



IEA Bioenergy
Technology Collaboration Programme

Gasification for Production of Biochemicals

Workshop report

IEA Bioenergy: Task 33

February 2025

Gasification for Production of Biochemicals

Workshop report

Jitka Hrbek, BOKU

Antonia Biebighäuser, BOKU

IEA Bioenergy: Task 33

February 2025

Copyright © 2025 IEA Bioenergy. All rights Reserved

Published by IEA Bioenergy

Table of Contents

List of Figures and Tables	b
Introduction	c
Product Gas Cleaning for successful Synthesis - Insights from Syngas Platform Vienna	2
Electrification of Gasification-Based Biomass-to-X Processes - Insight from TUM School of Engineering and Design	3
Making Small Scale Chemical Production Work	7
R-GAS Plus: A Pioneering Pathway for Maximizing Yields of Biofuels from Biomass Gasification - Insights from GTI Energy	10
Natural Gas Substitution by Syngas Made from Biomass and Waste Wood Gasification - Insights from SG Energies	12
Biomass Gasification Perspective of a Project Developer - Insights from POWER2X Leading in Energy	14
Bio-Acetate Production via Dual Fluidized Bed (DFB) Syngas Fermentation - Insights from TU Wien and ICEBE ImagineEring Nature	16
Waste to Chemical - Insights from NextChem Maire Tecnimont Group and MyRechemical	19
Renewable Olefins, Comparison of Production over Methanol or Fischer Tropsch Route - Insights from Karlsruhe Institute of Technology (KIT)	22
Fermentation of Syngas: Scalability for Single Cell Protein (SCP) for Feed and Food as well as Bioplastics (Polyhydroxyalkanoates, PHAs) - Insights by CIRCE BIOTECHNOLOGY GMBH	25
Integrating Waste Cracking with Existing Petrochemical Industry: The Fate of Contaminants - Insights from Synova	27
Conclusion	29

List of Figures

Figure 1 Reduction of tars during gas cleaning using water quench and RME scrubber.....	2
Figure 2 Stages of fuel conversion in entrained flow gasification (EFG).....	3
Figure 3 Indirect electrification (PBtX) for biomass-to-X processes	4
Figure 4 Direct electrification (eBtX) for biomass-to-X processes	4
Figure 5 Comparison of BtL and PBtL for liquid fuel production	5
Figure 6 Water demand comparison for BtL vs PBtL processes.....	6
Figure 7 Product yield vs hydrogen demand in PBtL processes.....	6
Figure 8 Comparison of direct and indirect gasification processes	7
Figure 9 MILENA indirect gasification system setup	8
Figure 10 MILENA-SMR route for methanol synthesis.....	8
Figure 11 MILENA-Thermal Cracking route for methanol synthesis.....	8
Figure 12 Scalability of R-GAS technology from pilot to commercial scale	10
Figure 13 R-GAS reactor design with rapid DI water quenching	11
Figure 14 R-GAS Plus system with syngas enhancement via hydrogen injection	11
Figure 15 Syngas production system at Stellantis aluminum smelter	13
Figure 16 Power2X Estonia biomass-to-green methanol process.....	14
Figure 17 Phase-wise development of Power2X Estonia project.....	14
Figure 18 Coupling DFB gasification with gas fermentation for acetate production	16
Figure 19 Acetate production profile under varying agitation rates	17
Figure 20 Time-resolved analysis of DFB product gas composition	17
Figure 21 Biodiesel scrubber water as a nutrient medium in fermentation.....	18
Figure 22 Waste gasification and granulation process flow diagram	19
Figure 23 Ethanol production from waste-derived syngas process flow	20
Figure 24 Methanol synthesis from waste-derived syngas with CO ₂ capture.....	20
Figure 25 Waste gasification integrated with electrolysis for methanol synthesis	21
Figure 26 Methanol-to-Olefins (MtO) pathway process flow diagram	22
Figure 27 Fischer-Tropsch (FT) synthesis pathway process flow diagram	23
Figure 28 Energy/material flows in Methanol-to-Olefins (MtO) pathway (Sankey diagram)	23
Figure 29 Energy/material flows in Fischer-Tropsch (FT) pathway (Sankey diagram)	24
Figure 30 Comparison of bioreactor types for syngas fermentation efficiency	26
Figure 31 MILENA-OLGA system for waste-to-chemical conversion.....	27

Introduction

The workshop, held on June 12, 2024, in Karlsruhe, Germany, offered a comprehensive exploration of the latest advancements in biomass gasification and production of biochemicals. Discussions highlighted the potential of gasification as a cornerstone technology for renewable energy generation and its critical role in achieving decarbonization goals. This report summarizes the key presentations and findings from the event.

A diverse group of experts shared their insights on biomass gasification's role in the energy transition. Speakers included Katharina Fürsatz and Miriam Huber (Syngas Platform Vienna), Dr.-Ing. Sebastian Fendt (TUM School of Engineering and Design), Berend Vreugdenhil (TNO Innovation for Life), Zach El Zahab (GTI Energy), Yannick Ferriere (SG Energies), Sriram Ragav (POWER2X), Alexander Bartik (TU Wien), Andrea Angeletti (NextChem Maire Tecnimont Group), Reinhard Rauch (Karlsruhe Institute of Technology), Dr. Maximilian Lackner (CIRCE Biotechnology GmbH), and Dr. Robin Zwart (Synova).

Electrification emerged as a central theme throughout the event. Dr.-Ing. Sebastian Fendt from the Technical University of Munich presented concepts such as Power-and-Biomass-to-X (PBtX) and Electricity-driven Biomass-to-X (eBtX). These approaches demonstrated how integrating renewable electricity into biomass conversion processes could enhance flexibility and improve environmental performance.

Small-scale applications of gasification technologies were another key focus area. Berend Vreugdenhil from TNO Innovation for Life introduced the MILENA indirect gasification system, showcasing its efficiency in methanol production. Similarly, Zach El Zahab from GTI Energy highlighted advances in biofuel production through the R-GAS Plus process, which offers improved yield and efficiency.

Industry perspectives added significant value to the discussions. Andrea Angeletti from NextChem Maire Tecnimont Group and Dr. Robin Zwart from Synova presented on waste-to-chemical processes, emphasizing their integration into existing industrial infrastructures. Their contributions underscored how circular economy principles can drive sustainable chemical production while reducing waste and reliance on fossil resources.

Complementing these industry insights, researchers from TU Wien, Karlsruhe Institute of Technology, and CIRCE Biotechnology explored innovations in renewable feedstocks. Topics included bio-acetate fermentation and renewable olefin production, highlighting sustainable alternatives to fossil-based chemicals and underscoring the importance of bioeconomy development.

A detailed summary of each presentation is provided in the following sections.

Workshop Presentations

PRODUCT GAS CLEANING FOR SUCCESSFUL SYNTHESIS - INSIGHTS FROM SYNGAS PLATFORM VIENNA

by Katharina Fürsatz and Miriam Huber

Efficient product gas cleaning is critical for transforming biomass into clean syngas, a precursor for sustainable fuels and chemicals. The Syngas Platform Vienna, with its advanced infrastructure, exemplifies efforts to address challenges in gasification and synthesis. This chapter highlights key findings and challenges in product gas cleaning, focusing on coarse and fine cleaning technologies.

The Syngas Platform Vienna integrates:

- A 1 MW dual fluidized bed (DFB) gasifier
- A 250 kW Fischer-Tropsch (FT) synthesis demonstration plant
- Laboratories for real syngas cleaning and upgrading experiments

Coarse Gas Cleaning

1. Tar Reduction

Tars are complex hydrocarbons that pose significant challenges in gas cleaning. The platform demonstrated a reduction in tar content from 6.8 g/Nm³ to 0.1 g/Nm³ using an RME (rapeseed methyl ester) scrubber, achieving a relative reduction of over 90 %. This also lowered the tar dew point from 167 °C to 86 °C, facilitating downstream processing (see **Figure 1**).

Coarse gas cleaning - Tar Reduction

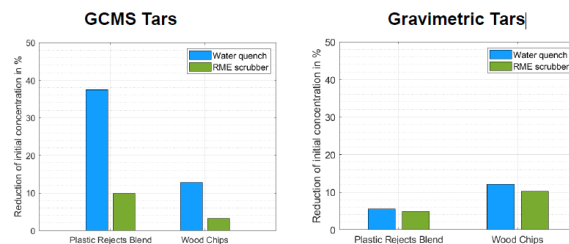


Figure 1 Reduction of GCMS and Gravimetric Tars during coarse gas cleaning using Water Quench and RME Scrubber for different feedstocks (Plastic Rejects Blend and Wood Chips)

2. Inorganic Impurity Removal

Inorganic impurities such as ammonia (NH₃), hydrogen cyanide (HCN), and sulphur compounds (H₂S, COS) were effectively reduced by up to 99 %, depending on the feedstock. The cleaning sequence included NH₃ scrubbers, activated carbon filters, and ZnO beds for sulphur removal. However, the impurity concentration was still exceeded the limits for Fischer-Trosch Synthesis (FTS) and further gas cleaning was required.

3. Fine Gas Cleaning

Fine Gas Cleaning for FTS is essential to ensure that trace impurities do not deactivate FT catalysts. The results are as follows:

- Temperature swing adsorption (TSA) was explored as an alternative fine-cleaning method. While promising for tar reduction, TSA still faces challenges in achieving complete impurity removal.
- Experiments using bark pellets and cashew nut shells highlighted variability in impurity profiles based on feedstock composition. Despite reductions in pollutants like benzene and naphthalene, heavy tar removal remains problematic

ELECTRIFICATION OF GASIFICATION-BASED BIOMASS-TO-X PROCESSES - INSIGHT FROM TUM SCHOOL OF ENGINEERING AND DESIGN

By Dr.-Ing. Sebastian Fendt

The main (primary) energy sources in fossil-free industry in Germany will come from solar, wind, and biomass/waste. The focus areas in entrained flow (EF) gasification include the following:

The use of low-grade or waste feedstock, such as sewage sludge, is explored in projects like GOLD, VERENA, and PyroGas. Another area is the coupling of biological and thermochemical processes to leverage synergies, as demonstrated in projects like ReGasFerm and GOLD. Additionally, power integration is a key focus, which involves approaches such as plasma integration for product enhancement, yield increase, or enabling the use of very difficult feedstock. This is highlighted in projects like Reallabor, GIFFT, and REDEFINE. Furthermore, hydrogen production is investigated in the VERENA project.

Entrained Flow Gasification (EFG)

EFG was investigated as part of a broader focus on gasification-based Biomass-to-X (BtX) processes (see **Figure 2**).

Entrained flow gasification (EFG)

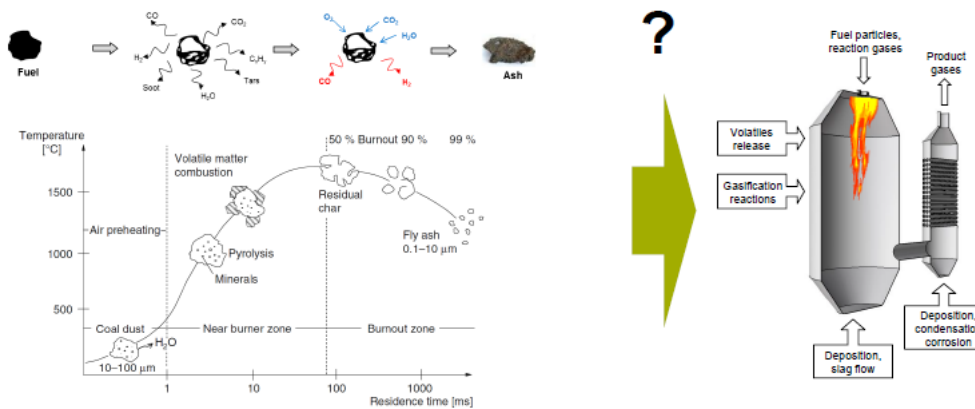


Figure 2 Overview of entrained flow gasification (EFG) processes, illustrating the stages of fuel particle conversion including pyrolysis, volatile matter combustion, and char burnout, along with associated temperature and residence time profiles. The schematic on the right highlights key reactions and challenges such as deposition, slag flow, and corrosion in the reactor

Experiments were conducted to understand the fundamental behaviour of fuel particle conversion in EFG systems. This included testing operating parameters, reactor designs, and optimization of plasma-torch configurations. Computational Fluid Dynamics (CFD) simulations were used to model reactor designs, analyse sensitivity, and optimize operating conditions. These simulations aimed to validate experimental data and refine models for better prediction and scalability.

An energetic and technical evaluation reveals that there is no single, 'optimal' BtX route. Additionally, considering the value of biogenic carbon in future energy systems, BtX routes that do not utilize the carbon (NH_3 , H_2CCS) only represent a solution in the short and medium term as a carbon negative technology.

Electrification of Gasification Processes

The research explored both indirect electrification (Power-and-Biomass-to-X or PBtX, see **Figure 3**) and direct electrification (eBtX, see **Figure 4**) with the goal to significantly increase carbon efficiency and product yields compared to conventional methods.

Indirect Electrification (PBtX)

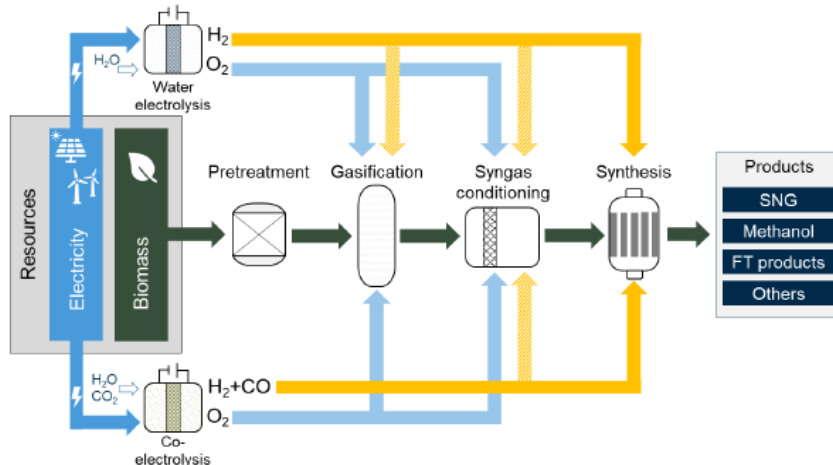


Figure 3 Process flow diagram for indirect electrification (PBtX) of biomass-to-X processes. The integration of water electrolysis provides hydrogen and oxygen for enhanced syngas production and downstream synthesis into products such as synthetic natural gas (SNG), methanol, and Fischer-Tropsch (FT) products.

Indirect electrification (PBtX) involves integrating hydrogen from water electrolysis into BtX processes to optimize the $H_2:CO$ ratio, which improves the downstream synthesis reactions. The overall results reveal an increase in the following compared to conventional BtX:

- **Carbon Efficiency:** approx. 100 % at 50/50 energy input from electricity and biomass
- **Product Yield:** 2-4x higher yield with electrification compared to conventional BtX
 → PBtX advantageous over PtX and BtX

Direct Electrification (eBtX)

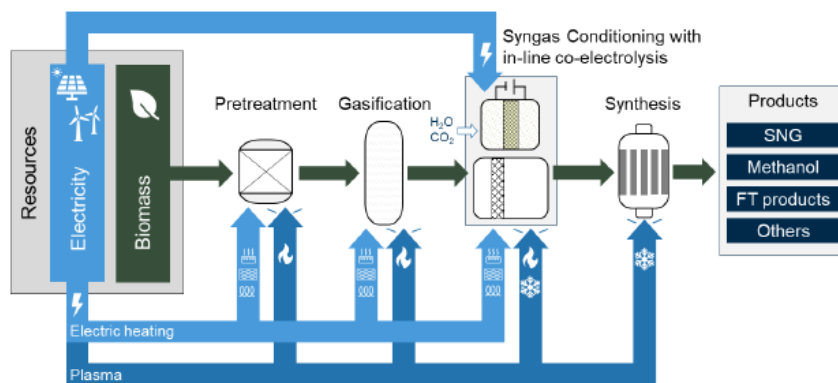


Figure 4 Process flow diagram for direct electrification (eBtX) of biomass-to-X processes. Electricity-driven heating methods (e.g., microwave, resistance, inductive, and plasma heating) replace conventional combustion to enhance reaction kinetics and reduce CO_2 emissions. In-line co-electrolysis of CO_2 and H_2O further optimizes syngas production

Direct Electrification (eBtX) focused on replacing conventional combustion with electricity-driven heat supply (e.g., resistance heating, microwave heating, plasma heating) to reduce CO_2 formation and enhance reaction kinetics. Solid oxide electrolysis cells (SOECs) are used to co-electrolyze CO_2 and H_2O into syngas, which can then be used in downstream synthesis.

- eBtX potentially advantageous compared to PBtX

Example: PBtL Study for advanced SAF Production

The study investigates the potential of PBtL processes to produce advanced SAF with enhanced carbon efficiency and higher product yields by integrating renewable electricity into biomass conversion.

Experimental Conditions:

- H₂ required for PBtL: 0.19 - 0.28 t/t(product)
- Total electricity required: 7.0 - 11.5 kWh/l(product)
- SOEL reduced size by about 20 %
- H₂ required for PtL: 0.6 t/t(product)
- Total specific electricity required for PtL: <24 kWh/l(product)

Key findings (see Figure 5, 6, and 7):

- Detailed process modelling shows huge potential of BtL and PtL combination
- Fuel yield is more than doubled at 97 % carbon efficiency adding H₂ to BtL process

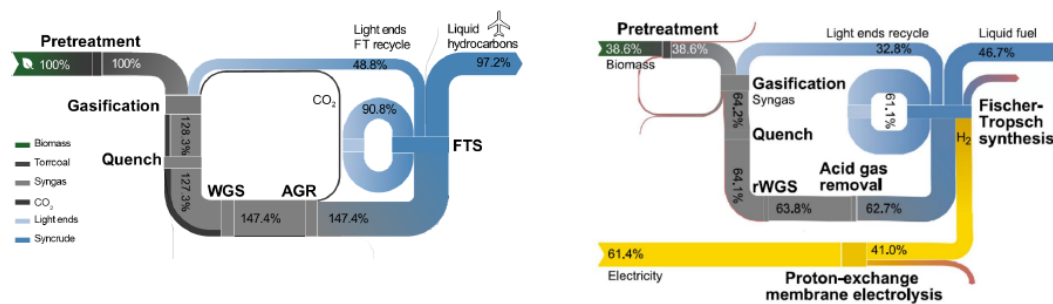


Figure 5 Comparison of conventional BtL (left) and PBtL (right) process configurations for advanced liquid fuel production. The PBtL process integrates proton-exchange membrane electrolysis to achieve higher carbon efficiency (up to 97 %) and product yield while utilizing renewable electricity

- Required electrolyser sizes are about 60 - 160 % of the biomass input
- Use of electrolysis O₂ within the process offers advantage over PtL process routes
- Novel process offers high potential to defossilize transportation, e.g., aviation
- Share of carbon recovered in the product can be enhanced from about 40 % to up to 97 %
- Electricity for the water electrolysis needs to come from renewables, otherwise the carbon footprint might very well be worse than fossil alternatives
- Use of electrolysis O₂ within the process offers advantage over PtL process routes
- Up to + 140 % in product yield are possible
- The process can be net water neutral

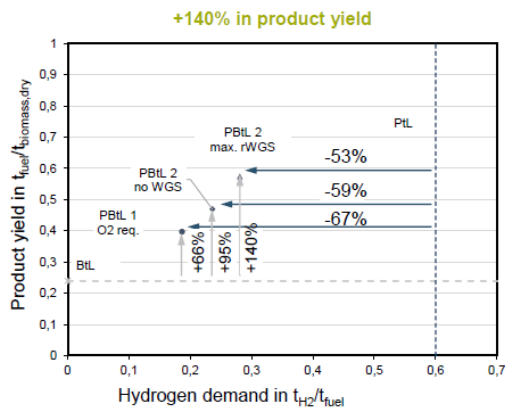


Figure 7 Product yield as a function of hydrogen demand for various PBtL process configurations. The graph demonstrates up to +140 % increase in product yield compared to conventional BtL processes, with configurations such as PBtL with no WGS, oxygen requirement, and maximum rWGS showing significant improvements in carbon efficiency

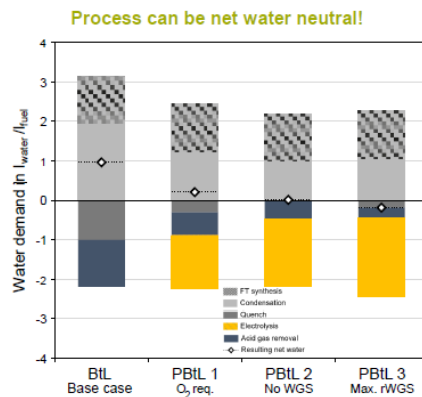


Figure 6 Water demand comparison for BtL and PBtL process configurations. The results highlight the potential for net water neutrality in PBtL processes by optimizing water use across Fischer-Tropsch synthesis, gasification, and electrolysis, particularly in the PBtL 3 (max. rWGS) configuration

Conclusion and Outlook

- **Renewable electricity (wind and solar) will become the largest energy vector on the way towards a net-zero emission energy system**
- **Carbon will be a valuable resource** we need to be very careful about. We need to make the most out of any sustainable/renewable carbon source!
- **Holistic view on sustainability** will increase additional concerns and challenges we need to face today, e.g. **water balance**, social acceptance and other aspects
 - ➔ **Electrification of chemical processes, especially BtX**
- **Special focus on: Plasma-assisted gasification** as a very promising option with a lot of potential but also many challenges to be solved by fundamental and applied research!

MAKING SMALL SCALE CHEMICAL PRODUCTION WORK

By Berend Vreugdenhil

Introduction to Indirect Gasification

Indirect gasification is a versatile and fuel-flexible process designed to convert biomass and other feedstocks into syngas, a precursor for various advanced biofuels. Unlike direct gasification (and entrained flow gasification), which rely on oxygen for combustion, indirect gasification transfers heat indirectly through materials like bed media (see **Figure 8**). This approach enhances feedstock flexibility and avoids the need for oxygen, making it economically viable at smaller scales (e.g., 50 kilotons per annum input). The MILENA system, developed by TNO, exemplifies this technology with its ability to process diverse feedstocks such as biomass, refuse-derived fuel (RDF), and plastic waste.

Several key factors of biomass gasification influence the process and its outcomes:

- **Temperature Range** (Low, Medium, High): Temperature significantly affects the composition of the produced gas, making it a crucial parameter in gasification.
- **Reactor Design** (Fixed Bed, Fluidized Bed, Entrained Flow): The type of reactor greatly determines how the technology is designed and implemented, influencing efficiency and scalability.
- **Heat Transfer Method** (Direct vs. Indirect): In direct gasification, heat is transferred via combustion, while in indirect methods, heat is supplied through mechanisms like heat pipes or bed material. This choice has a substantial impact on the quality of the resulting gas.

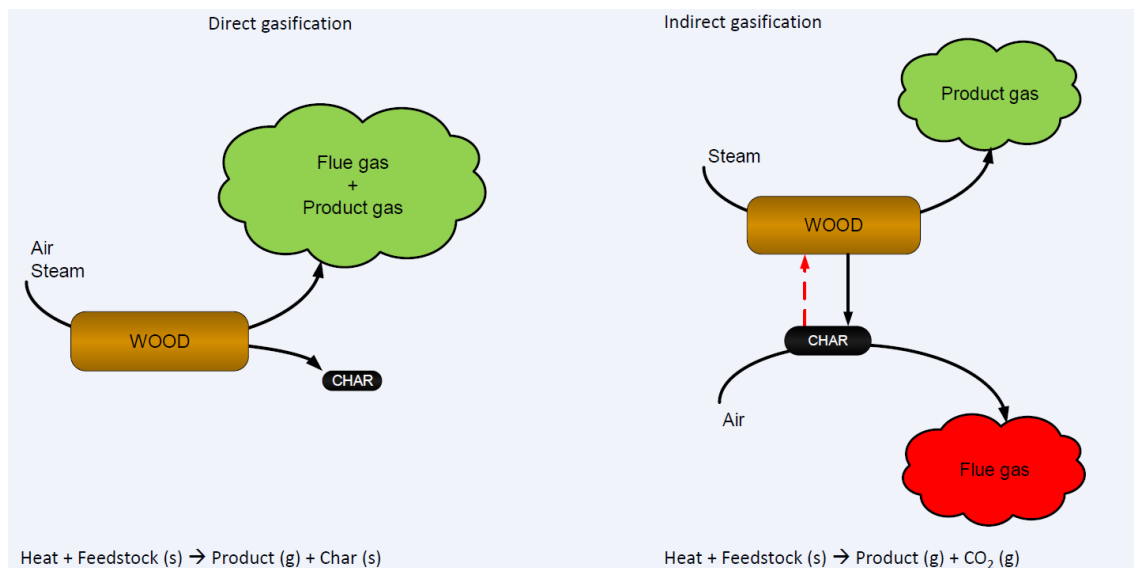


Figure 8 Schematic comparison of direct and indirect gasification processes. Direct gasification involves air and steam to produce flue gas, product gas, and char, while indirect gasification uses external heat transfer to generate product gas with minimal CO₂ emissions.

Pathways to Methanol Production

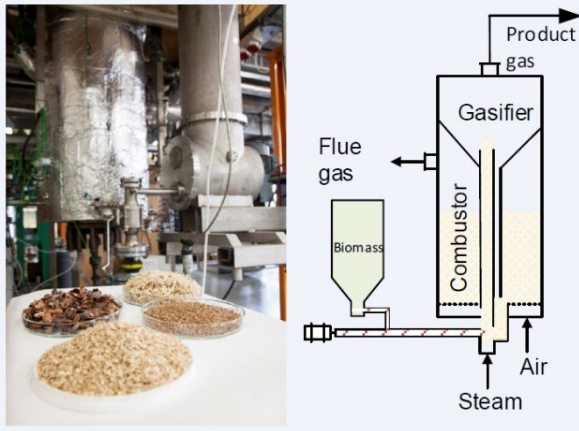


Figure 9 MILENA indirect gasification system setup. The system integrates a gasifier and combustor to process biomass into product gas and flue gas, showcasing its flexibility in handling diverse feedstocks.

The indirect gasifier by MILENA is designed to handle a maximum feedstock flow of 6 kg/h (see **Figure 9**). The range of feedstock types it can process includes biomass, refuse-derived fuel (RDF), and plastic waste. It utilizes supply gases such as nitrogen (N₂), carbon dioxide (CO₂), air, and steam, alongside trace gases like argon and neon. The system is externally heated and capable of reaching temperatures of up to 900 °C. It operates within a T-range of 550 to 850 °C and functions at atmospheric pressure. For monitoring and analysis, the gasifier examines the product gas and the flue gas.

Two primary pathways based on indirect gasification have been explored for methanol (MeOH) synthesis:

1. MILENA-Steam Methane Reforming (SMR) Route (see **Figure 10**):

This pathway integrates the MILENA gasifier with steam methane reforming to produce high-quality syngas suitable for methanol synthesis. Key processing steps include tar removal using

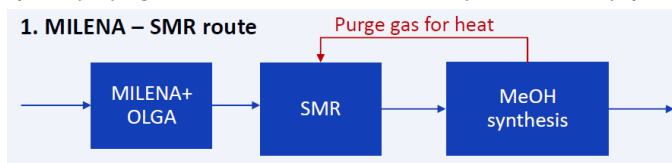


Figure 10 MILENA-SMR route for methanol synthesis. This pathway combines the MILENA gasifier with steam methane reforming (SMR) and OLGA tar removal technology to produce high-quality syngas for methanol production.

OLGA technology, water-gas shift (WGS) reactions, CO₂ scrubbing, and methanol synthesis. Advantages include higher fuel efficiency (62%), lower levelized cost of fuel (LCOF) at approximately €34/GJ, and a CAPEX of 55 M€.

2. MILENA-Thermal Cracking Route (see **Figure 11**):

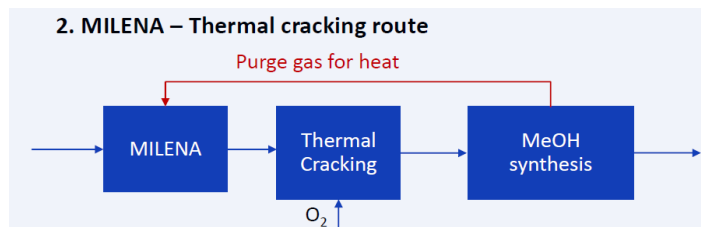


Figure 11 MILENA-Thermal Cracking route for methanol synthesis. This alternative pathway uses thermal cracking instead of SMR, requiring an air separation unit (ASU) for oxygen supply but eliminating additional reforming steps.

In this approach, thermal cracking replaces SMR to process the raw syngas from the MILENA gasifier. While this route eliminates the need for additional reforming steps, it has slightly lower fuel efficiency (57.5%) and a higher LCOF (~€51/GJ). The CAPEX lies at 63 M€ higher due to the inclusion of an air separation unit (ASU) and syngas compressors.

Outlook

To enhance the feasibility of indirect gasification-based methanol production:

- Focus should be placed on improving downstream processing steps after MILENA to achieve optimal syngas quality
- Development of process design packages and life cycle assessments (LCA) will help identify weaknesses in current setups
- Collaboration with industry partners is essential for advancing back-end solutions and scaling up production capacities

Conclusion

- TNO has several technologies under development to produce advanced fuels and/or developments that aid in the line up towards advanced biofuels
- Indirect gasification is a feedstock flexible, small to medium scale attractive pathway to produce advanced biofuels
- TNO is looking for partnership to:
 - Help develop your specific pathway by providing access to state-of-the-art lab facilities
 - Co-develop indirect gasification based value chains toward MeOH (DME, FT, H₂ etc not excluded)
 - Co-develop the back-end solutions for synthesis of biofuels considering the limited availability of feedstock and hence smaller scale compared to fossil routes

R-GAS PLUS: A PIONEERING PATHWAY FOR MAXIMIZING YIELDS OF BIOFUELS FROM BIOMASS GASIFICATION - INSIGHTS FROM GTI ENERGY

By Zach El Zahab

R-GAS Technology Overview

The R-GAS Plus technology represents a significant advancement in biomass gasification, aiming to enhance biofuel yields and improve the thermal efficiency of biorefineries, by employing entrained flow gasification, operating at extremely high temperatures ($>2500\text{ }^{\circ}\text{C}$) to achieve high carbon conversion efficiencies. The process involves rapid quenching of syngas using deionized water to cool it from $1450 - 1550\text{ }^{\circ}\text{C}$ to below $350\text{ }^{\circ}\text{C}$. However, this rapid quench system compromises thermal efficiency by not fully recovering the energy input required for high-temperature operation.

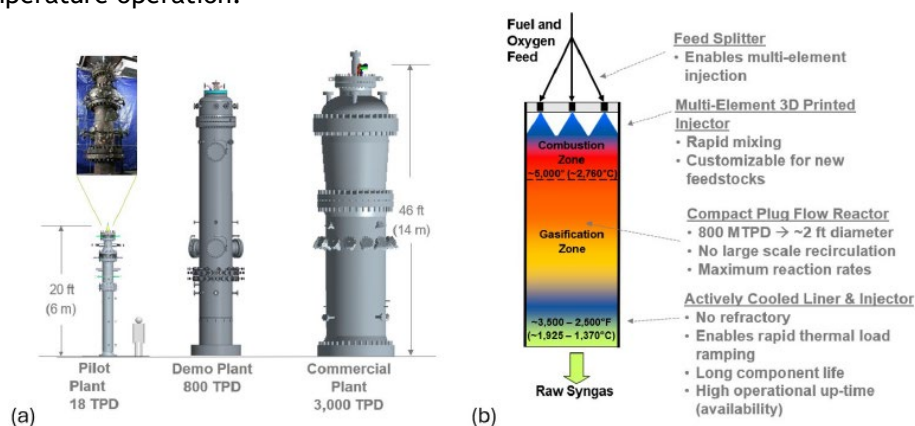


Figure 12 Scalability of R-GAS technology. The diagram illustrates the progression from the pilot plant (18 TPD, 6 m height) to the demo plant (800 TPD, 14 m height) and the commercial plant (3,000 TPD), showcasing the adaptability of R-GAS for various operational scales.

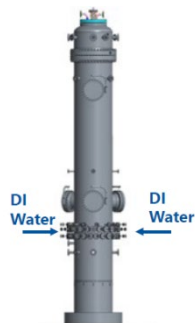
Figure 12 provides an overview of GTI Energy's R-GAS technology, showcasing its scalability, innovative reactor design, and operational efficiency. On the left, the diagram illustrates the scalability of the system, starting with the pilot plant, which processes 18 tons per day (TPD) and stands at a height of 20 feet (6 meters). This progresses to the demo plant, capable of processing 800 TPD with a height of 46 feet (14 meters), and culminates in the commercial plant, designed for industrial use with a capacity of 3,000 TPD. This scalability highlights the adaptability of R-GAS technology for varying operational needs.

The right side of the image focuses on the reactor's advanced design features. The feed splitter enables multi-element injection for efficient feedstock processing. A multi-element 3D-printed injector ensures rapid mixing and is customizable for diverse feedstocks, enhancing flexibility. The compact plug flow reactor operates at a high throughput of 800 metric tons per day (MTPD) within a compact diameter of approximately 2 feet, eliminating large-scale recirculation and achieving maximum reaction rates. Additionally, the actively cooled liner and injector feature a refractory-free design that allows rapid thermal load adjustments, ensuring long component life and high operational uptime.

The reactor operates in two distinct temperature zones. The combustion zone reaches temperatures of around $5,000\text{ }^{\circ}\text{F}$ ($-2,760\text{ }^{\circ}\text{C}$), enabling efficient breakdown of feedstock. Below this lies the gasification zone, maintaining temperatures between $3,500\text{ }^{\circ}\text{F}$ and $2,500\text{ }^{\circ}\text{F}$ ($-1,925\text{ }^{\circ}\text{C}$ to $-1,370\text{ }^{\circ}\text{C}$), where raw syngas is produced efficiently.

R-GAS Rapid Quench Shortcomings

Figure 13
Reactor design of the R-GAS system with rapid quenching using deionized (DI) water



The R-GAS process is based on entrained flow gasification, which operates at extremely high temperatures exceeding 2500°C. This ensures near-complete carbon conversion, making it highly efficient for biomass gasification. The syngas produced is rapidly quenched using deionized water, cooling it from 1450-1550°C to below 350°C (see Figure 13). While this rapid quenching ensures operational safety and stability, it results in a loss of thermal energy, which could otherwise be recovered for additional process efficiency.

The challenge of balancing high-temperature operations with energy recovery is addressed in the following

R-GAS Plus Syngas Enhancement Solution

R-GAS Plus enhancements address the limitations of traditional rapid quenching (see Figure 14). The primary innovation is the integration of a non-catalytic Reverse Water Gas Shift (RWGS) reaction. This reaction utilizes hydrogen to convert CO₂ into CO while simultaneously cooling the syngas endothermically. By injecting hydrogen at the exit of the gasification zone, the syngas temperature is reduced to an optimal range of 1100-1150°C without significant energy loss. Additionally, this approach eliminates the need for a separate carbon capture block, reducing both capital (CAPEX) and operational (OPEX) costs. The recycling of light ends and CO₂ within the gasifier further enhances process efficiency and biofuel yield.

Computational fluid dynamics (CFD) simulations are used to model RWGS injection and optimize reactor designs. The modified process achieves a biofuel output of approximately 189 gallons per dry ton of biomass. This represents a significant improvement over traditional gasification methods. The H₂/CO molar ratio in the syngas is optimized to approximately 2.0, which is ideal for downstream synthesis processes such as Gas-to-Liquid (GTL) conversion.

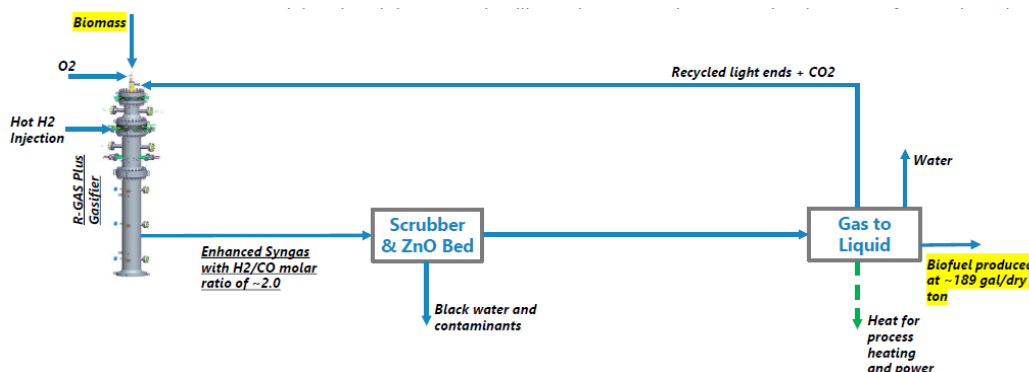


Figure 14 Process flow diagram of the R-GAS Plus system with syngas enhancement illustrates the integration of hydrogen injection into the gasifier, enabling the RWGS reaction to optimize syngas composition (H₂/CO molar ratio ~2.0). Enhanced syngas is processed through a scrubber and ZnO bed for contaminant removal before entering a Gas-to-Liquid (GTL) unit, producing biofuel at approximately 189 gallons per dry ton of biomass. Recycled light ends and CO₂ are reintegrated into the process

Future development needs are outlined, including:

- Conducting extended pilot demonstrations (500 hours)
- Retrofitting reactors with specialized hydrogen injection lances
- Refining techno-economic analyses (TEA) for commercial scalability
- Constructing a cold flow model to simulate RWGS injection dynamics

NATURAL GAS SUBSTITUTION BY SYNGAS MADE FROM BIOMASS AND WASTE WOOD GASIFICATION - INSIGHTS FROM SG ENERGIES

By Yannick Ferriere

The project at the Stellantis aluminium smelter in Mulhouse demonstrates the potential of substituting natural gas with syngas derived from biomass and waste wood gasification. This innovative initiative aims to reduce greenhouse gas (GHG) emissions, enhance energy independence, and establish a pioneering model for sustainable energy use in France. The syngas production process is designed to supply 40 GWh of energy annually, replacing a significant portion of the plant's natural gas consumption.

The main objectives of the project are:

- Reduce GHG emissions for the Stellantis Mulhouse plant
- Increase energy independence by sourcing biomass and waste wood locally or from circular economies
- Support France and Europe's energy independence.
- Contribute to regional GHG emission reduction goals.
- Implement a "first-of-its-kind" syngas production system in France.

The feasibility of the project depends on addressing several technical and economic challenges. Technically, it requires a reliable syngas production technology that is commercially validated, compatibility between the syngas plant's operation and the furnaces (including continuous operation and handling load variations), and the adaptation of furnaces to operate with syngas or bi-fuel burners. Economically, the project must ensure an acceptable cost per MWh for syngas production and secure financial support, such as the DECARB-IND Ademe grant, which could cover up to 40 % of capital expenditure.

Process Overview and Key Project Data

The syngas production process involves several critical steps. Biomass and waste wood are locally sourced, requiring an annual feedstock of 17,000 tons at 30% humidity. The process begins with a dosing hopper feeding biomass into gasifiers to produce raw syngas. This raw syngas undergoes filtration, cooling, cleaning, and compression to meet quality standards before being used in furnaces. The system operates at 9 MW input power, producing 6.7 MW of syngas power and 1 MW of heat power.

Key project data from the basic design study indicates that it operates for 7,800 hours annually. The estimated capital expenditure is €13.4 million, with syngas priced at €70-80/MWh and heat at €50 - 60/MWh. A preliminary layout integrates four aluminium furnaces with the syngas power plant. The project timeline includes multiple phases: opportunity study (one month), basic design (three months), front-end engineering design (three months), and detailed studies leading to commissioning (four months). Currently, the project is in the execution phase.

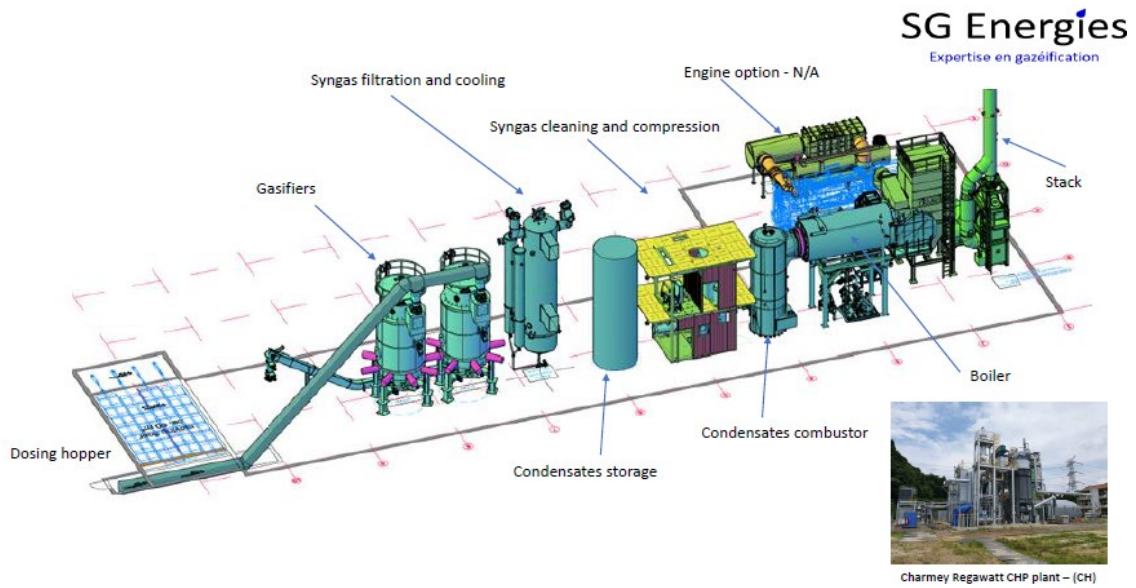


Figure 15 Process flow diagram of the syngas production system at the Stellantis aluminium smelter in Mulhouse. The diagram illustrates key components, including the dosing hopper for biomass feeding, gasifiers for syngas generation, filtration and cooling units for syngas cleaning, compression systems, a condensates combustor, a boiler for heat recovery, and the final stack. The system is designed to produce 6.7 MW of syngas power and 1 MW of heat power from locally sourced biomass and waste wood.

This technology (see **Figure 15**) has potential applications in industries requiring high-temperature processes such as brick manufacturing, lime production, and metal smelting. However, it is best suited for operations requiring continuous processes with moderate fluctuations in demand. Limitations arise when operating at temperatures above 1,200-1,300°C due to constraints in syngas burner technology.

BIOMASS GASIFICATION PERSPECTIVE OF A PROJECT DEVELOPER - INSIGHTS FROM POWER2X LEADING IN ENERGY

By Sriram Ragav

POWER2X explores the development of green methanol production through biomass gasification with a focus on the Power2X Estonia project (see **Figure 16**). It also highlights the challenges and opportunities in scaling up gasification technologies, emphasizing reliability and innovation.

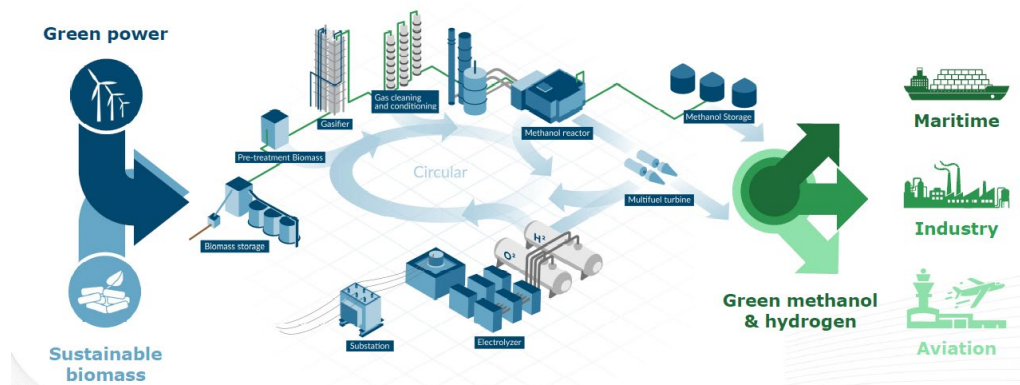


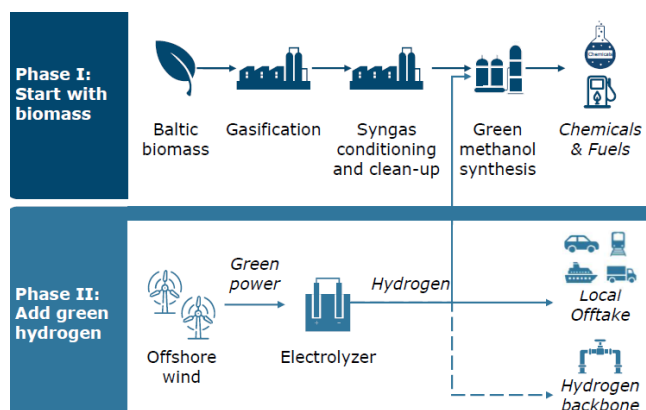
Figure 16 Schematic representation of the Power2X Estonia biomass gasification process. The diagram illustrates the conversion of sustainable biomass into green methanol and hydrogen through gasification, syngas conditioning, methanol synthesis, and integration with renewable energy sources. Applications include maritime, industrial, and aviation sectors.

Power2X Estonia: A Keystone Green Methanol Project

The Power2X Estonia initiative exemplifies the integration of biomass gasification into industrial decarbonization strategies. The project is structured in two phases:

Phase I: Biomass-Based Methanol Production

- Sustainable biomass serves as the primary feedstock.
- The biomass undergoes pre-treatment and processing on-site to produce bio-methanol compliant with REDII standards.
- The bio-methanol is targeted for export to specific markets.



Phase II: Integration of Green Hydrogen

- Offshore wind parks generate green power to produce hydrogen.
- The addition of green hydrogen doubles the output, enabling the production of both bio-methanol and e-methanol.
- Excess hydrogen supports local demand and contributes to Estonia's hydrogen economy.

Figure 17 Phase-wise development of the Power2X Estonia project. Phase I focuses on biomass-based green methanol production, while Phase II integrates offshore wind power to produce green hydrogen, enabling the production of e-methanol and supporting local hydrogen demand, enabling the production of e-methanol and supporting local hydrogen demand.

Technology Derisking and Challenges in Gasification

While gasification is a mature technology, it faces several challenges that must be addressed to ensure reliability and scalability:

- Operating demonstration-scale plants for extended periods is essential to understand and improve reliability
- Sharing operational data can foster collective learning and innovation
- Historical examples, such as the premature closure of waste-to-ethanol plants, underscore the importance of operational stability
- Reliability is critical for gaining confidence in gasification technologies, particularly for long-term investments
- Gasification offers flexibility in feedstock types and product outputs, but feedstock quality and consistency remain crucial factors
- Single-train gasifiers offer cost advantages due to economies of scale but may pose reliability risks
- Multi-train configurations could enhance reliability but may increase capital expenditure (CAPEX)

Conclusion

Despite these challenges, the future of biomass gasification remains promising. The Power2X Estonia project stands out as an example of how biomass can be utilized as a renewable carbon source, while simultaneously incorporating green hydrogen production. Achieving successful gasification, however, hinges on ensuring reliability. This reliability is gained through practical experience, particularly by studying real-world examples of continuous operation and successfully scaling up the technology.

BIO-ACETATE PRODUCTION VIA DUAL FLUIDIZED BED (DFB) SYNGAS FERMENTATION - INSIGHTS FROM TU WIEN AND ICEBE IMAGINEERING NATURE

by Alexander Bartik

This chapter explores the utilization of lignocellulosic biomass as a feedstock for dual fluidized bed (DFB) gasification, the subsequent production of syngas, and its conversion into valuable chemicals and fuels through gas fermentation. The process leverages thermophilic bacteria, such as *Thermoanaerobacter kivui*, to achieve high efficiency and sustainability in acetate production. This approach underscores the potential of coupling advanced gasification systems with microbial fermentation to create renewable bio-based products. The specific goal of this project was the coupling of 'real' DFB product gas with gas fermentation to produce acetate. The concept for coupling can be seen in **Figure 18** and is as follows:

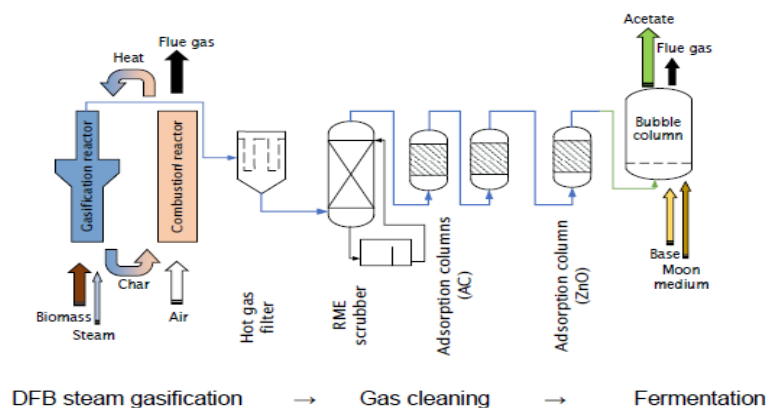


Figure 18 Schematic representation of the process flow for coupling dual fluidized bed (DFB) steam gasification with gas fermentation. Key stages include biomass gasification, gas cleaning (via hot gas filters, biodiesel scrubbers, and adsorption columns), and acetate production in a bubble column reactor using thermophilic bacteria. The integration highlights the use of real DFB product gas for microbial conversion.

1. DFB Steam Gasification

Pilot Plant Design: A 100 kW_{th} advanced DFB pilot plant at TU Wien utilizes two interconnected fluidized beds for efficient heat transfer via bed material circulation.

Product Gas Characteristics: The nearly nitrogen-free syngas enhances downstream fermentation by minimizing impurities.

2. Gas Cleaning

Advanced cleaning systems (i.e., biodiesel scrubber and activated carbon beds & zinc oxide) remove tars, hydrocarbons, sulphur compounds, and other contaminants to ensure compatibility with microbial fermentation.

3. Fermentation

Gas fermentation employs thermophilic acetogenic bacteria to convert syngas into acetate. A 20-liter bubble column reactor at TU Wien demonstrates the feasibility of continuous acetate production under controlled conditions.

The use of *T. kivui* offers several advantages:

- **Thermophilic Growth:** Optimal growth at -70°C reduces cooling costs and enhances reaction kinetics.
- **High Carbon Efficiency:** The Wood-Ljungdahl pathway enables the co-utilization of CO, H₂, and CO₂ with minimal energy loss.
- **Adaptability:** The bacteria can rapidly adapt to CO-rich environments, achieving high growth rates (0.20 - 0.25 1/h) after approximately 31 generations.

Results and Implications of Continuous Culture Experiment:

Experimental Setup:

The continuous culture experiments were conducted using a 4 × 200 mL parallel bioreactor system (DASBOX, Eppendorf). The system was designed to simulate industrial conditions with precise control over gas and liquid feeding. Key parameters included:

- Gas Composition: Syngas with CO: H₂: CO₂ ratios of 52:24:21.
- Dilution Rate: 0.075 h⁻¹.
- Temperature: 66 °C (optimal for thermophilic growth).
- pH: Maintained at 6.4.
- Gas Flow Rate: 0.0633 vvm

This configuration allowed for continuous feeding of syngas and nutrient medium while ensuring steady-state operation over extended periods.

Growth and Productivity:

The continuous culture system demonstrated robust performance over 818 hours of operation, producing acetate as the primary product (see **Figure 19**). Key metrics included:

- Growth Rate: 0.0766 h⁻¹.
- Acetate Productivity: 0.9527 g/L/h.

These results underscore the adaptability of *T. kivui* to syngas fermentation under continuous conditions, achieving stable growth and product formation over prolonged periods.

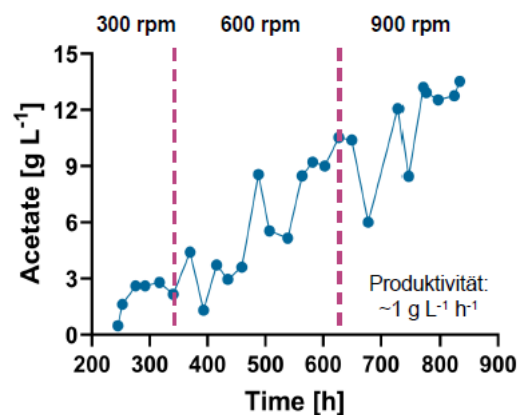


Figure 19 Acetate concentration profile during continuous culture experiments with varying agitation rates (300, 600, and 900 rpm). The system achieved a productivity of approximately 1 g/L/h, demonstrating stable acetate production under controlled conditions.

Coupling with real DFB product gas:

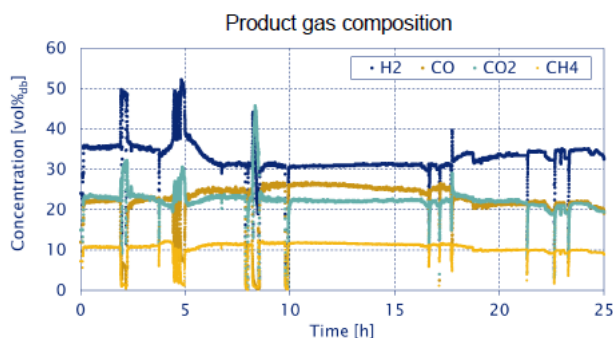


Figure 20 Time-resolved analysis of product gas composition from the DFB system, showing concentrations of H₂, CO, CO₂, and CH₄. The nearly nitrogen-free syngas composition ensures compatibility with downstream fermentation processes.

Growth and Productivity (at 0.075 vvm):

- Growth Rate: 0.102 h⁻¹
- Acetate Productivity: 0.083 g/l/h

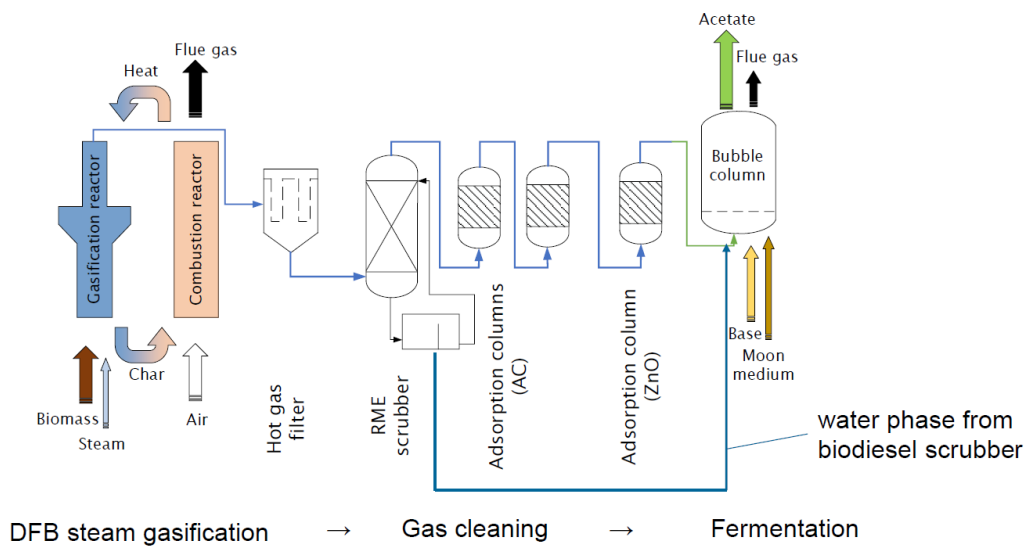
Successful acetate production with productivity limited due to mass transfer limitations of bubble column reactor (see **Figure 20**)

Could we use product gas downstream the biodiesel scrubber without activated carbon, as demonstrated in step 2: Gas Cleaning?

Experimental Conditions: *T. kivui* is introduced to typical impurities found in product gas streams, such as benzene (4000 ppm), toluene (4000 ppm), and H₂S (25 ppm).

Results (see Figure 21):

- 1) The bacterium demonstrated high tolerance, suggesting that gas cleaning systems could potentially omit activated carbon scrubbers without compromising fermentation efficiency.
- 2) The use of the water phase from the biodiesel scrubber is conceivable



Steiner et al. 2024, in preparation

Figure 21 Updated process schematic showing the potential use of biodiesel scrubber water phase as a nutrient medium in fermentation. The modified design omits activated carbon scrubbers, leveraging *T. kivui*'s high impurity tolerance.

WASTE TO CHEMICAL - INSIGHTS FROM NEXTCHEM MAIRE TECNIMONT GROUP AND MYRECHEMICAL

By Andrea Angeletti and Alessia Borgogna

Defining the Green Perimeter: NextChem's Vision

NextChem, a subsidiary of Maire Tecnimont, strives to redefine the green energy landscape with advanced waste conversion technologies. The group's initiatives align with Europe's green transition policies, emphasizing waste management, reduced emissions, and circularity.

Key highlights:

- Inclusion of municipal waste incineration in the ETS from 2028
- Transformation of municipal solid waste (MSW) into methanol, hydrogen, and sustainable fuels.
- Implementation of carbon capture technologies to minimize CO₂ emissions from Waste-to-Energy (WTE) facilities.

Waste Composition and Gasification

Key feedstock attributes include:

- Carbon 38.88 %,
Hydrogen: 5.38 %,
Oxygen: 21.54 %
- Nitrogen: 0.85 %,
Sulphur: 0.20 %,
Chloride: 0.93 %
- Moisture: 15.70 %,
Fly ashes: 16.52 %

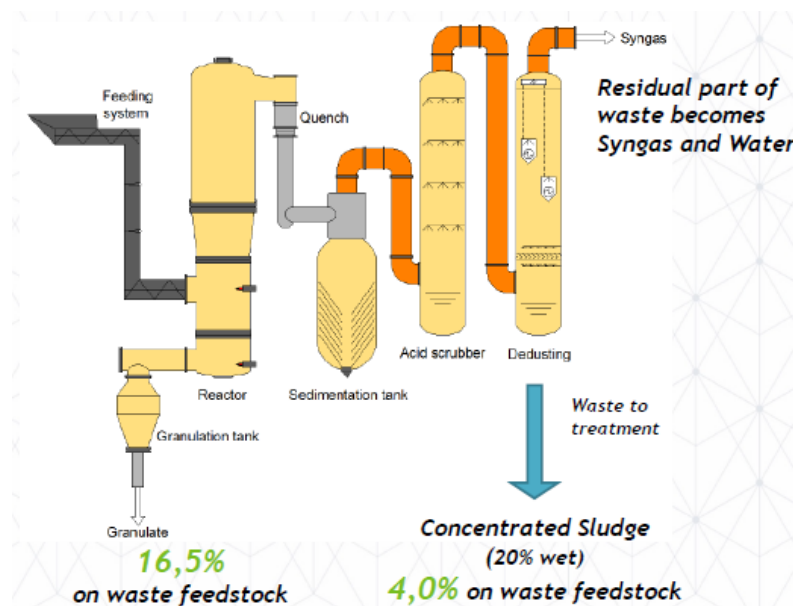


Figure 22 Simplified process flow diagram for waste gasification and granulation, showing the conversion of waste feedstock into syngas, water, granulate (16.5 % of feedstock), and concentrated sludge (4 % of feedstock).

The resultant syngas can be chemically converted to:

- Urea, Fertilizers (via NH₃ synthesis)
- Olefins, Sustainable Aviation Fuel (SAF) (via Paraffins, methanol, and/or ethanol)
- Chemicals, heating, and green steel (via methane, circular hydrogen, and clean syngas)

The production procedure for SAFs via chemical conversion of ethanol (Figure 23), as well as the production procedure of waste to methanol (Figure 24), and the production procedure of waste to methanol and electrolysis (Figure 25) is as follows:

Waste to Ethanol to SAFs

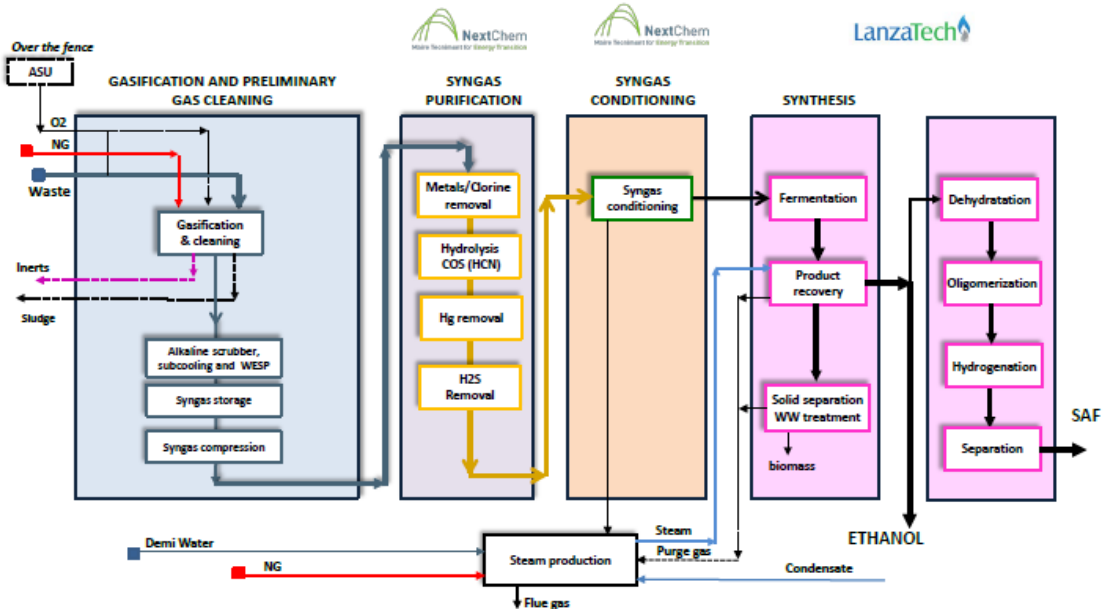


Figure 23 Process flow diagram to produce ethanol from waste-derived syngas, including gasification, syngas purification, conditioning, and synthesis steps leading to sustainable aviation fuel (SAF) production.

Waste to Methanol and H

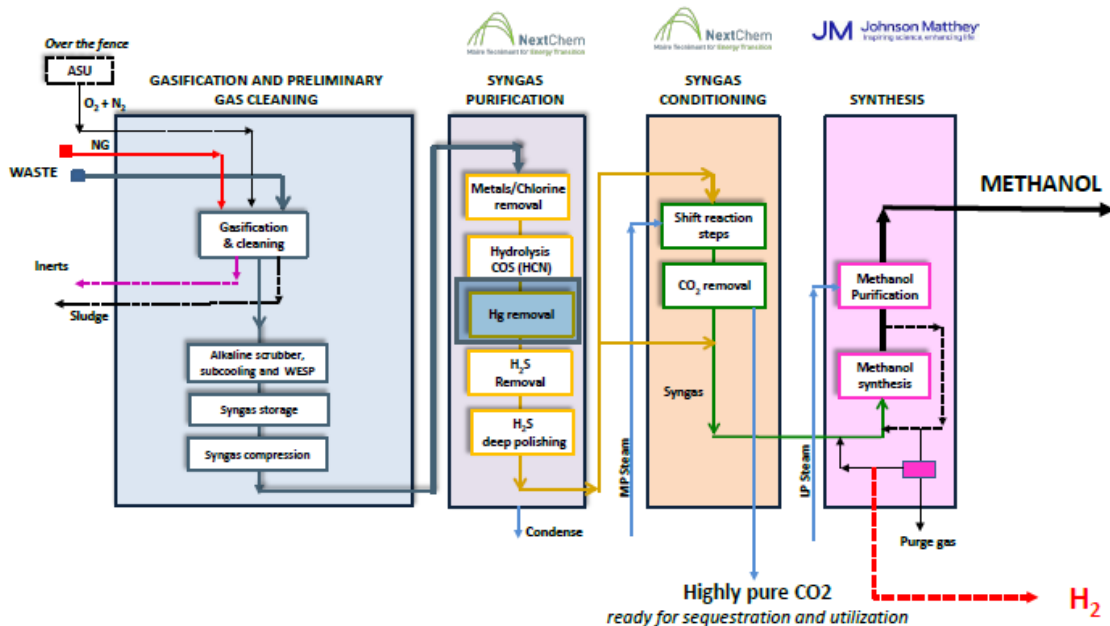


Figure 24 Process flow diagram to produce methanol from waste-derived syngas, highlighting gasification, syngas purification, conditioning, and methanol synthesis with CO₂ capture for sequestration.

Waste to Methanol and Electrolysis

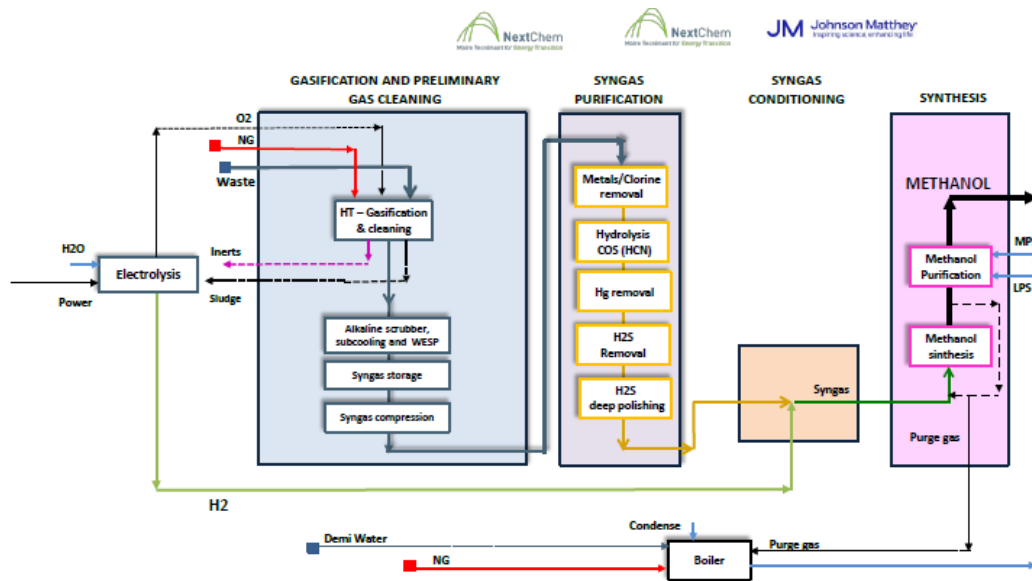


Figure 25 Process flow diagram integrating waste gasification with electrolysis for hydrogen production and subsequent methanol synthesis, showcasing the use of renewable energy inputs.

The integration of waste-to-chemicals technologies into the circular economy is a cornerstone of NextChem’s strategy. Benefits include:

- **Reduced landfill dependency:** By converting waste into valuable products
- **Low-carbon footprint:** Technologies ensure compliance with EU decarbonization policies
- **Product versatility:** Outputs include green steel, renewable fuels, and biopolymers

Results and Industry Impact

NextChem has successfully demonstrated the following:

- **Economic Viability:** Competitive costs compared to traditional fossil-based processes.
- **Environmental Benefits:** Integration of carbon capture reduces the overall carbon footprint.
- **Scalability:** Waste-to-chemical plants have been proposed globally, with capacities exceeding 200 kta of feedstock.

Example: The Rome Hydrogen Valley Project, funded with €194 million under the IPCEI Hy2USE initiative, highlights the scalability and impact of NextChem’s technologies.

RENEWABLE OLEFINS, COMPARISON OF PRODUCTION OVER METHANOL OR FISCHER TROPSCH ROUTE - INSIGHTS FROM KARLSRUHE INSTITUTE OF TECHNOLOGY (KIT)

By Reinhard Rauch

This chapter explores the production of renewable olefins, focusing on two primary pathways: the Methanol-to-Olefins (MtO) process and the Fischer-Tropsch (FT) synthesis. Both methods utilize synthesis gas (syngas) as a feedstock, derived from biomass or other renewable sources. The study evaluates their efficiency, integration potential, and suitability for sustainable chemical production.

Overview of Renewable Olefin Production

Renewable olefins are essential building blocks for the chemical industry, traditionally derived from fossil fuels. Transitioning to renewable sources involves utilizing syngas through either the MtO or FT pathways. This study compares these methods under identical input conditions: 100 MW syngas at 40 bar and ambient temperature, with a H₂:CO ratio of 2 for MtO and 2.27 for FT, respectively. Internal recycles were not modelled in detail, but included in the analysis

Methanol-to-Olefin (MtO) Pathway

The MtO process involves three key steps (see Figure 26):

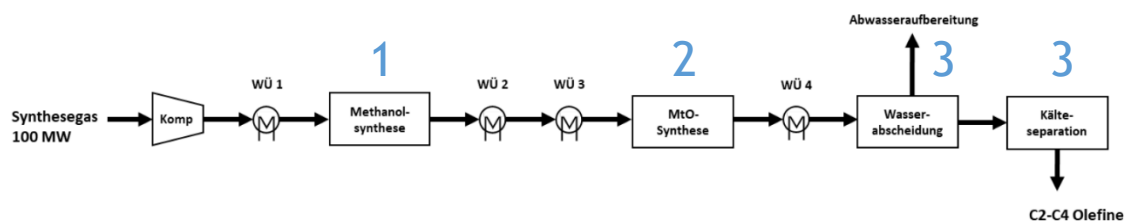


Figure 26 Process flow diagram of the Methanol-to-Olefins (MtO) pathway. The process includes methanol synthesis, olefin production, and cryogenic separation of olefins, starting from 100 MW syngas feedstock. Key outputs include C2-C4 olefins and water as a byproduct.

- 1. Methanol Synthesis:** Syngas is converted into methanol at 80 bar and 250 °C
- 2. Olefin Formation:** Methanol undergoes catalytic conversion at 2 bar and 500 °C, producing a mixture of olefins and byproducts
- 3. Separation:** Cryogenic distillation isolates raw olefins

The composition of the MtO product stream includes:

- Water: 56.2 %
- Ethene: 21.9 %
- Propene: 13.5 %
- Butene: 5.2 %
- Minor components like ethane and carbon

Fischer Tropsch (FT) to Olefins

The FT process operates at 350 °C and 15 bar, with a chain growth probability (α) of 0.75. Key steps include:

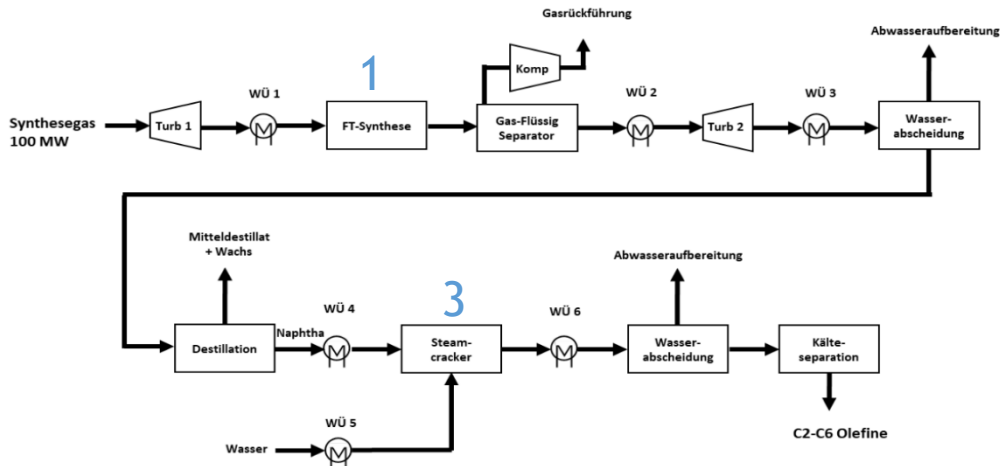


Figure 27 Process flow diagram of the Fischer-Tropsch (FT) synthesis pathway. The pathway involves FT synthesis, gas-liquid separation, distillation, and steam cracking of naphtha to produce C2-C6 olefins. The process also generates middle distillates, waxes, and water as byproducts.

1. **FT Synthesis:** Produces hydrocarbons across a wide range of chain lengths.
2. **Naphtha Cracking:** The C5-C11 fraction is cracked in a steam cracker to generate olefins.
3. **Recycling:** Paraffins are recycled internally for enhanced efficiency.

The FT pathway yields a variety of products, including olefins, paraffins, and heavier hydrocarbons.

Energy Efficiency and Integration

MtO Process (see Figure 28): Exhibits higher overall efficiency due to its streamlined conversion steps but is best suited for greenfield plants. It can also integrate renewable CO₂ and H₂ as feedstocks.

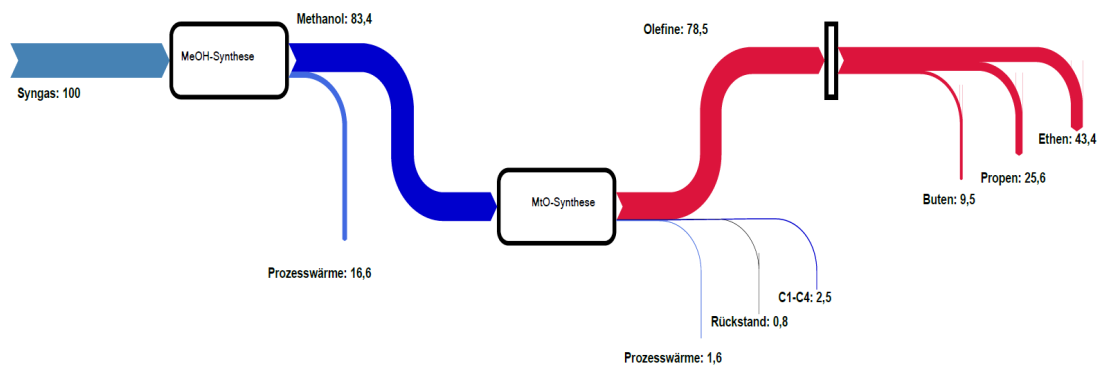


Figure 28 Sankey diagram illustrating energy and material flows in the Methanol-to-Olefins (MtO) pathway. It highlights methanol production (83.4 MW), olefin formation (78.5 MW), and the distribution of olefin products such as ethene (43.4 MW), propene (25.6 MW), and butene (9.5 MW).

FT Process (see Figure 29): Offers easier integration into existing infrastructure like steam crackers but produces more byproducts and has lower olefin efficiency.

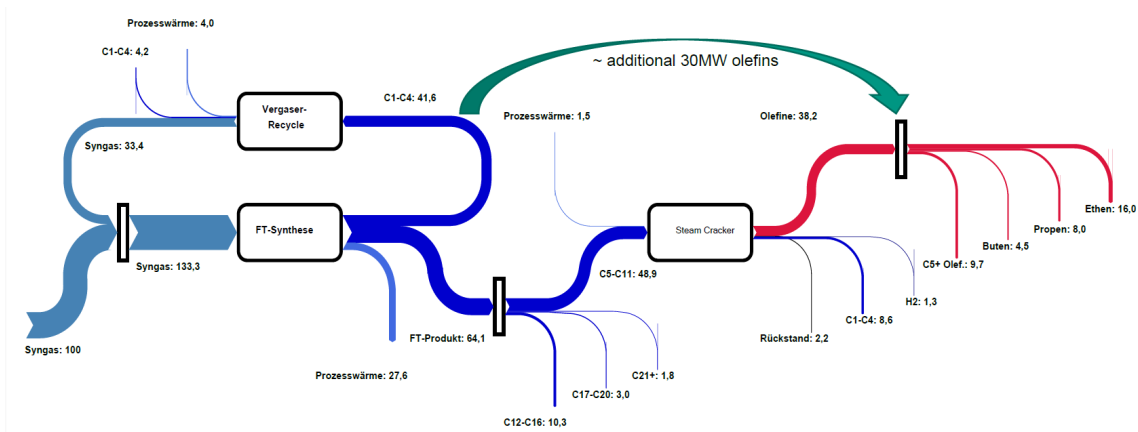


Figure 29 Sankey diagram illustrating energy and material flows in the Fischer-Tropsch (FT) pathway. It shows syngas recycling, FT product distribution, and steam cracking outputs, including olefins (38.2 MW) with a breakdown into ethene (16 MW), propene (8 MW), and butene (4.5 MW). Additional olefins are generated through integration with a steam cracker.

Conclusion

- The MtO pathway achieves higher efficiencies in olefin production but requires dedicated facilities
- The FT pathway benefits from compatibility with existing systems but has a broader product spectrum, including non-olefin hydrocarbons
- Recycling gaseous byproducts into the gasifier enhances the FT process's sustainability
- Both pathways demonstrate potential for renewable chemical production, with trade-offs in efficiency, integration, and byproduct management

The choice between MtO and FT pathways depends on specific project goals, infrastructure availability, and feedstock sources. While MtO offers higher efficiency for olefin production, FT provides flexibility in product diversity and integration into established systems. Future studies could explore low-temperature FT processes optimized for jet fuel and naphtha production as byproducts, further enhancing the viability of renewable olefin pathways.

FERMENTATION OF SYNGAS: SCALABILITY FOR SINGLE CELL PROTEIN (SCP) FOR FEED AND FOOD AS WELL AS BIOPLASTICS (POLYHYDROXYALKANOATES, PHAS) - INSIGHTS BY CIRCE BIOTECHNOLOGY GMBH

By Dr. Maximilian Lackner

The project by CIRCE Biotechnology GmbH focuses on the potential of syngas fermentation to produce alternative proteins and bioplastics, particularly Single Cell Protein (SCP) for feed and food, and polyhydroxyalkanoates (PHA) as sustainable bioplastics. This approach leverages gas fermentation technologies to address global challenges in food security, plastic pollution, and carbon emissions.

Single Cell Protein (SCP): A Sustainable Protein Source

Single Cell Protein (SCP) serves as a microbial-based protein source for animal feed or human consumption. The production of SCP through syngas fermentation provides numerous advantages. It capitalizes on low-cost feedstocks, such as syngas derived from biomass, reducing dependence on traditional agricultural resources like land, water, and fertilizers. This decoupling from conventional inputs makes SCP production more environmentally sustainable and economically viable. Moreover, the process achieves high carbon efficiency while minimizing waste, positioning it as a promising solution for the rapidly growing alternative protein market.

Polyhydroxyalkanoates (PHA): Bioplastics of the Future

Polyhydroxyalkanoates (PHA), including polyhydroxybutyrate (PHB), are biodegradable polymers that offer properties comparable to conventional plastics. Their production through syngas fermentation presents an environmentally friendly alternative to fossil-based plastics, which are produced with 400 million tons per year. PHAs can be used in various applications due to their versatility as thermoplastics and precursors for thermosets, with a potential of covering 90 % of all plastics produced today. Additionally, replacing traditional plastics with PHAs could significantly lower CO₂ emissions associated with plastic manufacturing. Advances in bioreactor technology have made large-scale PHA production feasible, with ongoing efforts to enhance energy efficiency and productivity.

Gas Fermentation: State-of-the-Art Technology

Gas fermentation is a versatile and innovative biotechnology approach that utilizes microbes to convert gaseous substrates into valuable products. This process has several state-of-the-art attributes. It employs low-cost feedstocks, which can be sourced from biobased materials, making it both economical and environmentally friendly. Depending on the feedstock and process, gas fermentation can operate aerobically, using methane (e.g., from biogas), or anaerobically, utilizing carbon monoxide, hydrogen, and carbon dioxide (e.g., derived from biomass gasification). One of the advantages is its low environmental footprint, requiring minimal land, water, and fertilizers, making it sustainable and highly efficient. Moreover, this technology can decouple production from agricultural primary resources, offering independence from traditional farming inputs. However, a notable challenge remains: the low solubility of feed gases in water, which can limit efficiency. Despite this, gas fermentation boasts a long history of development and is now on the brink of large-scale commercialization, signalling its potential to transform industrial biotechnology.

The target products of gas fermentation include high-value materials such as bacterial single-

cell protein (SCP), which can be used as a sustainable source of feed and food. Additionally, it can produce biopolymers such as polyhydroxybutyrate (PHB) and other polyhydroxyalkanoates (PHA), which are biodegradable plastics with significant applications in reducing plastic waste and advancing a circular bioeconomy.

Carbon Circularity: A Holistic Solution

To tackle the problem of CO₂ emissions resulting from biogas production, methane fermentation and syngas production, respectively, it is suggested to keep CO₂ circular. This can be achieved by coupling of aerobic and anaerobic fermentation processes to achieve CO₂-neutral gas fermentation. This approach ensures that all carbon in the feedstock is converted into useful products rather than being released as waste.

Current Status

The current focus of research is on strain selection and development, alongside the advancement and scale-up of fermenter technology. The comparison seen in **Figure 30** emphasizes the strengths and weaknesses of each reactor type for industrial applications, with the Vertical Loop Bioreactor standing out due to its high productivity and energy efficiency.

Reactor	Continuously stirred tank reactor (CSTR)	forced-liquid loop vertical bioreactor (VTLB)	forced-liquid horizontal loop tubular bioreactor (HTLB)	Airlift (AL) fermenter	Bubble column fermenter (BC)
Methane conversion	medium	high	high	high	high
Energy efficiency	Lowest	high	highest	medium	medium
Cooling	Difficult at large scale	best	best	good	good
$k_L a$ value	0.0056 s^{-1}	0.034 s^{-1}	0.037 s^{-1}	0.0482 s^{-1}	0.028 s^{-1}
Productivity	0.14 g/(L-h)	1.0 g/(L-h)	0.786 g/(L-h)	0.15 g/(L-h)	0.18 g/(L-h)

Figure 30 Comparison of different bioreactor types for syngas fermentation, highlighting methane conversion efficiency, energy efficiency, cooling capability, mass transfer coefficient (kLa), and productivity. The Vertical Loop Bioreactor (VTLB) demonstrates the highest productivity (1.0 g/L/h) and energy efficiency, making it particularly suitable for industrial applications. Data also illustrate trade-offs in cooling capabilities and kLa values across reactor types.

Conclusion

- Bacterial single cell protein (SCP) attractive for feed and food
- PHB (and its copolymers) attractive to replace fossil and nondegradable plastics
- Coupled process can achieve CO₂-neutral gas fermentation
- Maximum growth rates of 3.75 g/(l*h) were measured. Contents of 51 to 72 % of crude protein and max. 78 % of PHB were found (dry cell mass)
- The mass balance shows that by coupling the aerobic and the anaerobic fermenters, all carbon in the feedstock can be converted to product

INTEGRATING WASTE CRACKING WITH EXISTING PETROCHEMICAL INDUSTRY: THE FATE OF CONTAMINANTS - INSIGHTS FROM SYNOVA

By Robin Zwart

Synova is a company focused on delivering innovative defossilization solutions by integrating advanced waste recycling technologies with the existing petrochemical industry. They specialize in developing and licensing chemical recycling solutions that transform waste, such as plastic-rich materials, into high-value chemicals, as well as renewable fuels technologies that convert biomass into sustainable energy sources. Synova's proprietary technologies, which include the MILENA gasifier and OLGA tar removal system, are designed to process waste into clean feedstocks efficiently and sustainably.

Overview and Key Features of the MILENA-OLGA Technology

The MILENA-OLGA system represents a scalable solution for chemical recycling and renewable fuel production, utilizing a dual fluidized bed (DFB) gasification process to transform waste materials into chemicals and fuels. The MILENA gasifier is based on Fluid Catalytic Cracking (FCC) technology couples with fluidized beds and operates at approximately 750 °C, relying

on circulating sand for heat transfer without requiring external fuels. This process is complemented by the OLGA tar removal system, which ensures the efficient cleaning of product gas by removing 99.9 % of polyaromatic hydrocarbons (PAHs) and particles. It is designed to integrate seamlessly with existing petrochemical facilities, such as steam crackers.

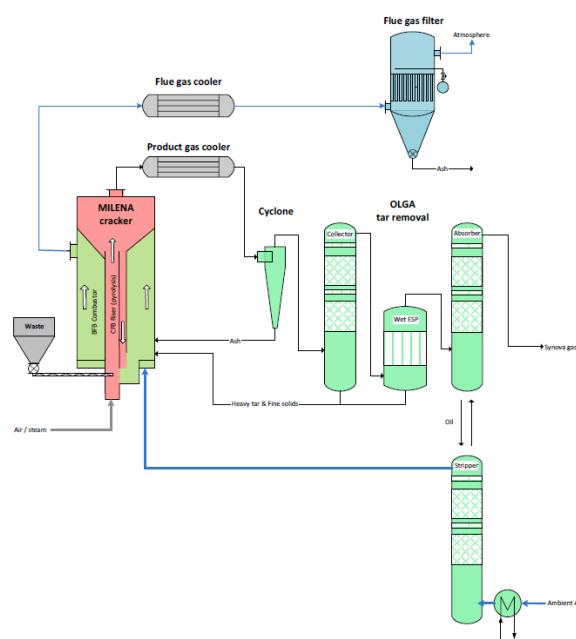


Figure 31 Schematic representation of the MILENA-OLGA system for waste-to-chemical conversion. The MILENA gasifier utilizes a dual fluidized bed process to crack waste into syngas, while the OLGA tar removal system ensures efficient cleaning of the product gas by removing tars and particulates. The system integrates seamlessly with existing petrochemical facilities, enabling the production of olefins and other valuable chemicals from waste materials.

Applications and Integration Possibilities

The MILENA-OLGA system is capable of bypassing cracker furnaces, facilitating direct conversion of waste-derived gases into olefins or other valuable products, offering solutions for various waste-to-chemical pathways:

- **Plastic-rich Waste to Olefins:** Integration downstream of steam cracker furnaces.
- **Plastic-rich Waste to BTX (Benzene, Toluene, Xylene):** Suitable for refineries or as a standalone operation.
- **Polystyrene-rich Waste to Styrene:** Directly integrates with existing polystyrene production facilities

Contaminant Management in Product Gas

Typical impurities from FCC gas and their effects are for example:

- H₂S: Poisons catalysts
- COS, RSH, Acetylene, HCN, Arsine: Affect product specifications (C₂= or C₃=)
- Chlorides: Corrosive to aluminium
- Ammonia and Nitric Oxides: Can form hazardous compounds like NO₃ or nitroso gums
- Mercury: Attacks aluminium in cold sections
- H₂O: Freezes in cold sections

To address these issues, effective contaminant removal is critical. The MILENA-OLGA system addresses this through:

- Absorption techniques: Solid bed absorbents for chlorides, mercury, arsine, and HCN
- Hydrogenation: Converts impurities like acetylene into less harmful compounds
- Amine/caustic washes and molecular sieves: For H₂S and H₂O removal

For a real-life example, industrially sorted DKR-350 waste - which includes a biogenic fraction, PET, and other plastics not classified as naphtha - was tested for contaminants. The key findings are as follows:

- Over 40 % of the gas produced is composed of C+ components (on a dry and N₂-free basis)
- Processing 50 kta (kilotons per annum) of mixed waste generates:
 - 13.5 kta of ethylene and propylene
 - 19 kta of high-value chemicals
- The mixed waste composition includes:
 - 59 % mixed plastics
 - 29 % biomass (plus other inert materials)
- Ethylene/propylene yield is approximately 45 wt% of the processed plastic

However, there are additional concerns raised for the MILENA-OLGA product gas as of the differences in feedstock. These are as follows:

- **Operational Disturbances:** High quantities of hydrogen (H₂), carbon monoxide (CO), carbon dioxide (CO₂), and water (H₂O) can disrupt the Steam Cracker Unit (SCU), affecting its efficiency.
- **Catalyst Poisoning and Fouling:** Several impurities, including aromatic hydrocarbons (tars), acetates, aldehydes, acids (e.g., fatty acids), alcohols, diols, ketones, esters, ethers, and silicones, promote fouling and poison catalysts. Silicones, in particular, cause permanent catalyst damage.
- **Product Contamination:** Sulphur compounds (H₂S, COS, mercaptans, thiophenes) and nitrogen compounds (NH₃, HCN) pollute final products or specific outputs such as ethylene. Chlorine compounds (HCl, Cl₂, organic chlorides) not only contaminate products but also pose corrosion risks.
- **Environmental and Safety Risks:** Dioxins and PFAS contaminate products and create environmental hazards. Oxygen and nitric oxides introduce significant safety concerns due to their explosion potential.

The analysis of the 200+ contaminants is being done by external laboratories of SABIC, Intertek, SGS and Bureau Veritas

Conclusion

The IEA Bioenergy Task 33 workshop on gasification for production of biochemicals, held in June 2024 and hosted by KIT, provided a detailed exploration of the latest advancements and challenges in this transformative field. The findings highlighted the potential of biomass gasification to drive decarbonization, support renewable energy systems, and contribute to sustainability goals.

Key technological advancements were discussed, such as R-GAS and MILENA-OLGA processes, which improve syngas quality, carbon efficiency, and scalability for biofuel and chemical production. Electrification of gasification, particularly through Power-and-Biomass-to-X (PBtX) and eBtX processes, was emphasized for its ability to significantly enhance product yields when integrated with renewable electricity. Indirect gasification technologies like MILENA demonstrated flexibility in processing diverse feedstocks such as waste, biomass, and plastics, making them economically viable for small-to-medium scale applications. Integration with downstream processes like Fischer-Tropsch synthesis and methanol-to-olefins conversion further showcased the versatility of syngas as a feedstock for renewable chemicals and fuels.

Sustainability was a focal point, with discussions on carbon circularity and innovations in renewable biochemicals production aligning with global decarbonization targets. Projects coupling biological systems with thermochemical processes, such as microbial fermentation for bio-acetate and single-cell protein (SCP) production, underlined the role of gasification in advancing circular economies. Industrial scaling was also addressed through initiatives like Power2X Estonia and NextChem's waste-to-chemical projects, which exemplify practical pathways for scaling biomass gasification into impactful industrial applications such as green methanol and sustainable aviation fuels (SAF). However, economic competitiveness and policy support remain significant barriers to widespread adoption.

The workshop concluded with a unanimous agreement on the critical role of biomass gasification in achieving a net-zero energy system. Success depends on investments in research and industrial-scale projects to ensure reliability and cost reduction, adoption of renewable electricity for integrated processes to maximize carbon efficiency, cross-sector collaboration to develop robust value chains, and supportive regulatory frameworks to accelerate deployment. These advancements reinforce the viability of biomass gasification as a cornerstone technology for renewable energy and sustainable chemical production.



IEA Bioenergy
Technology Collaboration Programme