Upscaling the CLARA technology

Design and simulation of a 200 MW_{th} BtL plant

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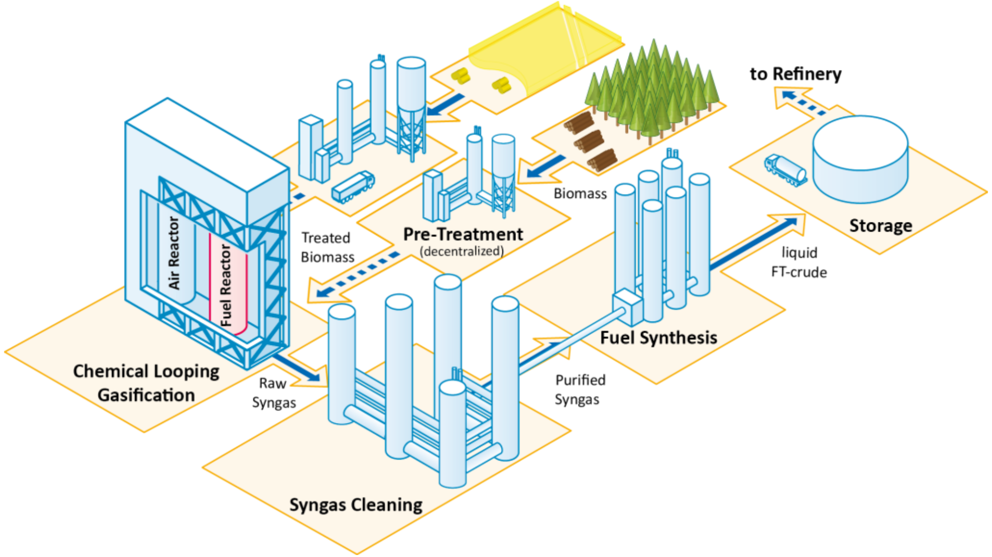
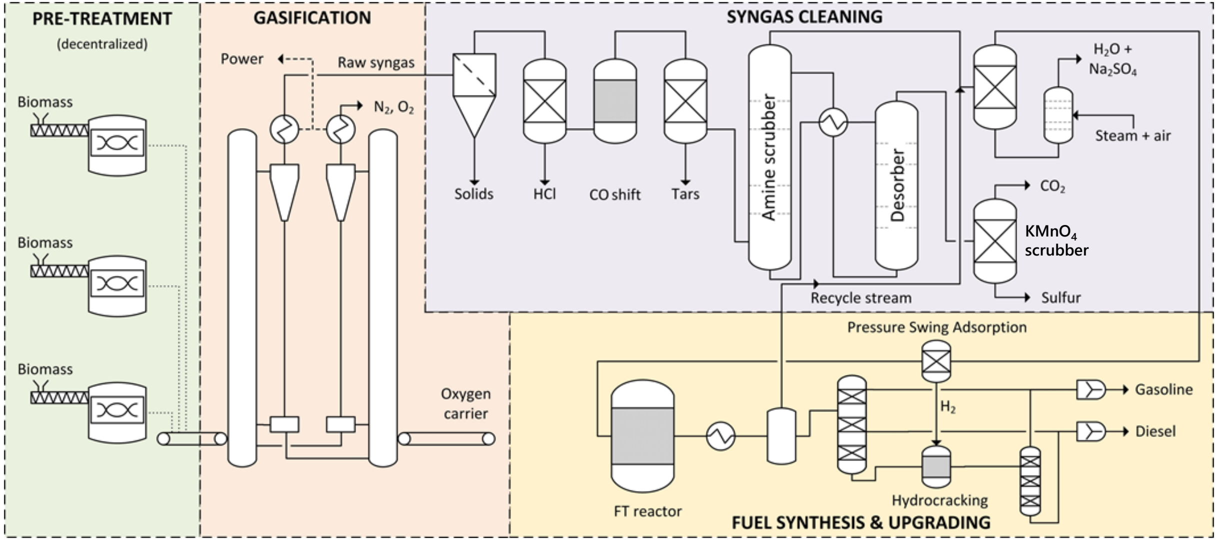


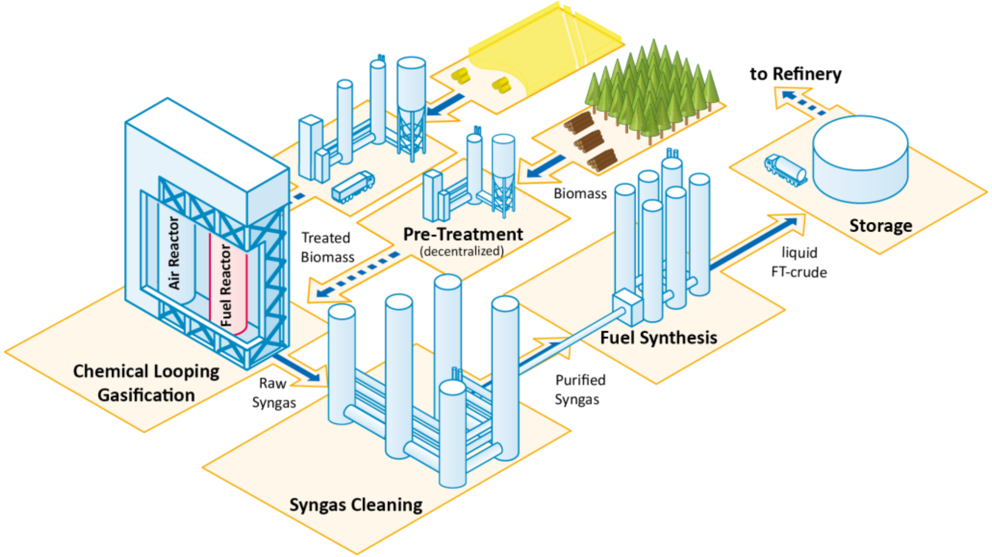
Introduction

- Upscaling of the whole process chain from 1 MW_{th} to 200 MW_{th}
- Estimation of process performance by simulation

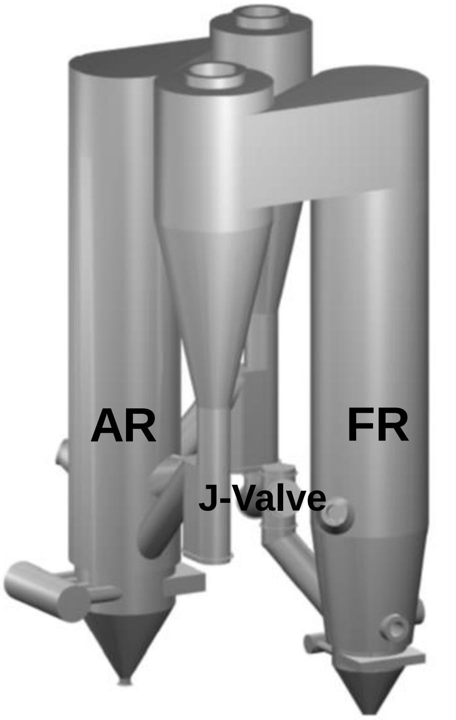


Part 1: Plant design

Layout of a 200 MW_{th} gasifier, syngas cleaning and fuel synthesis



Layout of a 200 MW CLG Unit



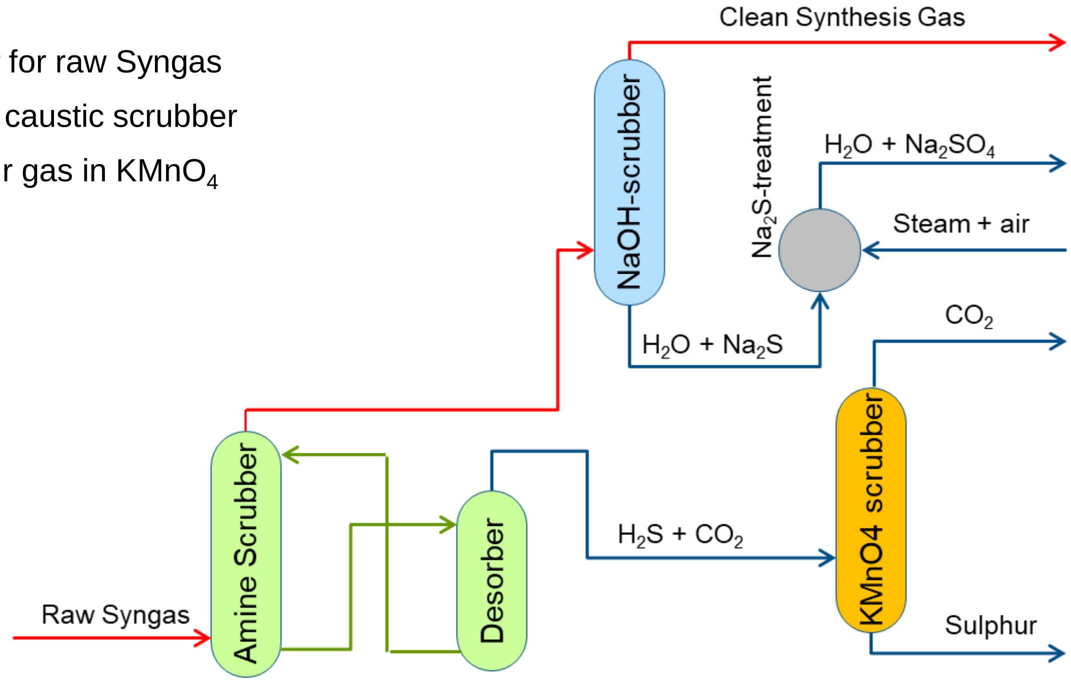
	Fuel Reactor	Air Reactor
Inner diameter	4.74 m	4.51 m
Gas Velocity	5.5 m/s	4.5 m/s
Riser height	25.75 m	22.72 m
Cyclone inner diameter	4.84 m	4.07 m
Total height	31.25 m	30.25 m
Foot print of the whole assembly	16.5 x 13.4 m	

Gas Treatment Unit

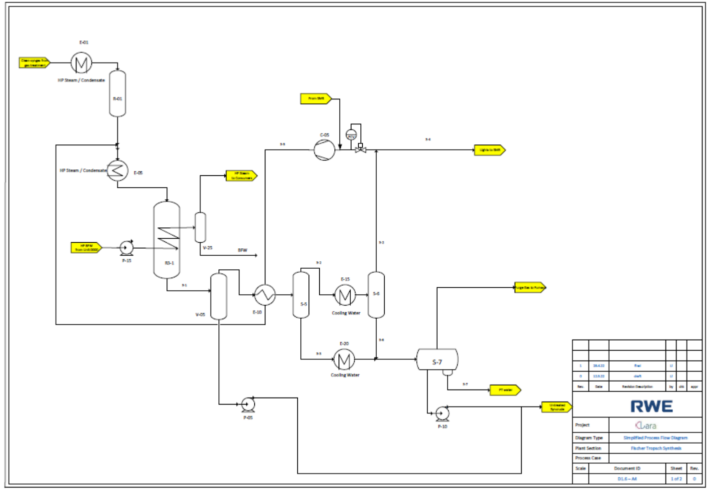
Gas Treatment consists of:

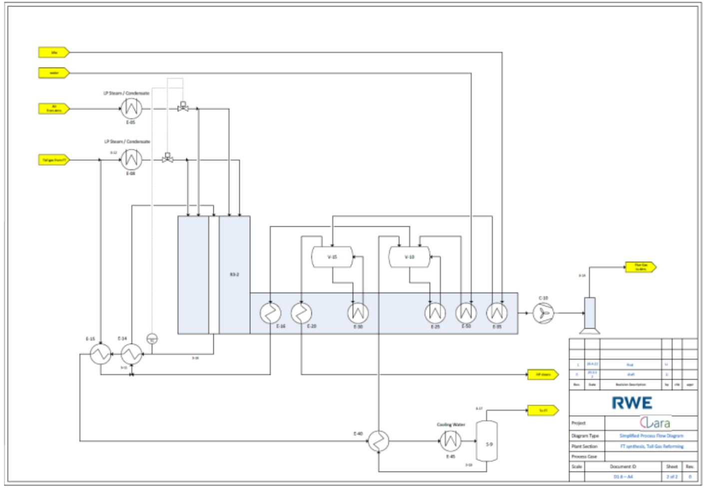
- Amine scrubber and amine regenerator for raw Syngas
- Fine Treatment of pretreated syngas in caustic scrubber
- Selective H_2S oxidation to Sulfur of sour gas in $KMnO_4$ contactor (details are filed for patent)

	D	L
Amine Scrubber	2.6	45
Desorber	3.6	25
Caustic scrubber	1.8	25
KMnO4 Scrubber	1.8	25



FT-Synthesis Unit & Steam Reformer





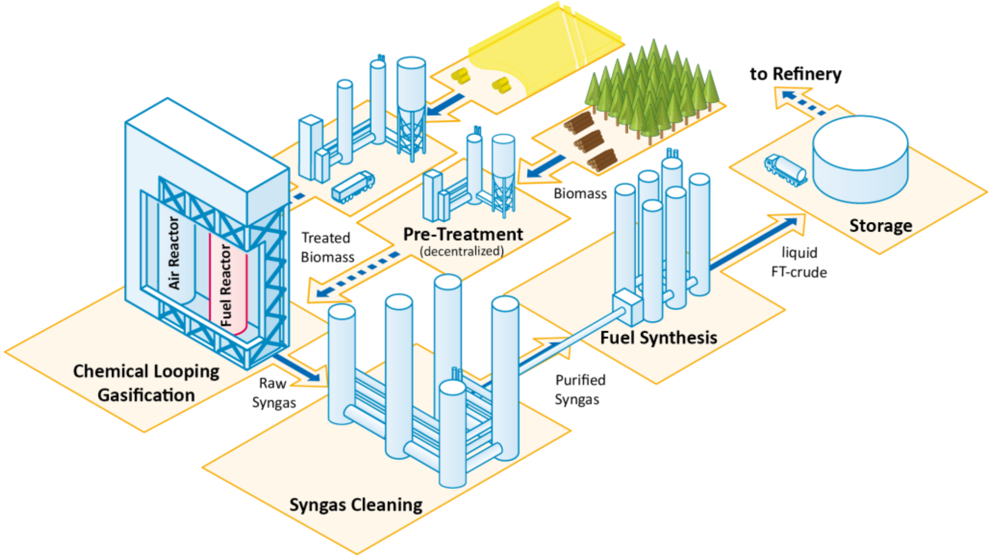
	D	L
FT Reactor	2.5	12
Reformer	25 x 10 x 10	

Synthesis Unit consists of:

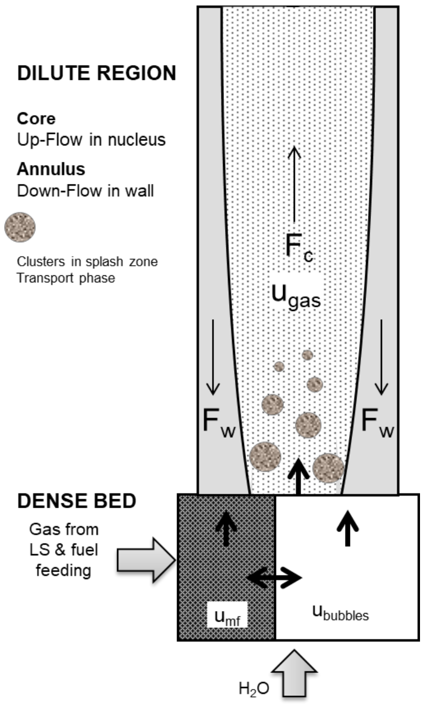
- Low Temperature FT Synthesis in fixed bed reactor
- Reforming of formed short chain hydrocarbons

Part 2: Performance estimation

Results of full-chain process simulations of the 200 MW_{th} CLARA concept



Gasifier Unit – Model overview



Model

- fluid-dynamics
- biomass devolatilization & gasification
- oxygen carrier redox kinetics
- Water-gas shift reaction: kinetics

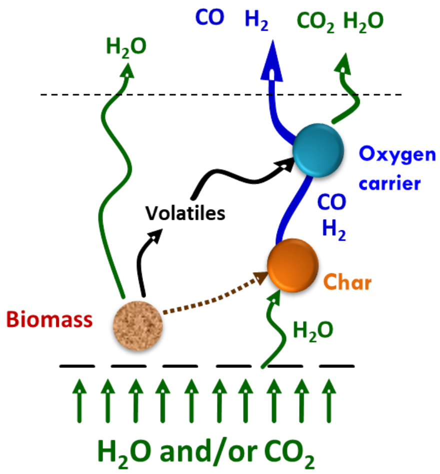
Input data

- Reactor geometry
- Operating conditions (T, λ, circ., S/B)
- Properties of OC and biomass
- Kinetics of reactions

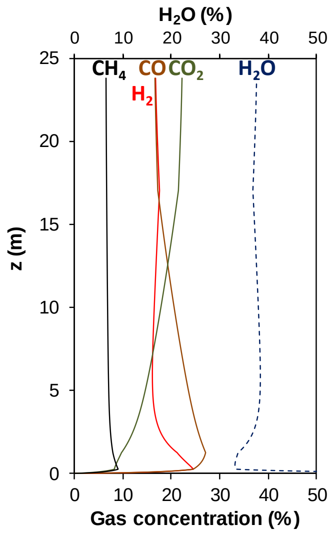
Output data

- Axial profiles of gas and solids
- Pressure drop
- Syngas composition
- Syngas and HC yields
- OC and char conversion
- Cold gas efficiency
- Carbon capture

Reactions in FR



Gas concentration profiles

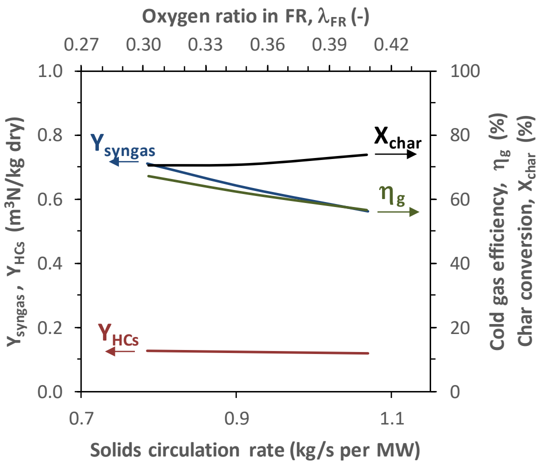


Gasifier Unit – Simulation results

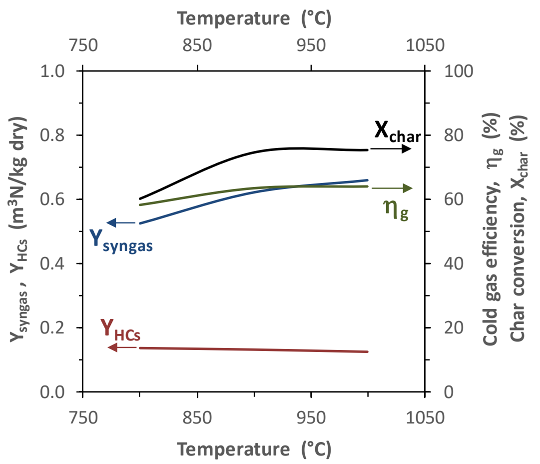
Parametric evaluation of the main operating variables

- Reactor temperature
- Oxygen ratio (λ) - solid circulation flowrate
- Steam to biomass ratio (S/B)
- Cross sectional area (m^2 /MW)
- Process control mode

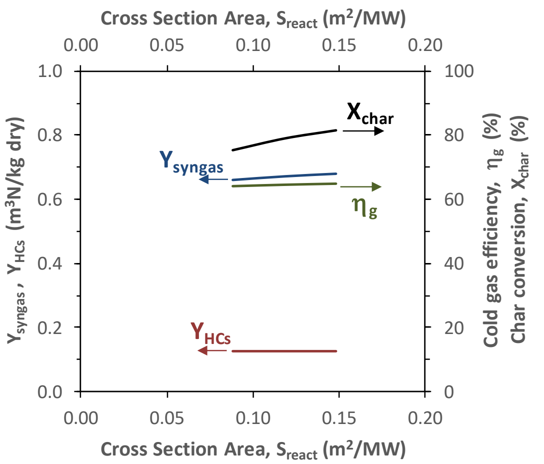
Oxygen ratio



Reactor temperature



Cross section area



Gasifier Unit - Expected gasifier KPIs

Process optimization (0.18 m^2/MW)

Optimum operating conditions in the gasifier are derived from the simulation. Mass and energy balances to the whole unit (air & fuel reactor) are necessary to know the temperature for the autothermal operation of each unit.

Fuel reactor temperature	°C	950	900
Steam to biomass ratio	kg/kg dry biomass	1.2	1.2
Solid circulation flowrate	kg/s MW	0.95	0.86
Solid inventory	kg/MW	400	400
Mean residence time	s	420	465
Oxygen to fuel ratio in AR	--	0.41	0.41
Oxygen to fuel ratio in FR	--	0.34	0.33
Syngas yield	Nm^3/kg biomass	0.68	0.65
HC yield	Nm^3/kg biomass	0.13	0.14
Cold gas Efficiency	%	65.6	66.0
CO_2 capture efficiency	%	93.5	91.3
Char conversion	%	80.8	74.4
Gas composition			
CO	Vol%	9.7	12.8
H_2	Vol%	13.5	9.8
CO_2	Vol%	16.3	12.6
H_2O	Vol%	55.9	60.1
CH_4	Vol%	4.5	4.7

Oxygen carrier
Ilmenite

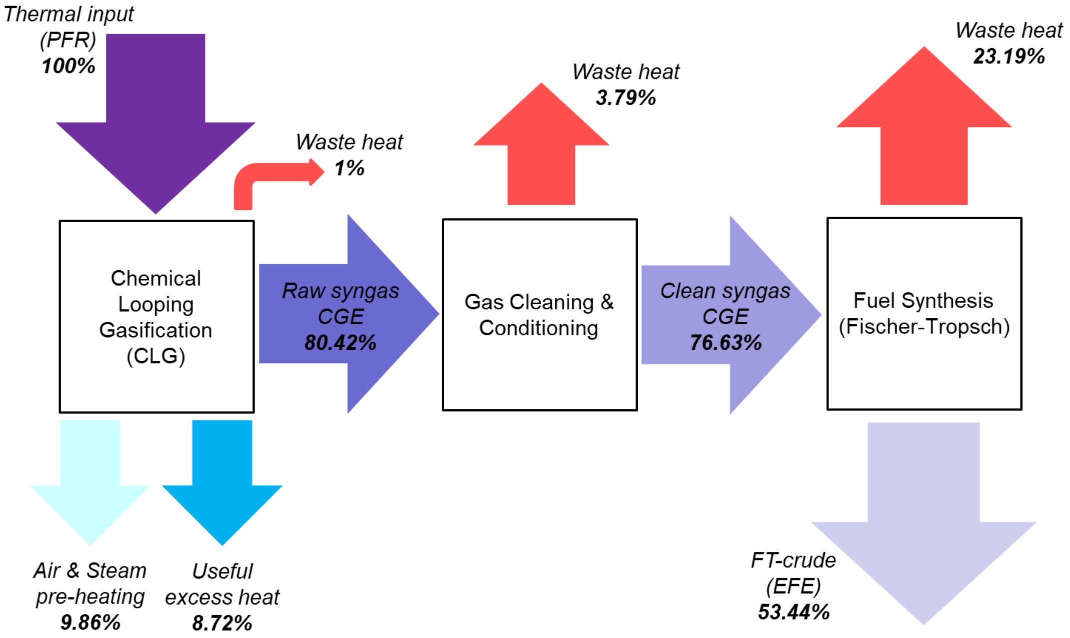
Fuel
Biomass pellets (6 ID)

Key Performance Indicators (KPIs)

- **Cold Gas Efficiency (CGE)**: It is the fraction of the chemical energy in the initial feedstock that is transferred to syngas in the CLG unit
- **Carbon Conversion (CC):** It is the carbon conversion in the CLG unit considering both reactors (FR & AR) combined
- **Carbon Utilization (CU):** It is the fraction of carbon in initial feedstock that is converted to the final liquid fuels
- **Energetic Fuel Efficiency (EFE):** It is the fraction of the chemical energy in initial feedstock that is converted to the final liquid fuels

KPI	Full-scale process simulations	Project initial targets
CGE (%)	80.42	82
CC (%)	100	98
CU (%)	32.48	33
EFE (%)	53.44	55

Process chain - Energy Balance

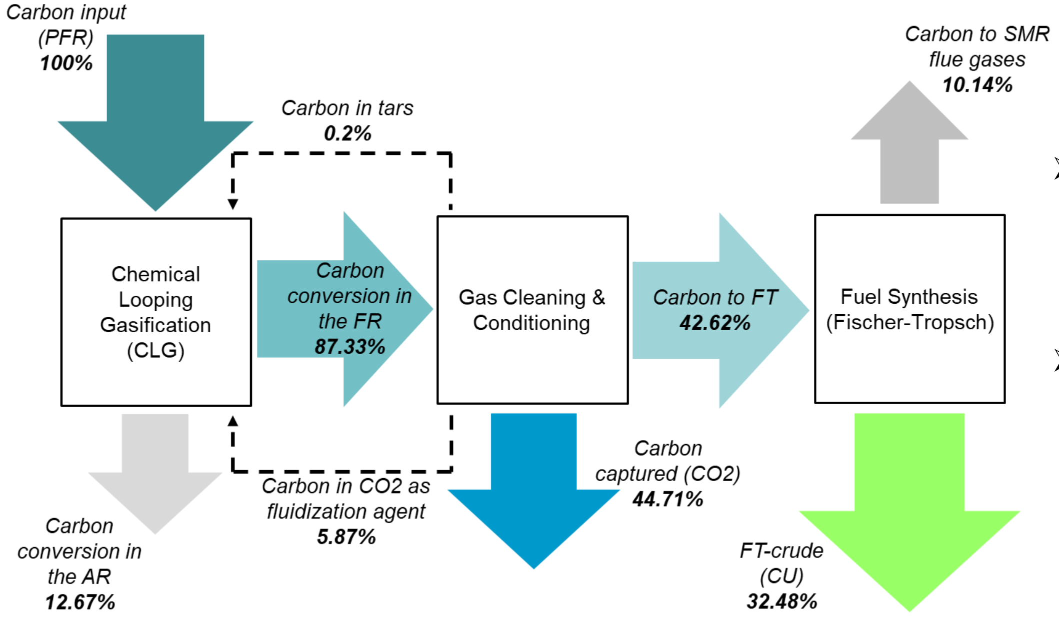


- **A Cold Gas Efficiency (CGE) of around 80%** is achieved. The remaining energy is used for **pre-heating of the inlet streams (~10%)** and for **further steam generation (~9%)** that can be used in other plant units (e.g. gas cleaning).

- **The main heat losses of the process are observed in the FT-synthesis unit (~23%)**, due to the **highly exothermic Fischer-Tropsch reactions** as well as the **partial syngas combustion for steam reforming** of longer hydrocarbons in the fuel synthesis unit.

- An Energetic Fuel Efficiency **(EFE) around 53%** is achieved, meaning that **more than half of the chemical energy contained in the initial feedstock is found in the final product of the process (i.e. FT-crude)**.

Process chain - Carbon Balance



- The **majority of carbon (~87.5%)** contained in the solid feedstock **is transferred to the produced syngas**, while **the remainder (~12.5%) is combusted in the air reactor** of the CLG unit.

- **A high percentage of carbon (~45%) is captured in the form of pure CO_2** in the acid gas removal unit. A small part of the captured CO_2 is recycled back to the CLG unit along with any tars removed via oil washing.

- The carbon left in clean syngas (i.e. CO & CH_4) is directed to the FT-synthesis unit. There, partial **syngas/carbon combustion for the thermal assistance of steam reforming takes place (~10%)**, while the remaining carbon is found in the valuable **FT products (liquid hydrocarbons), yielding an overall Carbon Utilization (CU) around 32.5%**.

Conclusion

- Design of commercial scale 200 MW_{th} plant
  - Detailed layout of gasifier unit
  - Conceptual design of gas cleaning and fuel synthesis units

- Performance estimation by simulation
  - Plant performance meets expected KPI

➢ Next step: 10-30 MW_{th} demo unit

Thank you for your attention

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