Deliverable D4.3

Integration of the mobile fermentation unit to synthesis gas plant

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Abbreviations

BBMPP	Bio Base Mobile Pilot Plant
TAG	Triglyceride
DEM	Demonstration

Contents

1 Executive Summary

This deliverable D4.3 *Piloting of the integrated synthesis gas and mobile fermentation unit* is demonstration (DEM) deliverable and shows the highlights of the integration activity that was conducted in WP4. The technical results will be presented in detail in D4.4. *Results of the pilot run*.

BBEPP's mobile gas fermentation unit arrived to VTT in March 2023. Syngas fermentation started in May 2023 and piloting runs were successfully executed between 5/2023 and 10/2023. The pilot was operated for around 2 000 hours in total. Different syngas qualities containing different amount of impurities were tested during the piloting runs. The objectives for the piloting runs were following:

- Define the interface between the synthesis gas plant and mobile fermentation unit (especially definition of the required cleaning steps)
- Meet the pre-defined specifications acquired from WP3 covering maximum concentration of impurities (e.g. C_xH_y, H_2S, COS, HCN), temperature range, pressure range, optimal H_2/CO/CO_2 concentration and limits for process fluctuations
- Reduce OPEX and CAPEX by modifying the syngas plant to meet the pre-defined specifications for syngas fermentation.
- Pilot runs execution at the integrated plant at TRL5

After the piloting run, decommissioning and shipping of the unit back to Belgium started in October 2023. Detailed reporting of the technical results are expected be finished by the end of December 2023 (M45) in Deliverable 4.4.

2 Integration and piloting runs in WP4

2.1 Shipping of the mobile gas fermentation unit to VTT's Bioruukki piloting facility from Belgium

BBEPP prepared the shipping from Belgium to Finland and the unit arrived to VTT on 27th of March 2023. The shipping required deinstallation of the unit in Belgium and transportation of the unit from Belgium to Finland by ship.

The BBMPP unit was placed onto a concrete foundation that was built for carrying the heavy load of the BBMPP unit for avoiding sinking of the unit. The BBMPP was placed on 27th of March to its place with a crane and the installation work started after the placement.

Figure 1 Lifting in place of the BBMPP at the site of Arcelor Mittal Ghent for its relocation.

Figure 2 The BBMPP loaded onto a truck to leave Arcelor Mittal Ghent for its relocation.

Figure 3 The BBMPP loaded onto a truck delivered to its new relocation at VTT Bioorukki.

2.2 Installation of the mobile fermentation unit at VTT's site

Installation of the unit started after the BBMPP unit arrived to Bioruukki piloting facility in March 2023. The main installation work related to installing the connections to BBMPP and supply of utilities such electricity and nitrogen.

The gas connection goes trough a wall and is supplied to BBMPP’s gas buffer tank. The installation work was finished during May 2023.

Figure 4 Placement of the BBMPP unit at VTT's Bioruukki site on 27th of March 2023.

Figure 5 BBMPP unit with exhaust pipes on the roof installed in March 2023.

Figure 6 Mobile gas fermentation unit fully operational during May 2023.

2.3 Short description of the campaigns

The first target was to show that clean synthesis gas can be delivered to the BBMPP unit continuously and the acetate production is possible with gasified feedstock. In total, the BBMPP units was operated approximately for 2000 hours during piloting period between 5/2023-10/2023.

One of the main objectives of the campaigns was to demonstrate that simplified gas processing system can be used in syngas fermentation that can lead to cost savings and reduced CAPEX and OPEX. Detailed information of the test campaigns will be available in D4.4 by the end of December 2023.

Three different campaigns were executed with three different gas qualities:

1. Ultra-cleaned syngas
2. Acid-scrubbed syngas
3. Alkaline-scrubbed syngas

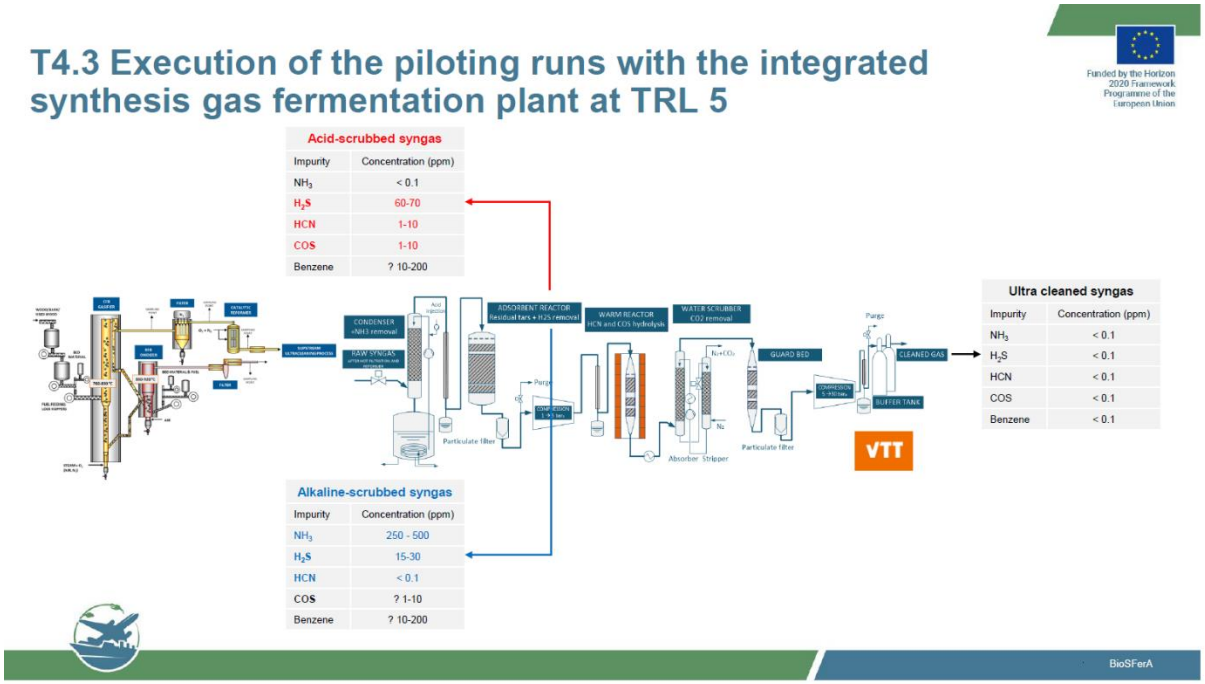

Figure 7 Different gas qualities after acid-scrubber, alkaline-scrubber, and full ultra-cleaning system.

2.4 Start-up and operation of the system

Final preparations and proof testing were done, and the system was started without problems on the 22nd of May 2023. During each gasification campaign, gas produced by VTT is stored at 10 barg in a 1.5 m³ gas buffer tank present in the gas fermentation mobile unit. This way BBEPP can run several fermentation tests using the gas stored.

Dried and pre-processed biomass streams were used in the piloting campaign. The dry biomass is gasified at 700–900 °C inside a fluidized-bed gasifier. Following the gasifier, gas is sent to a hot gas filter and a reformer where residual organic impurities are converted into syngas. Ultra cleaning unit is divided into different cleaning steps, to remove selectively the impurities. After the reformer unit, the syngas containing trace impurities goes through the following steps in the full ultra-cleaning system:

- Scrubber, where impurities are adsorbed into an aqueous solution, it can be acid or alkaline according to the target impurities.
- H_2S, residual tars and benzene are removed by a dry-bed adsorption unit,
- Guard Bed 1 and 2 consist of 2 dry adsorption units where HSN and COS are selectively adsorbed.

In BioSFerA campaigns some of above-described cleaning steps were removed to investigate the effect of different impurities concentration on the microorganism, a more detailed explanation is reported below and in the deliverable D4.4. The syngas comes out of the cleaning unit, at a pressure of approx. 200 mbar. At such pressure, syngas cannot be fed directly to the bioreactors, since the fermentation occurs at 0.5 barg or above. Thus, it is compressed to 12 barg and stored inside a gas buffer tank. In this way, the gas can be used directly or later, when it is needed.

Figure 8 Used feedstocks during the piloting campaign. Straw pellet that was crushed prior to gasification on the left side and crushed bark on the right side.

Figure 9 The scrubber that was used in ultra-cleaned, acid-scrubbing and alkaline scrubbing campaigns on the left side. The cleaned syngas was fed to the buffer tank shown on the right side.

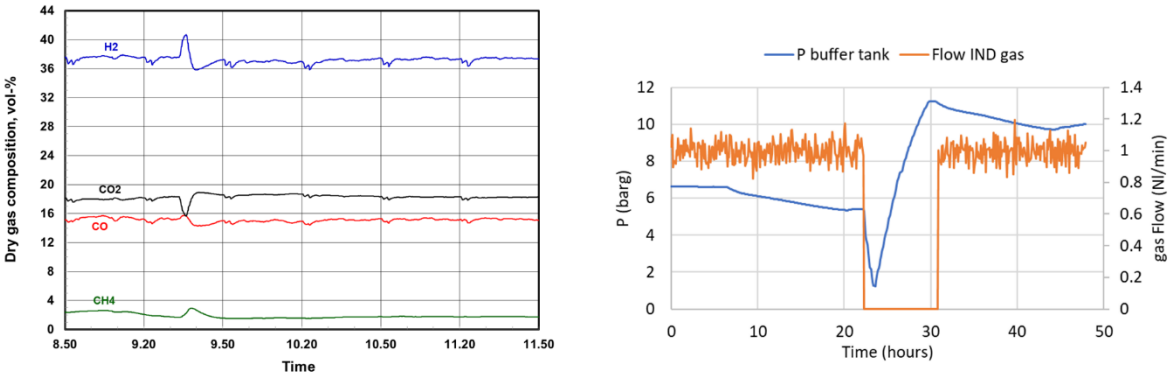

Figure 10 Example: Concentration of the main gas components after reformer prior to gas cleaning. The cleaned gas was sent to a buffer tank of which pressure is shown on the left side picture.

The picture above shows the main components of the reformed gas and trend of the pressure in the storage buffer tank during the filling with syngas from the gasification unit. In a normal fermentation process, syngas is fed to the bioreactor continuously, orange line in Figure 12, until the syngas in the buffer tank is depleted. When syngas is depleted, buffer tank is filled with new syngas. The blue line shows the trend of pressure into the buffer tank.

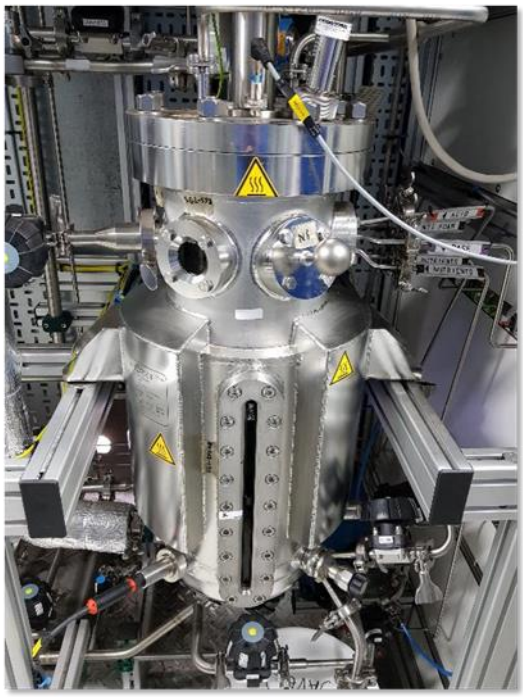

Figure 11 Bioreactor used during the syngas fermentation campaign

Figure 12 Sampling of the acetate from the gas fermenter.

Figure 13 A group picture during the final days of BBEPP at VTT Bioruukki 26th of October 2023.

3 Dissemination activities in WP4

The coupling of the gasification unit with the gas fermentation unit as well as the securement of continuous and efficient operation at pilot scale was the major accomplishment of the BioSFerA project. The BioSFerA WP4 activity has been disseminated in conferences and journals:

1. *eebionews* published by EERA in Issue 19 July 2023.
2. International gasification conference - Syngas & hydrogen from challenging secondary feedstock 19 – 21 September 2022 Freiberg, Germany

PILOTING OF GASIFICATION AND GAS FERMENTATION PLANTS: BioSFerA PROJECT

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The BioSFerA project aims to develop a cost-effective interdisciplinary technology to transform maritime transport and aviation into green sectors. In this line, biogenic residues will be converted into jet and bunker fuels, combining thermochemical, biological, and thermocatalytic processes. The overall BioSFerA concept involves biomass gasification to produce syngas (CO_2, CO, and H_2) and a 2-stage fermentation process. The latter aims to first convert the syngas into acetate through gas fermentation (1st stage), which then is used as feedstock to produce triacylglycerides (TAGs) in an aerobic fermentation process (2nd stage).

Under the scope of this EU project, VTT and Bio Base Europe Pilot Plant (BBEPP) aim to validate the integration of the gasification and gas fermentation processes for the production of acetate from biomass-derived syngas at pilot scale (TRL5) (Figure 1).

Figure 1. Overall BioSFerA project concept, and piloting integration of gasifier and gas fermentation unit

VTT and BBEPP are respectively owners of a gasification plant and a mobilized gas fermentation plant utilized in process piloting (Figure 2). VTT's pilot plant consists of a Dual Fluidized Bed (DFB) gasifier and a syngas ultra-purification unit (Figure 3). BBEPP gas fermentation pilot plant, the Bio Base Mobile Pilot Plant (BBMPP), consists of a containerized mobile unit that contains high-pressure gas fermentation reactors (25L and 150L), analysis equipment, and all required utilities to operate it in a stand-alone manner. The BBMPP can be placed close to the gas-emission source, avoiding the issues related to industrial gas compression and transport, and enabling the validation of different gas fermentation processes in an industrial environment (Figure 4).

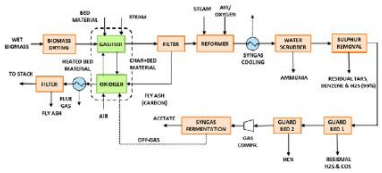

Figure 2. Schematic diagram of integrated gasification and synthesis gas fermentation pilot at VTT Bioruukki pilot centre

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ISSUE 19 July 2023

Figure 3. DFD gasification pilot and syngas ultra-purification unit at VTT Bioruukki pilot centre

Figure 4. Bio Base Mobile Pilot Plant (BBMPP), a containerized mobile unit dedicated for gas fermentation processes. BBMPP at the site of Arvalor Pittal Ghent (Belgium) in the framework of BIOCONI-CO2 project (top picture) and BBMPP loaded onto a truck and delivered to its new location at VTT (Finland) (bottom picture)

The piloting activities aim to validate the integrated processes using real syngas, which contains impurities that cannot be tested or simulated reliably in a lab. Therefore, tests at TRL5 are needed in order to validate the process in an industrial environment. One of the main goals is to study the effect of these impurities on the microorganism and process performance. Several tests will be performed in order to evaluate to which extent the syngas produced by VTT requires purification before it can be adopted as an adequate feedstock for the gas fermentation process. To this end, modifications will be implemented into the syngas cleaning unit to obtain different qualities of syngas (in terms of impurities and their concentration) and evaluate the tolerance of the microorganisms.

Additionally, BBEPP and VTT aim to improve acetate productivity and gas conversion rates. When the processes are validated with real syngas, the main focus will be on the improvement of the fermentation conditions to boost the acetate productivity. The project targets to achieve a high acetate production rate, which will be achieved by combining the optimal gas processing requirements and optimizing the fermentation conditions (e.g. installation of a cell recycle system to allow continuous fermentation). This latter approach will eventually aid in increasing the total gas conversion rates as it allows an increase in biomass concentration while removing the produced acetate, which inhibits the microorganism at high concentrations. Another strategy to increase the total gas conversion rates would be to recycle the off-gas back to the fermenter.

Figure 5. Ilkka Hiltunen, Stefano Rebecchi and Pedro Acuña Lopez in front of the BBMPP in its new location at VTT Bioruukki pilot centre (Espoo, Finland)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement 884208.

Figure 14 BioSFerA article published in eebionews published by EERA.

Fluidized bed gasification of wastes and syngas processing

Author: Ville Nikkanen

Fluidized bed gasification:

VTT has long experience in developing various gasification and syngas technologies for different feedstocks. The development of fluidized bed waste gasification began already in the 1990s and culminated in building a 160 MW_{th} SRF waste gasifier which was integrated into a CHP plant in Lahti, Finland.

High-temperature syngas processing:

After gasification, the gas is filtered at high temperatures. High filtration temperature is preferred for avoiding unnecessary cooling before the subsequent reforming unit in which tars are converted to valuable syngas components H_2 and CO. The reforming unit operates at around 900°C and utilizes nickel and/or noble metal catalysts.

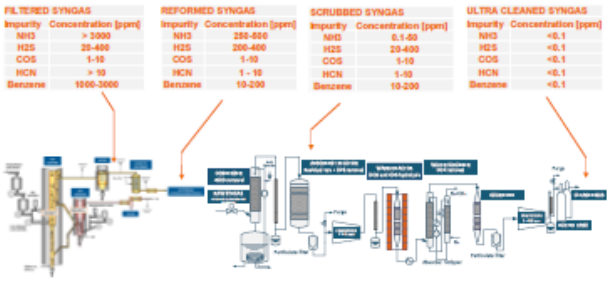
With lower quality waste feedstocks additives are required prior to the filter for capturing excessive chlorine and sulfur from the gas. In addition to additives, filtration temperature is required to be lowered down for allowing proper operation of the hot-gas filter and effective separation of harmful volatile components such as alkali metals that can cause problems in the downstream equipment.

VTT's Bioruukki piloting-facility in Espoo, Finland.

Ultra-cleaning of syngas:

After tar reforming, syngas can be cooled down and fed to an ultra-cleaning process, where trace components such as NH_3, H_2S, COS, HCN, and residual benzene can be removed down to < 0.1ppm levels.

The current adsorption-based ultra-cleaning concept is developed originally for medium-size (150 MW_{th}) synthetic fuel and chemical production considering the limited availability of local feedstocks, logistic costs, and economies of scale of the processing units.



End-use of syngas:

In addition to CHP applications, the processed and cleaned syngas has multiple different valuable end-uses. VTT has a long history in developing Fischer-Tropsch production from syngas. The existing mobile synthesis unit (MOBSU) is able to convert a 5 m^3/h syngas slipstream into crude quality Fischer-Tropsch.

BioSFerA

In the on-going BIOSFERA project, VTT's syngas production pilot will be integrated with BBEPP's mobile gas fermentation unit, where syngas is converted into acetate following microbial oil production. The project explores the benefits of microbes that can tolerate, or even utilize, gaseous impurities such as hydrogen sulfide and ammonia in converting syngas to valuable components.

VTT's role in the project is to enable the conversion of multiple different low-cost waste feedstocks (< 10 €/MWh) in a fluidized bed gasifier to a valuable gas. The produced and processes syngas is provided to the gas fermentation process at required quality levels.

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beyond the obvious

Figure 15 Poster presentation of BioSFerA in International gasification conference in Freiberg, Germany.

4 Next steps

The piloting campaigns have been in finished during October 2023 and decommissions and shipping of the BBMPP unit back to Belgium has been started. The results of piloting campaigns will be reported in detail in D4.4 *Results of the pilot run*.

Further dissemination actions related to the obtained results are expected until the end of the project and beyond.