Process Analysis Of Chemical Looping Gasification Of Biomass For FT-Crude Production With Net-negative CO_2 Emissions

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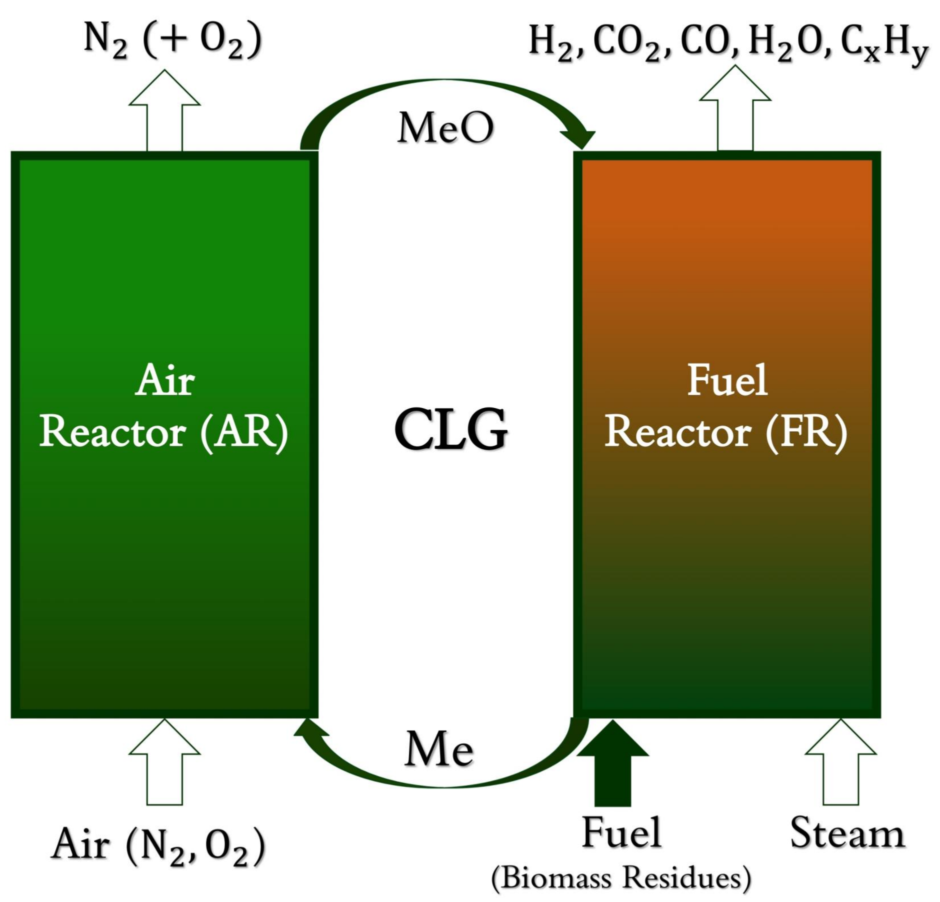
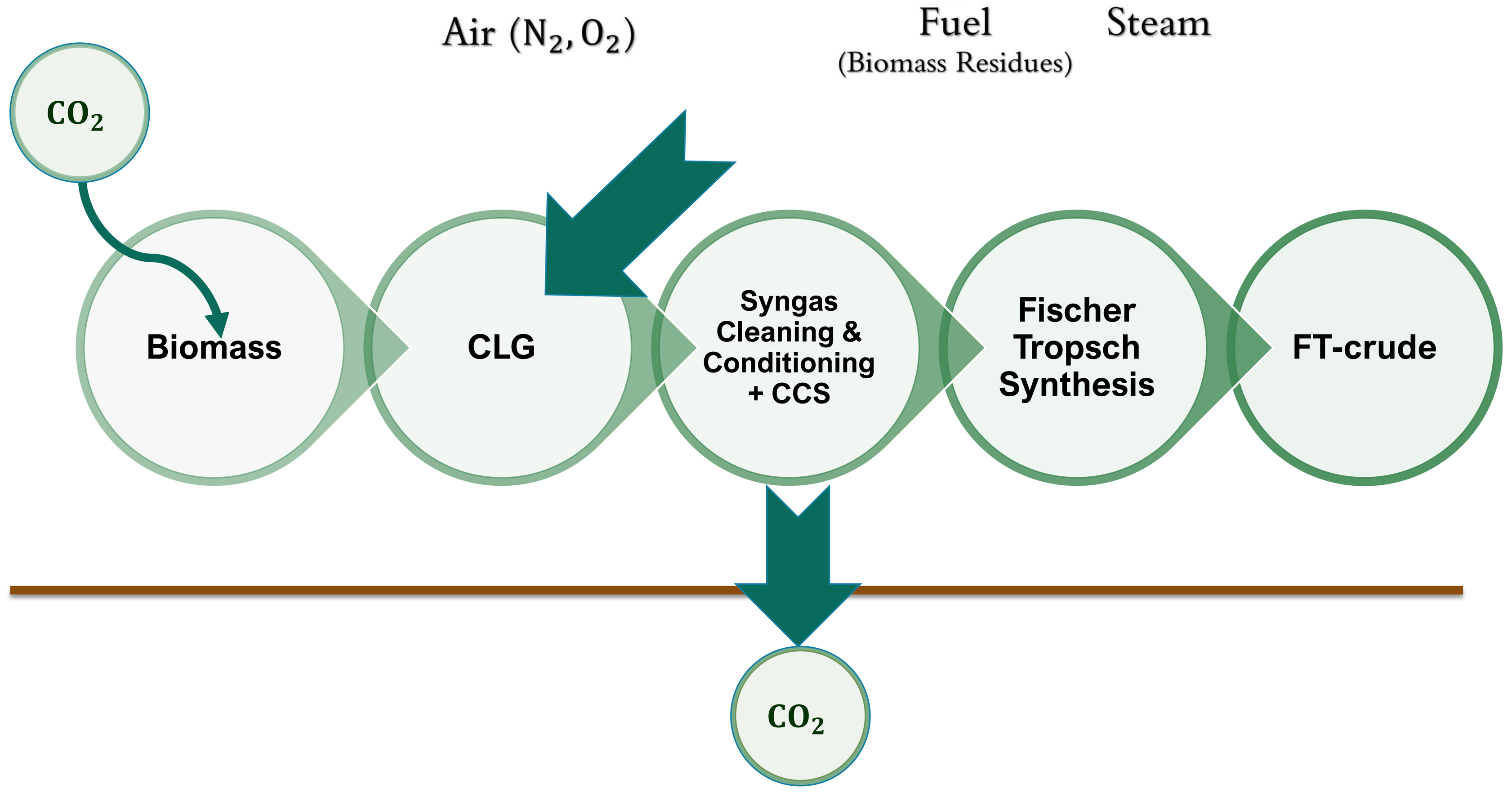
Introduction

- Chemical Looping Gasification (CLG) is a novel gasification technology that resembles indirect gasification in circulating fluidized bed, but instead of inert bed material, a so-called oxygen carrier (e.g. steel converter slag or mineral ores rich in iron or manganese) is utilized.
- The oxygen carrier (OC) particles undergo cyclic oxidation and reduction in the air reactor and the fuel reactors, respectively, providing heat and oxygen for gasification. Thus, the raw syngas produced is more oxidized than in a conventional gasifier, with a lower concentration of tar and a higher concentration of CO_2, enabling feasible CO_2 capture and storage.
- Capturing and storage of CO_2 in the subsequent gas cleaning stages would result in FT-crude production with net-negative or net removal of CO_2 emissions from the atmosphere.
- The costs are expected to be comparably low since CLG should allow for reduced costs for gas and tar cleaning, including the avoided cost for air separation.

Objective

The objective of the study was to estimate the gasification and chemical efficiency of an integrated biomass-to-liquid chain employing chemical looping gasification (CLG) as the primary gasification technology and estimate the liquid fuel production and CO_2 capture capacity from the integrated process plant sized to 100 MW_{th} thermal input of waste biomass.





Methodology & Assumptions

- An integrated steady-state process model was developed using Aspen Plus® simulation software, where the CLG process model was sized to 100 MW_{th} thermal input of forest residues with a moisture content of 15%. This CLG model is then integrated with a downstream Fischer Tropsch Synthesis model[1] developed at Chalmers.
- The model was complemented with Fortran statements to calibrate thermodynamic equilibrium deviations, experienced during associated experimental activities reported in the literature
- LD-slag, an inexpensive and readily available by-product from steel production, was used as the primary oxygen carrier in the process models, with an oxygen transport capacity of 1.12%[2]

LD-Slag Composition	Fe_2O_3	MnO_2	SiO_2	CaO	MgO	Al_2O_3	TiO_2	K_2O
w/w %	28.8	3.3	14.1	42.0	9.1	1.2	1.3	< 0.09

- Oxygen carrier circulation is controlled to achieve an autothermal operation between the two reactors; with FR temperature maintained at 935°C.
- The CLG model was validated with published experimental data[3] available on CLG operation with LD-slag as the oxygen carrier. Sensitivity analysis was conducted to the integrated model.

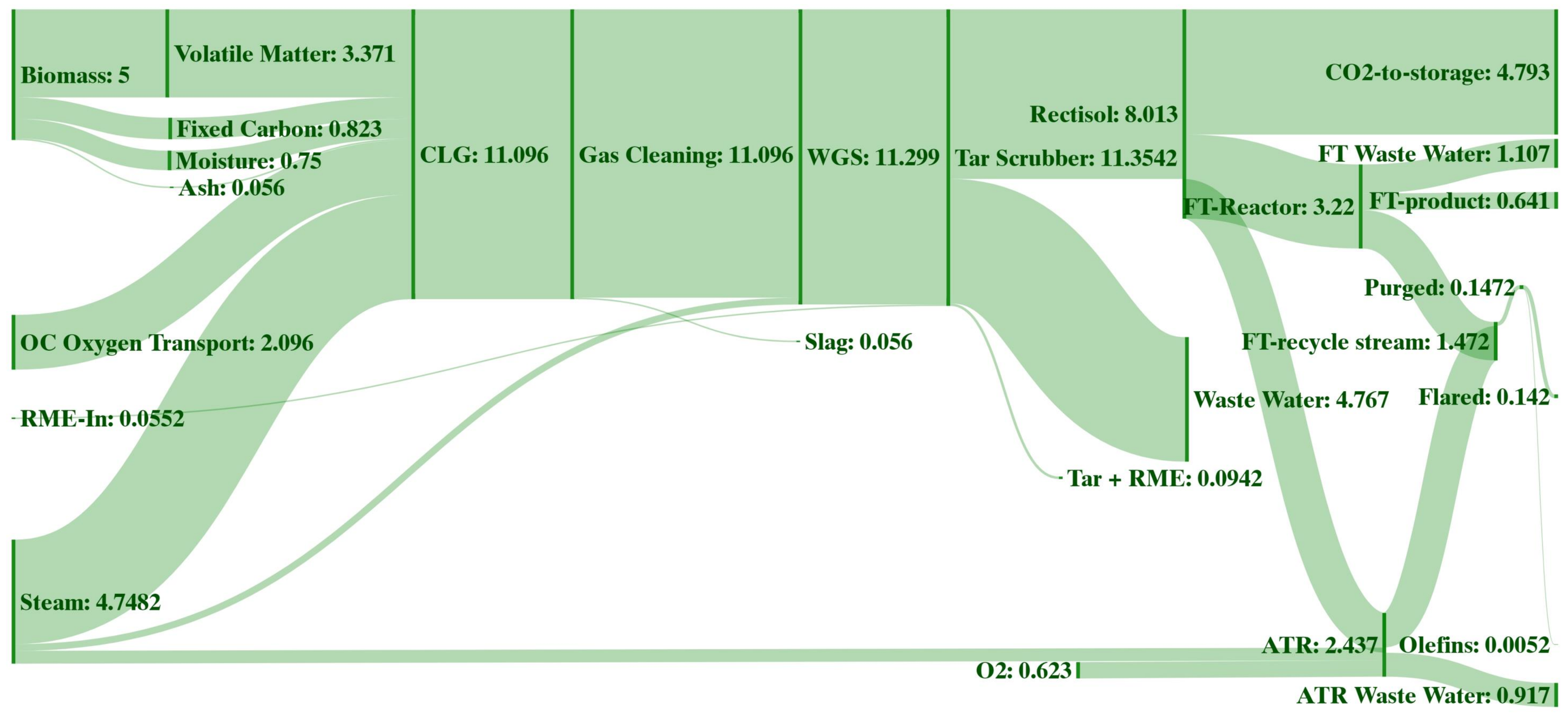
Model Sections	Main units	Sub-models	Unit operators	Description
Chemical Looping Gasification	Fuel Reactor	Fuel Decomposition	RYield	Biomass defined as non-conventional component decomposes to constituent elements
		Char-steam gasification	RStoic	Stoichiometric reaction with defined by a mechanism factor; S/B ratio = 0.8
		N,S conversion	RStoic	Fuel-bound N and S conversion
		Volatiles Combustion	RGibbs	Adiabatic reactor, with OTC of LD-slag defined
	Air Reactor	OC oxidation	RStoic	Adiabatic reactor
	Main units	**Unit operators**		**Description**
Gas Cleaning	Solids removal	SSplit		Ash removal
	Tar scrubber	Separator		RME-based scrubber
	Rectisol®	Separator		Separation efficiencies based on conv. Units; selective removal of CO_2, H_2S and NH_3
Fischer Tropsch Synthesis	Water Gas Shift	RGibbs		Conditioning step, to obtain H_2/CO – 2.05-2.15
	FT-Reactor	RStoic		220°C, 30 bar, reactions defined in a calc. block, with CO conv. 50 - 70% assumed. (LTFT, Co-based catalyst)
	Autothermal Reformer	RStoic		Reforming of FT recycle stream

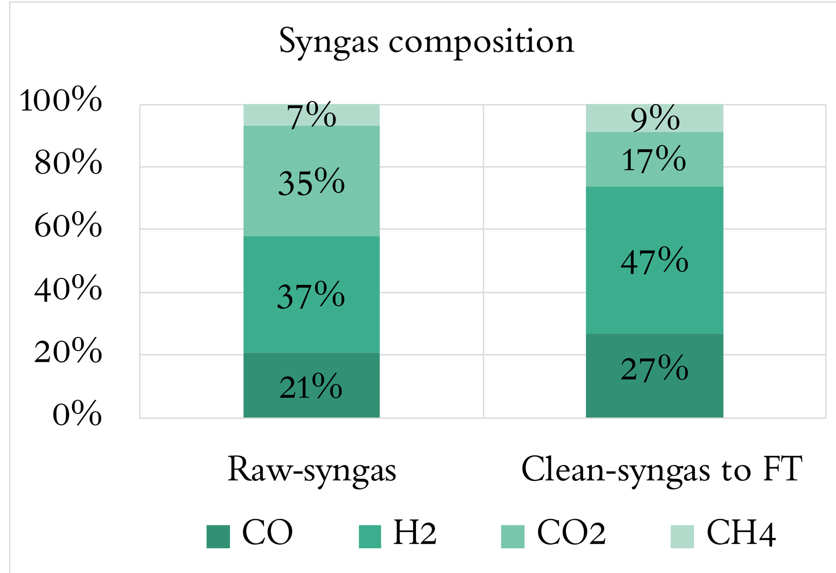
Assumptions

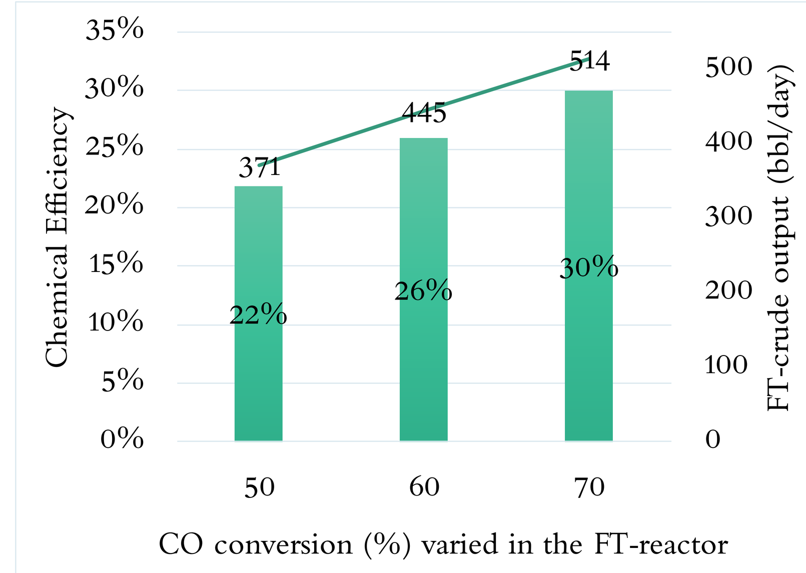
- 100% Char conversion assumed, no leakage to the AR
- Complete oxidation of OC in the AR
- Heat losses and pressure drops in the system are not considered
- Fuel-bound sulphur completely converts to H_2S and nitrogen converts to 60% NH_3 and the rest to N_2

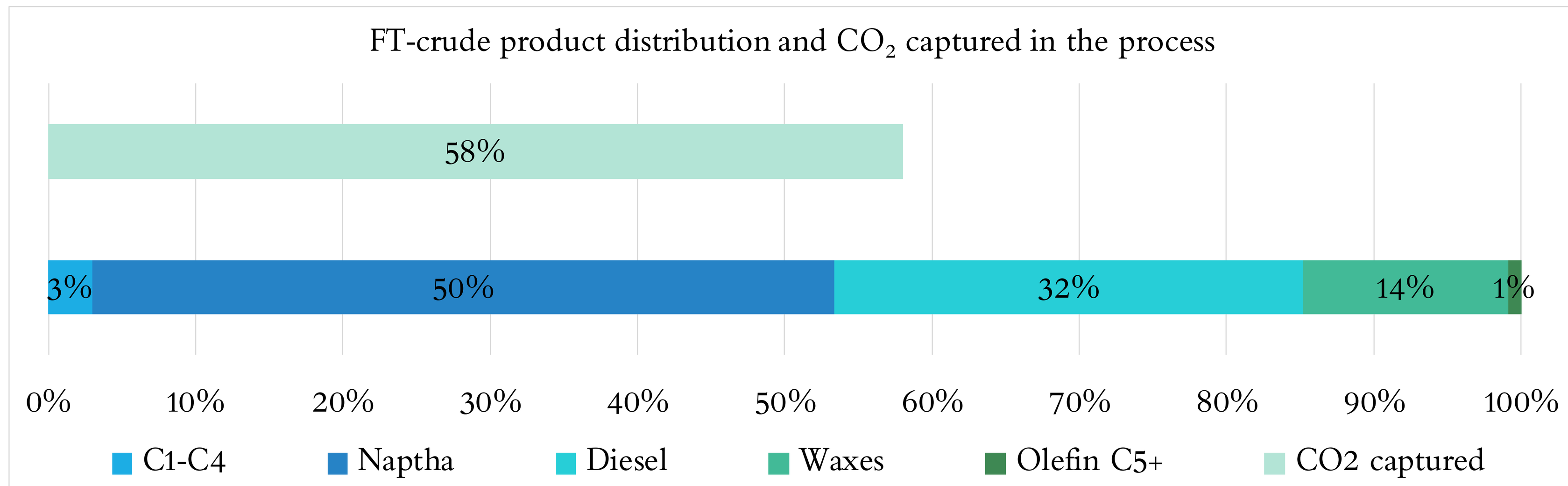
Results

Mass balance (kg/s) in the integrated CLG-Fischer Tropsch model









Conclusions

- The CLG model has an average cold gas efficiency of approximately 56.6 % with a biomass input with 15% moisture content (MC), producing a high-energy content syngas with 12 MJ/Nm³ (LHV-basis). The CGE tends to increase with lower MC in the fuel.
- The overall integrated plant has an FT-crude production capacity of 371-514 barrels per day depending on the FT reactor conditions such as catalyst amounts, operating pressure and temperatures
- Out of the total carbon fed to the process, approximately 58% is captured for storage, enabling net-negative CO_2 emissions from the process. This corresponds to a net carbon capture capacity of roughly 149.79 $ktCO_2$/year, including the penalty of flared gas.
- Excess heat on-site provides adequate heat recovery possibilities to meet the steam demand in the gasification and gas cleaning sections.

Performance Indicators

$$CGE = \frac{LHV_{sg} * G_v}{LHV_{fuel,daf} * m_{fuel}} \times 100$$

$$\eta_{ch} = \frac{HHV_{product} * \dot{m}_{product}}{(HHV_{biomass} * \dot{m}_{biomass}) + \sum Q_f}$$

- CGE – Cold gas efficiency (on an LHV-basis) (G_v – syngas yield, sg – syngas, daf – dry-ash free)
- η_{ch} - Chemical efficiency or biomass-to-product (FT-crude) efficiency, Q_f – RME consumption

References

[1] M. Pondini and M. Ebert, Process synthesis and design of low temperature Fischer-Tropsch crude production from biomass derived syngas, Master's Thesis. 2013.
[2] F. Eliason, Ash interactions with oxygen carriers Glödskal and LD-slag in biomass-CLC, Master's Thesis. 2018.
[3] P. Moldenhauer, C. Linderholm, M. Rydén, and A. Lyngfelt, "Experimental investigation of chemical-looping combustion and chemical-looping gasification of biomass-based fuels using steel converter slag as oxygen carrier," in Proceedings of the International Conference on Negative CO2 Emissions, 2018, pp. 1–17.

Acknowledgements

This work was carried out under the framework of the project 'Kemcyklisk förgasning av biomassa för produktion av biodrivmedel' (CLG of biomass for production of biofuel) and was financed by Swedish Energy Agency: Project 43220-1.

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