Advanced Fischer-Tropsch biofuels production from syngas derived from Chemical Looping Gasification: A preliminary process simulation study

EUBCE 2020 28th European Biomass Conference & Exhibition *Transition to a Bioeconomy* MARSEILLE – FRANCE | 6 - 9 JULY

N. Detsios[1], K. Atsonios[1], P. Grammelis[1], M-A. Kougioumtzis[1], P. Dieringer[2], C. Heinze[2], J. Ströhle[2]

[1]Centre for Research & Technology Hellas/Chemical Process and Energy Resources Institute, 6th km. Charilaou-Thermis, GR 57001 Thermi, Greece.
detsios@certh.gr, atsonios@certh.gr, grammelis@certh.gr, kougioumtzis@certh.gr

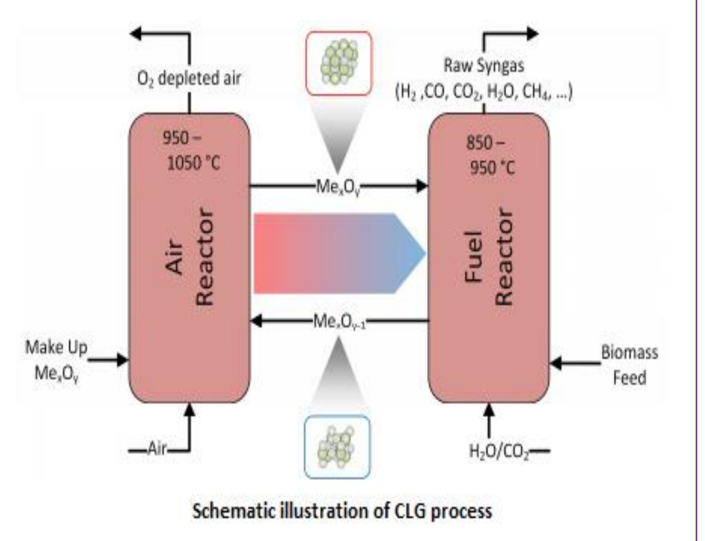
[2]Energy Systems and Technology Technische Universität Darmstadt, Otto-Berndt-Str. 2 Postfach 100636 D-64206 Darmstadt, Germany.
paul.dieringer@est.tu-darmstadt.de, christian.heinze@est.tu-darmstadt.de, jochen.stroehle@est.tu-darmstadt.de

Introduction

In recent decades, there has been a considerable increase in the production of greenhouse gases (GHG) worldwide with negative effects related to the climate change and its consequences. EU targets to a 20% reduction of the GHG emissions by 2020 and 40% by 2030. Taking into consideration that the transport sector contributes almost 30% of total EU greenhouse gas emissions, a major challenge to reach these goals is to increase the share of renewable energy in the nowadays highly petroleum-dependent transport sector. Biofuels have been identified as an effective strategy to reduce CO_2 emissions in transport sector. Lignocellulosic biomass conversion into liquid biofuels through thermochemical routes has been considered as a promising option that offers several advantages. The main challenge for these pathways is to develop advanced technologies with reduced energy consumption. **The main advantages of chemical looping gasification (CLG) compared to the most common gasification technologies is the avoidance of an expensive and energy-consuming Air Separation Unit (ASU), the wide feedstock flexibility and the light biomass handling before gasification.**

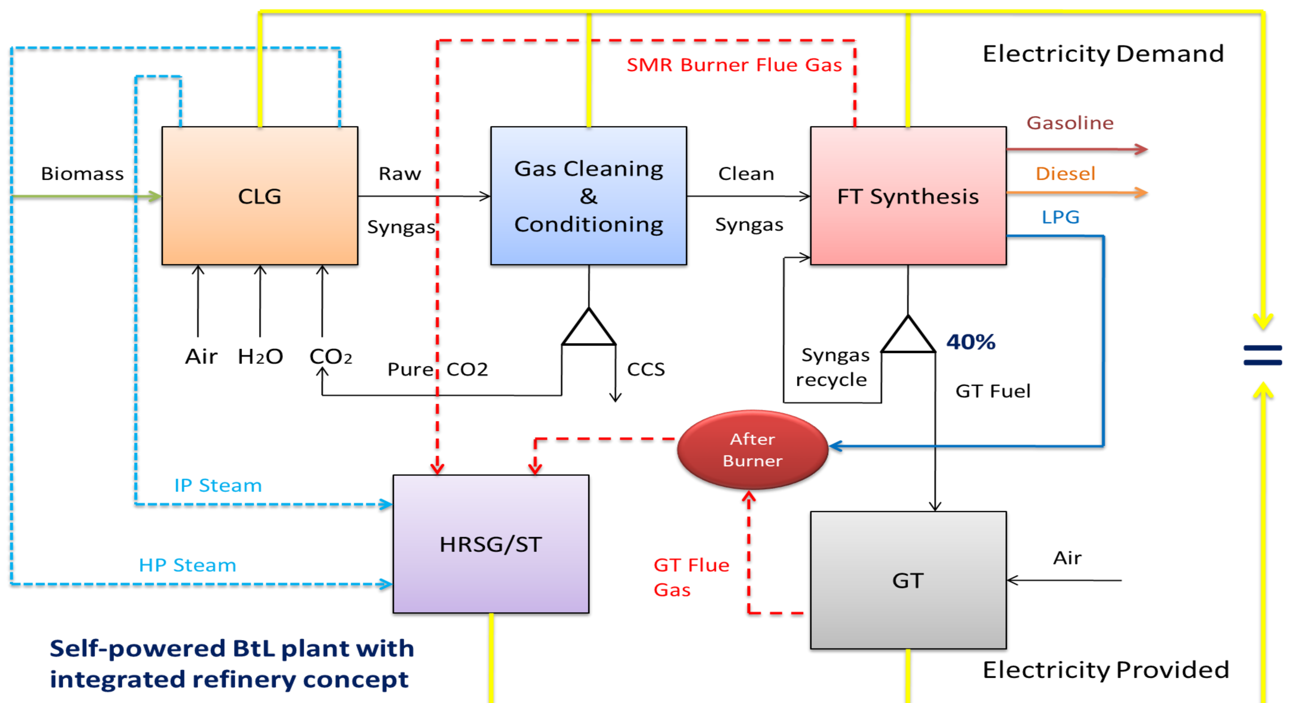
Methodology

This study presents the conceptual process design for the production of Fischer-Tropsch (FT) liquids from syngas derived from CLG. **Process simulations of the overall system for multiple feedstock are performed, investigating the potential of a self-powered Biomass to Liquid (BtL) plant with integrated refinery concept in comparison with a non self-powered BtL plant with separate refinery concept.** The main objective is to perform the necessary energy and mass balance calculations, to determine the appropriate process configuration and to compare the technology efficiency with the corresponding thermochemical route based on oxygen blown CFB gasifier. The model development and the process simulations were carried out with Aspen Plus™.



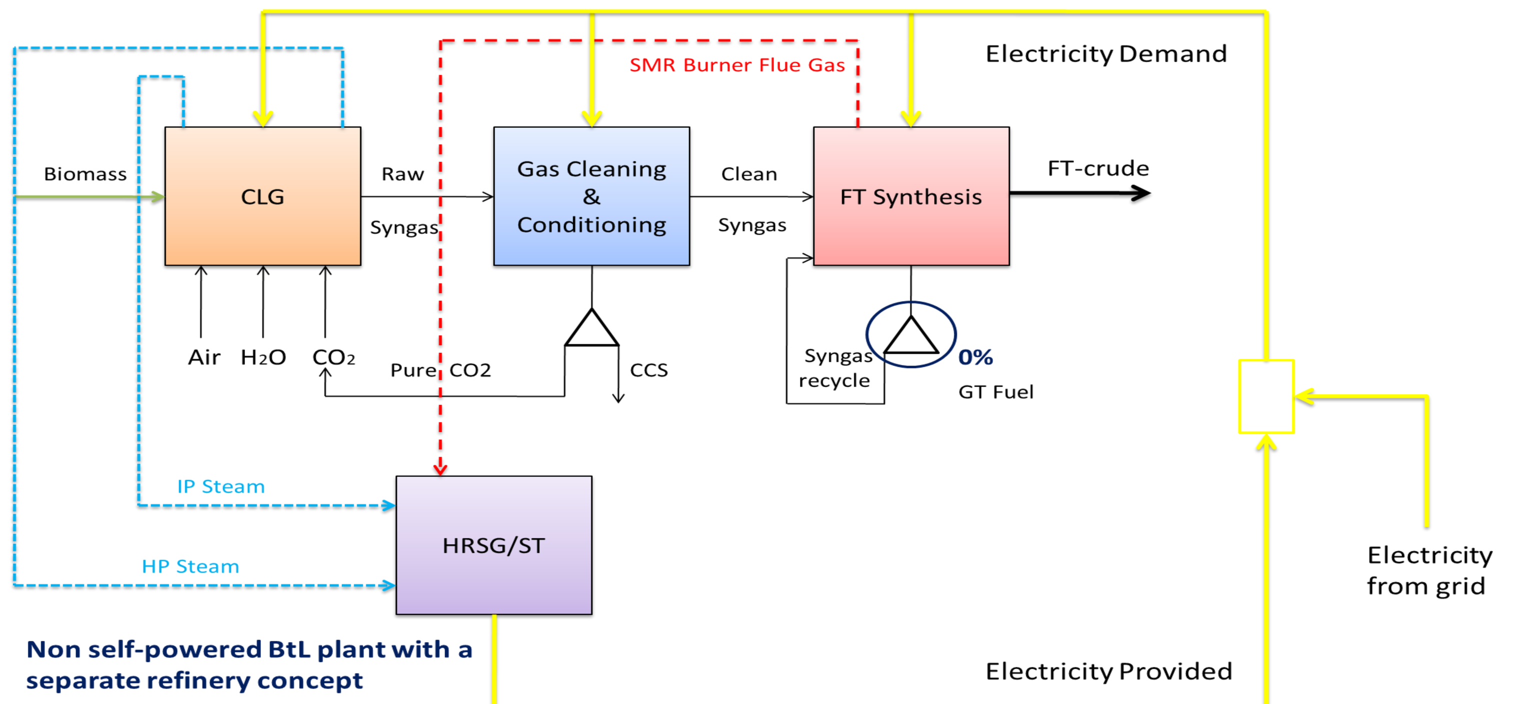
Schematic illustration of CLG process

Self-powered BtL plant with integrated refinery concept



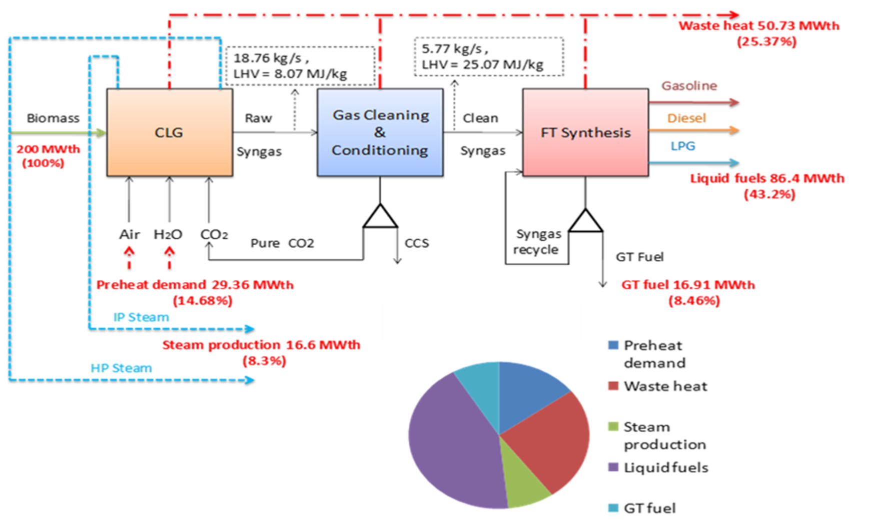
The individual parts that were taken into consideration for the integrated concept are the Chemical Looping Gasification (CLG) unit, the Syngas Treatment & Purification unit, the Fuel Synthesis unit and a Combined Cycle Gas Turbine plant (CCGT). The role of the latter is to cover the heat and power demands of the biomass-to-biofuel process, ensuring the potential of self-powered operation.

Non self-powered BtL plant with a separate refinery concept

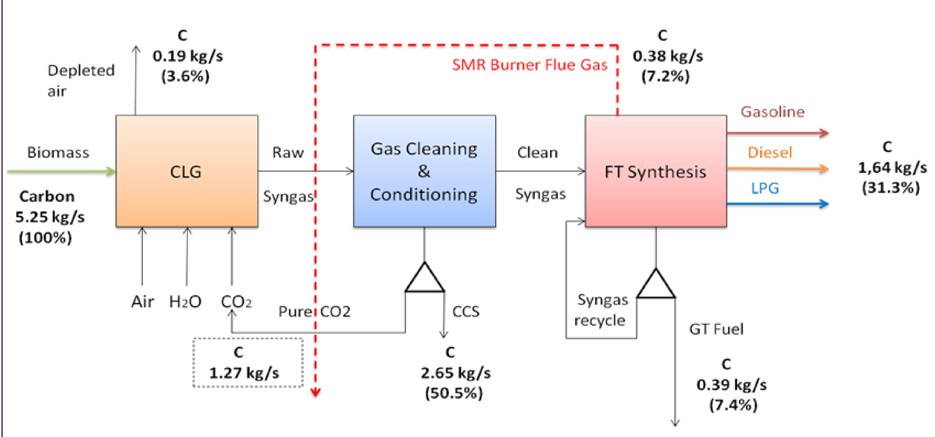


In this case, no GT fuel is provided from the FT unit (splitter value 0%) and the LPG is considered among the final products (not driven to an afterburner), the only power provider of the plant is the ST, utilizing recovered heat from the CLG unit and flue gas after SMR reactor. For this scenario, LPG is a side product formed in the refinery, which can be used for other purposes (e.g. fuel upgrading, energy provision) at the refinery site.

Energy and Mass Balance for the self-powered BtL plant

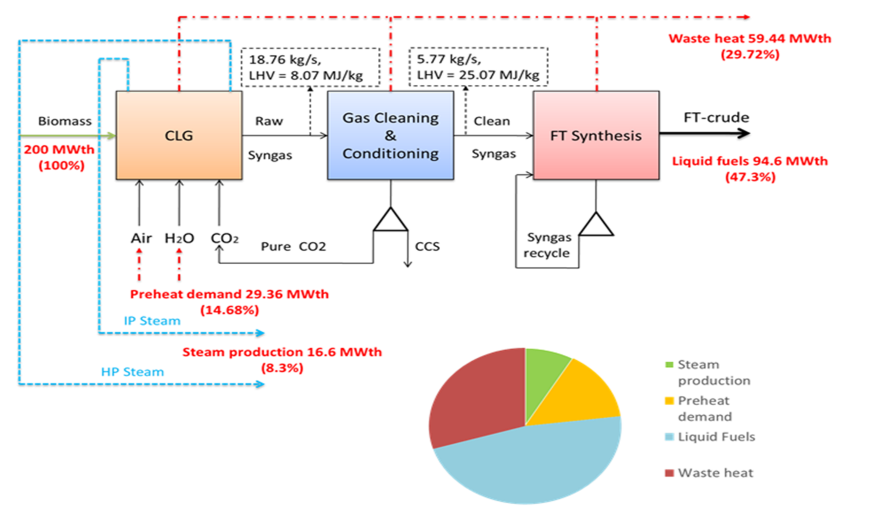


Energy Balance: Approximately 8.5% of the total thermal input is provided to the GT for power production, **yielding an energetic content of the liquid fuels of 43%**. It is also revealed that a considerable amount of heat is rejected from the system as waste heat, meaning that potential enhancement in waste heat recovery may lead to higher overall plant efficiency

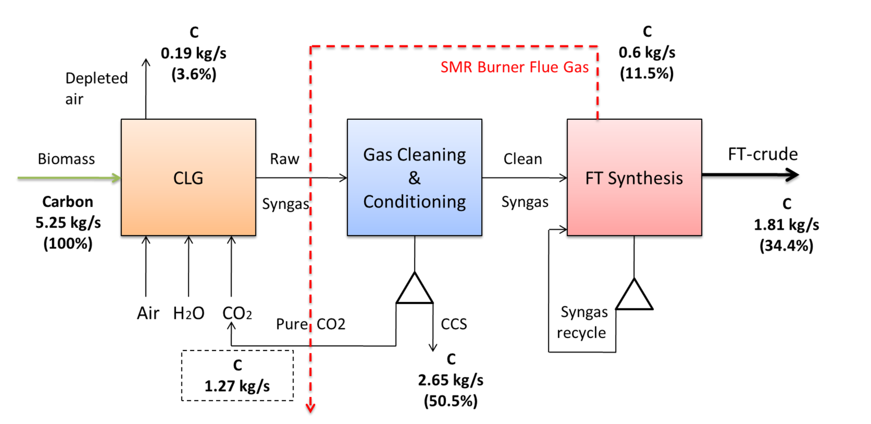


Carbon balance: The feedstock constitutes a carbon source for the BtL process chain. This carbon is distributed to the depleted air from the Air Reactor (AR), the CO2 captured within the Rectisol® process, the Flue Gas produced from the Steam Methane Reformer (SMR) supporting Burner and is driven to the HRSG, the extracted gas fuel that is driven to the GT, and **the final liquid products carbon content (31.3%).**

Energy and Mass Balance for the non self-powered BtL plant



Energy Balance: In this case, where no syngas is used for power production, **a surge in the energetic content of the liquid final products is observed (47.3%).** On the other hand, the biorefinery is not anymore power independent and external electricity requirements come to the forefront.



Carbon Balance: Following the same logic, the absence of GT and therefore the avoidance of partial syngas utilization for power production, **leads to higher carbon content in the final liquid products (34.4%)** as well as in the FT synthesis off-gases (SMR burner flue gases).

Multiple feedstock results for the self-powered BtL plant

Feedstock type	Wood pellets	Wheat straw	Pine residues
LHV (MJ/kg)	17.96	17.12	18.41
Mass flow (kg/s)	11.13	11.68	10.86
Carbon conversion at CLG (CC)	96.4%	98.0%	97.0%
Cold gas efficiency (CGE)	76.0%	77.0%	77.2%
Total power consumptions (MW_e)	22.05	21.12	22.1
Power from grid (MW_e)	0	0	0
Gasoline yield ($kg/kg_{feedstock}$)	0.054	0.051	0.056
Diesel yield ($kg/kg_{feedstock}$)	0.119	0.112	0.124
LPG yield ($kg/kg_{feedstock}$)	0.004	0.005	0.004
Total biofuels yield ($kg/kg_{feedstock}$)	0.173	0.163	0.180
Carbon utilization (CU)	31.3%	31.8%	32.3%
Energetic Fuel Efficiency (EFE)	43.2%	43.0%	43.8%

Multiple feedstock results for the non self-powered BtL plant

Feedstock type	Wood pellets	Wheat straw	Pine residues
LHV (MJ/kg)	17.96	17.12	18.41
Mass flow (kg/s)	11.13	11.68	10.86
Carbon conversion at CLG (CC)	96.4%	98%	97%
Cold gas efficiency (CGE)	76.0%	77.0%	77.2%
Total power consumptions (MW_e)	22.5	21.4	22.7
Power from grid (MW_e)	8.4	6.4	8.8
Gasoline yield ($kg/kg_{feedstock}$)	0.058	0.056	0.061
Diesel yield ($kg/kg_{feedstock}$)	0.128	0.120	0.133
LPG yield ($kg/kg_{feedstock}$)	0.007	0.008	0.007
Total biofuels yield ($kg/kg_{feedstock}$)	0.193	0.184	0.201
Carbon utilization (CU)	34.4%	34.8%	35.2%
Energetic Fuel Efficiency (EFE)	47.3%	47.2%	48.1%

Conclusions

- **Chemical Looping Gasification (CLG) facilitates a functional conversion of the pre-treated biomass precursor materials and allows a continuous and efficient production of a high calorific raw synthesis gas.** In general, the selected fuels exhibit similar behavior concerning the plant performance. The ash content of the biomass feedstock should be taken into consideration when the most appropriate feedstock will be selected, since high ash presence may affect the OC stability at the CLG unit.
- Each process design approach yields certain benefits. On the one hand, **the self-powered case is independent of the location of a conventional refinery and its final products can be marketed directly.** On the other hand, **a BtL Plant with separate refinery concept enhances the efficient utilization of existing sophisticated infrastructure, ensures lower plant CAPEX along with higher biofuel yields, and increases the potential for negative GHG emissions as higher carbon fraction is found in the final products and are not emitted.** The simulation results showed that a holistic socio-techno-economic consideration is required to arrive at a final conclusion regarding the final process design.

Acknowledgements: This work has been carried out in the framework of the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 817841 (Chemical Looping gAsification foR sustainable production of biofuels – CLARA).

www.clara-h2020.eu