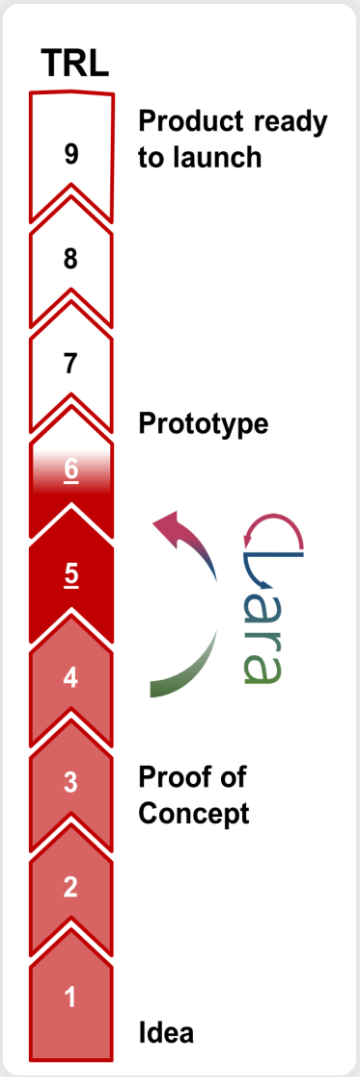
Development of a Novel Gas Cleaning Concept

- Further Test runs with stirred glass reactors and column have been performed, showing decent H_2S capture rates for $KMnO_4$.
- The novel Sulphur capture concept, relying on $KMnO_4$ has been patented.
- The test rig has been in operation during full-scale testing at the 1 MW_{th} facilities, showing $KMnO_4$ conversion (see below).

Demonstration of the Full Process Chain

- Production of pine forest residue and wheat straw pellets for the 1 MW_{th} pilot tests at the Torkapparater facilities in Sweden has been finalized.
- CLG was demonstrated in semi-industrial scale for the first time, in the 1 MW_{th} pilot plant in Darmstadt (see below) underlining its promise for industrial-scale implementation.
- More than 75 t of biomass pellets (woody biomass as well as wheat straw) were fired in chemical looping mode.
- The novel control concept, developed within the CLARA project, was successfully employed for 240 hours
    - Here, for the very first time autothermal CLG operation was achieved for a total of approx. 130 h
    - For autothermal CLG operation, cold gas efficiencies exceeding 50 % achieved in the 1 MW_{th} scale
- The effect of effect of different variables on process efficiency was evaluated (e.g. reactor temperatures, thermal loads, Particle size distribution of OC)

➔ The CLG technology was elevated from TRL 4 to TRL 5/6.



Risk Assessment

- Using the detailed layout of the full-scale BtL chain and initial operational experience from the consortium, the technological risks of the process chain were specified.
- Subsequently, the risks were classified, using state-of-the art risk analysis tools, in order to account for severity and likelihood of these risks. Here, no “show-stoppers” were found.
- Finally, risk mitigation strategies were developed for each risks.

Techno- & Socio-Economic and Environmental Assessment

- The techno-economic-assessment (TEA) result shows that the break-even selling points of biofuel production cost range from 0.79 to 0.82 €/liter without revenues from by-product sales.
- If the CO2 credit (20 €/tCO2) is included, the biofuel production costs are reduced, ranging from 0.71 to 0.73 €/liter.
- The TEA also indicates that the BtL process will be able to capture 44.7-45.4% of the carbon contained in the biomass feedstock. If sustainably-grown biomass is considered to be carbon dioxide neutral, this approach is also conducive to net negative CO2 emissions.

AB TORKAPPARATER
THERMAL PROCESSING EQUIPMENT

AB Torkapparater has a strong expertise in thermal processing of solid materials. ABT offers turn-key systems for drying, cooling, pyrolysis, gasification and other thermal processing of a wide spectrum of materials, e.g. minerals, chemicals, industrial and municipal wastes and sludge, biomass and recycled products. Since 1937 ABT has delivered more than a thousand plants adapted to a hundred different types of material. ABT's customers are found in most industries, around the world. The systems are recognized by a quality and design that gives customers appropriately adapted equipment and sustainable solutions combined with competitive overall economics. In Sweden the use of biomass application started in the middle 80s with drying and gasification systems for bark, chips and different fractions of saw dust and other mixed fractions. ABT has supplied many of the drying systems to the Swedish biomass industry. Furthermore, in 2012 ABT successfully managed a torrefaction project together with Vattenfall, Sveaskog, Sweden's largest forest owner and and Korsnäs an industrial partner.

Getting to Know the Partners – AB Torkapparater

Producing a high quality syngas from various feedstocks is a challenging task. To achieve this, preparation of the utilized feedstock is key. AB Torkapparater is a Swedish SME, with strong expertise in thermal processing of solid materials, ranging from of drying, cooling, pyrolysis, gasification and other thermal processing of a wide spectrum of materials, e.g. minerals, municipal wastes, and biomass. In the CLARA project, ABT focused on preparing biomass feedstock for the pilot tests, using their expertise and novel findings generated within the project. We had the chance to talk to Ulf Bojner from ABT, to learn about the industry view on the CLARA project and promises invested industry stakeholders associate with the novel pre-treatment concept, developed by the CLARA consortium.

What appealed to you in the CLARA project, sparking the interest to get involved in it?

About 2009/2010 we had the original contact with TU Darmstadt and the Department of Prof Bernd Epple. We started by doing some contract drying of ilmenite in one of our test dryers in Sweden that was required for tests at TUDA. In the year 2012, we supplied TUDA with torrefied material in a project where co-combustion of torrefied material and coal was used in order to demonstrate this *Energiewende*-technology. Project representatives and stakeholders visited our production plant for torrefaction at Gotland in Sweden. Later on, the CLARA project came up and the preparation of different biomass raw material streams were required. Pinpointing these qualities and amounts resulted in our participation in the project.

We certainly appreciate the international contacts through not only the CLARA network, but also the network of TUDA and Prof. Bernd Epple. We also trust that we as suppliers to the north European biomass industries through a large number of years can supply some valuable input to the CLARA project.

Ulf Bojner is the MD and owner of the company. Ulf has a MBA from the Stockholm School of Economics (SSE) as well as a MSc degree from the Royal Institute of Technology (Mech Eng) in Stockholm (KTH).

What is your role in the project and what expertise do you bring to the consortium?

Our role was to supply two biomass batches, Pine Forest Residue (PFR) and Wheat Straw (WS), each 72 tons and each in the form of 8 mm pellets. The two separate above streams required a completely different set-up of materials handling equipment in order achieve a proper pelletization.

The PFR consists of a stream of very abrasive material that has to be pre-treated through grinding and milling already in the forest before being able to insert into the dryer and the subsequent steps in the pellet factory. The carry-over of stones, sand and foreign objects also put constraints on the feeding equipment. The wear and tear of this equipment tends to be very large if the materials pretreating steps are not carefully thought through.

The WS on the other hand is very voluminous and puts other types of constraints on the materials handling equipment. Relatively large screw conveyors and enlarged chutes between the different pieces of machinery thus had to be installed in order to safeguard the feed-rate required for the pellet press.

As far as we know very few manufacturers of standard pellets have been able to up-grade a standard pellet manufacturing line to such a flexibility that is required for the use with PFR and WS as raw materials.

What role do you see biomass playing in future energy markets in the EU and beyond?

We see the role of biomass, in particular the biomass that is today un-used, as a very large and important resource for energy generation in today's energy environment. The reason is the greenhouse impact that is detrimental to the world. The challenge lies in an effective logistic solution that could be incorporated in the respective schemes, especially in the developing countries.

Why is biomass pre-treatment crucial both in very general terms and for the suggested CLARA concept?

Enormous amounts of biomass are incinerated today in the forests and in the fields. A solution to use this energy for electricity production and grid distribution is a large task for the young engineers to come.

Do you see the newly developed and tested pre-treatment concept finding a broader use for other applications, using wheat straw as the feedstock?

Absolutely. It was a crop that was wisely selected by the CLARA project management in its already universal availability as a crop (and fuel). Many ideas have already come up on how to do the sourcing and transporting this crop. Storing from harvesting until the time for use will be a special challenge.

What was your biggest success in the project so far?

This is a difficult question as I see it as a two-fold success that refers only partly to us, but instead to the CLARA project as such. The success for the project is without doubt to collect waste energy streams from forestry and agriculture, that would otherwise risk only to generate greenhouse gases, and add value to these products and produce liquid fuels. This generates an enormous impact on the environment.

For us as a company the largest success was to see both the feed of the PFR and WS flow without bridging through the complete drying, grinding and pelleting line. As mentioned, only few suppliers of pellets, if any, have achieved this before.

Dissemination Activities

Scientific publications (selection)

- Andrea Di Giuliano, Ibai Funcia, Raúl Pérez-Vega, Javier Gil and Katia Gallucci,"Novel Application of Pretreatment and Diagnostic Method Using Dynamic Pressure Fluctuations to Resolve and Detect Issues Related to Biogenic Residue Ash in Chemical Looping Gasification", *Processes 2020, 8 (9), 1137*.
- Andrea Di Giuliano, Stefania Lucantonio and Katia Gallucci, "Devolatilization of residual biomasses for chemical looping gasification in fluidized beds made up of oxygen-carriers", Energies 2021, 14 (2), 311.
- Ali Hedayati, Amir H.Soleimanisalim, Carl Johan Linderholm, Tobias Mattisson, Anders Lyngfelt, "Experimental Evaluation of Manganese Ores for Chemical Looping Conversion of Synthetic Biomass Volatiles in a 300 W Reactor System", *Journal of Environmental Chemical Engineering, 2020*.
- Falko Marx, , Paul Dieringer, Jochen Ströhle, and Bernd Epple, "Design of a 1 MWth Pilot Plant for Chemical Looping Gasification of Biogenic Residues", Energies, 2021.
- Lucantonio, S.; Di Giuliano, A.; Gallucci, K. Influences of the Pretreatments of Residual Biomass on Gasification Processes " Devolatilizations Study in a Fluidized Bed". *Appl. Sci.* 2021, *11*, 5722.
- Oscar Condori, Francisco García-Labiano, Luis F.de Diego, María T. Izquierdo, Alberto Abad and Juan Adánez, *"Biomass Chemical Looping Gasification for syngas production using LD slag as oxygen carrier in a 1.5 kWth unit"*
- Andrea Di Giuliano, Stefania Lucantonio, Barbara Malsegna, Katia Gallucci, "Pretreated residual biomasses in fluidized beds for chemical looping Gasification: Experimental devolatilizations and characterization of ashes behavior"
- Andrea Di Giuliano, Marta Gallucci, Barbar Malsegna, Stefani Lucantonio, Katia Gallucci, "*Pretreated Residual Biomasses in Fluidized Beds for Chemical Looping Gasification – Part II: Analysis of Devolatilization Data by Statistical Tools*"
- Ali Hedayati, Amir H.Soleimanisalim, Tobias Mattisson, Anders Lyngfelt „Thermochemical conversion of biomass volatiles via chemical looping: Comparison of ilmenite and steel converter waste materials as oxygen carriers"
- Oscar Condori, Luis Francisco de Diego, Francisco Garcia-Labiano, María Teresa Izquierdo, Alberto Abad, and Juan Adánez, "*Syngas Production in a 1.5 kWth Biomass Chemical Looping Gasification Unit Using Fe and Mn Ores as the Oxygen Carrier* "
- F. Lebendig, I. Funcia, R. Pérez-Vega, M. Müller, *"Investigations on the Effect of Pre-Treatment of Wheat Straw on Ash-Related Issues in Chemical Looping Gasification (CLG) in Comparison with Woody Biomass"*

Consortium

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