Sorption enhanced gasification (SEG) of biomass with CO2 capture for the production of Synthetic Natural Gas (SNG) and DME for transport sector with negative emissions

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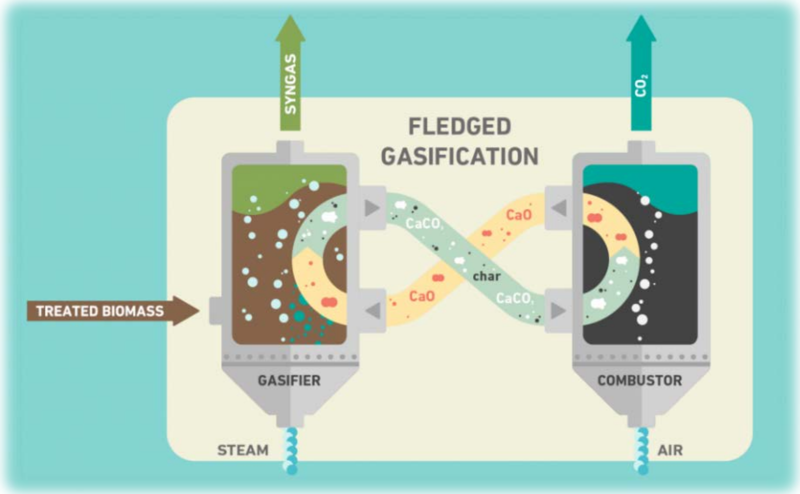
- Background: FLEDGED project and scope of the work
- Process description
- Performance index definition
- Results

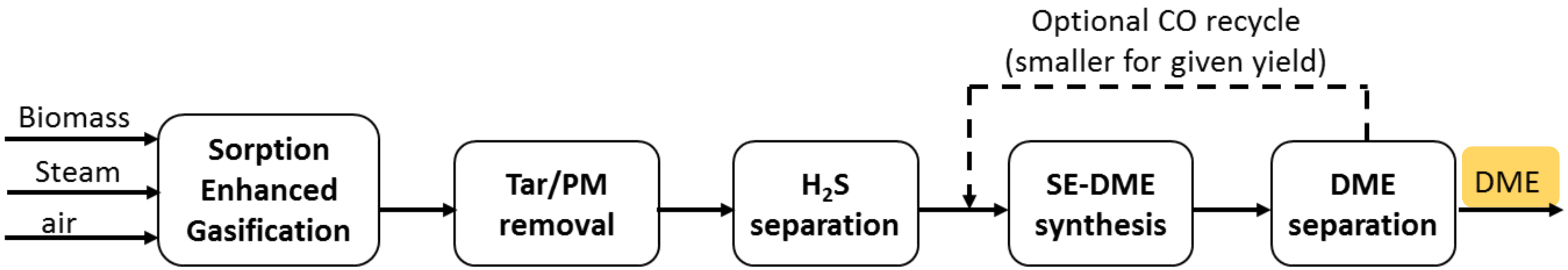
Background: FLEDGED project and scope of the work

- Synthetic biofuels production from renewable energy sources like biomass has an important role to play in the decarbonized scenario needed in the coming years for fulfilling the 1.5ºC target
- Indirect gasification has a great potential due to its inherent advantages
- Using a CO2 acceptor as bed material: Sorption Enhanced Gasification results

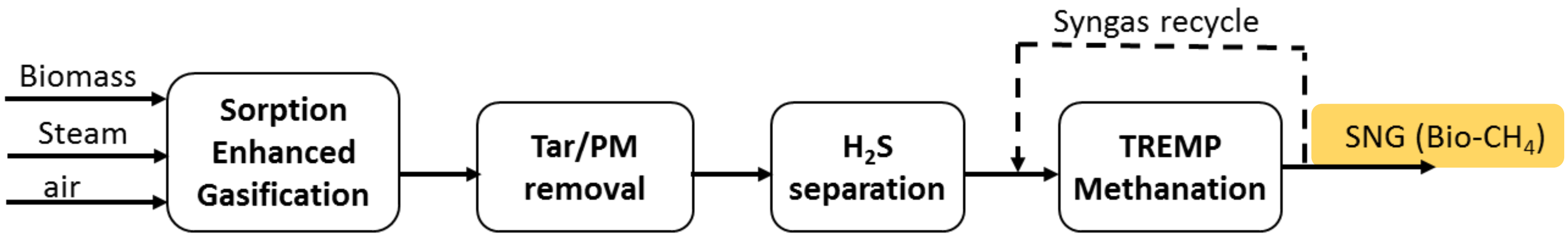


- **Dual fluidized bed** system using CaO as circulating bed material
- **Energy needed for gasification** supplied by **CaO carbonation** (→ CaCO3) and by sensible heat of **circulating solids**
- **Unconverted char** leaving the gasifier supplies the **energy needed in the combustor**
- The presence of CaO **simplifies the syngas cleaning and purification section**

OBJECTIVE FLEDGED: **Develop a highly intensified and flexible process for DME production from biomass and validate it under industrially relevant environments** (i.e. Technology Readiness Level 5 (TRL))



OBJECTIVE of this WORK: **Solve the mass and energy balances of two synthetic fuel production plants based on sorption enhanced gasification, one focused on DME and other on Synthetic Natural gas (SNG), to compare their performance**



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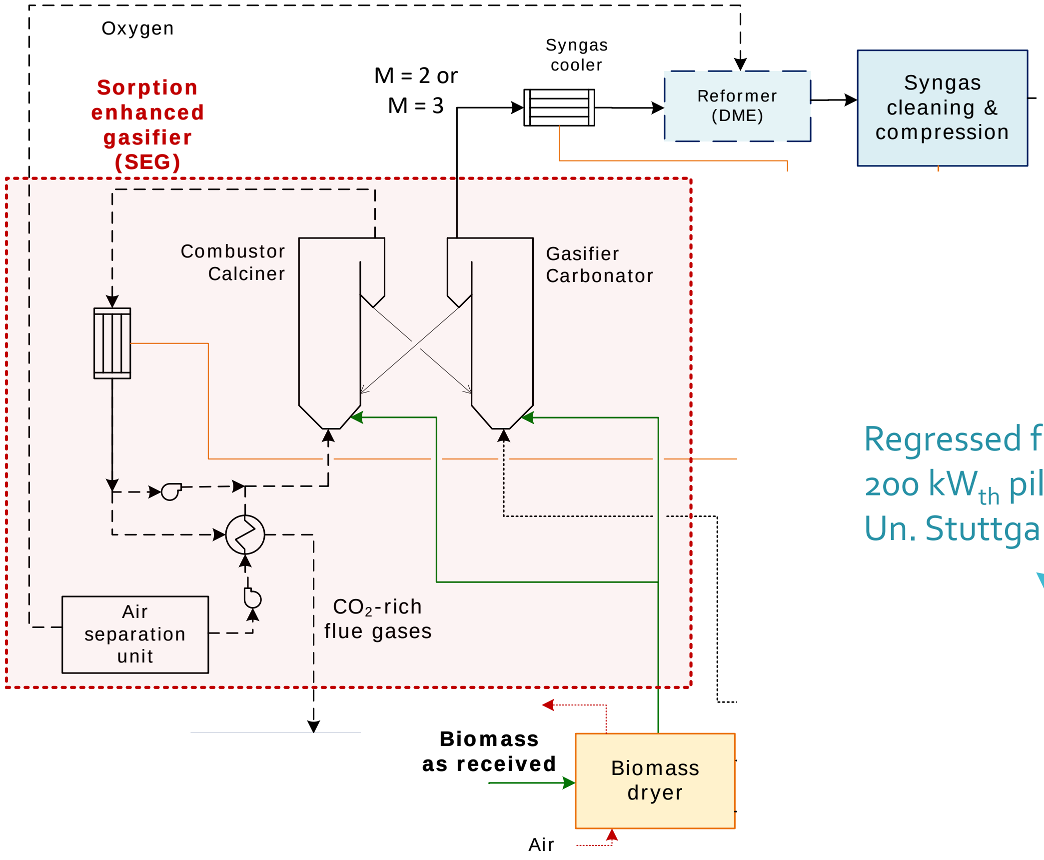
- **Biomass drying and sorption enhanced gasification (SEG)**



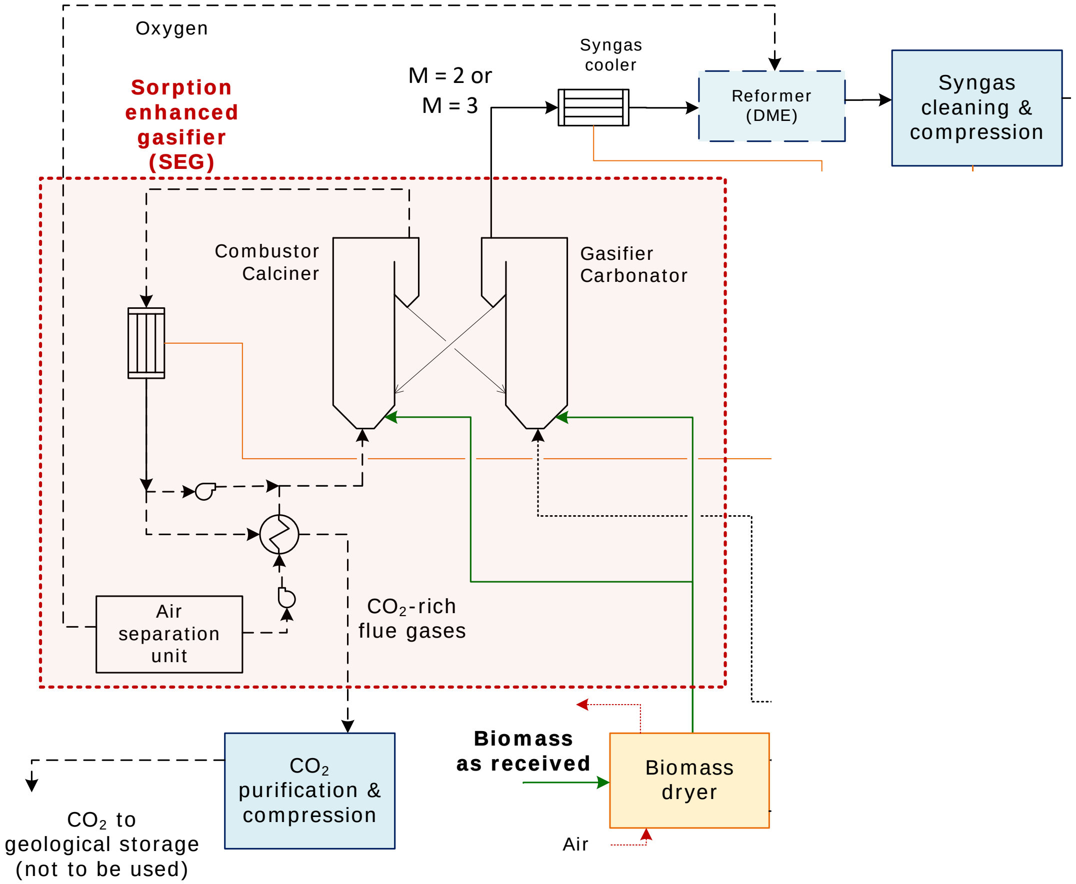
Ultimate composition [%wt. db]	
C	51.19
H	6.08
N	0.20
S	0.02
O	41.30
Cl	0.05
Ash	1.16

- **Drying**: tube bundle dried using condensing steam at 6 bar. Moisture from 45 to 20%wt.
- **Gasifier-carbonator**:
  - Steam-to-carbon (molar) = 1.5
  - Gas composition:
    - CO, H_2, CO_2, H_2O → WGS equilibrium deviation with T
    - CH_4 → $kg_{CH_4}/kg_{biomass,\ db}$ constant
    - C2+ (C_2H_4) → decrease with temperature
  - Solids to Combustor-Calciner:
    - Unconverted char → min. [Conversion=*f*(T), % FC]
    - $CaCO_3$ → conversion CaO= min. [X=0.75·Xave, Equilib.]

Regressed from the 200 kW_{th} pilot at Un. Stuttgart

- **Combustor-calciner:**
  - Complete combustion of char and calcination of $CaCO_3$
  - 910°C with 30%vol. O_2 at inlet (from an ASU)

- **Biomass drying and sorption enhanced gasification (SEG)**

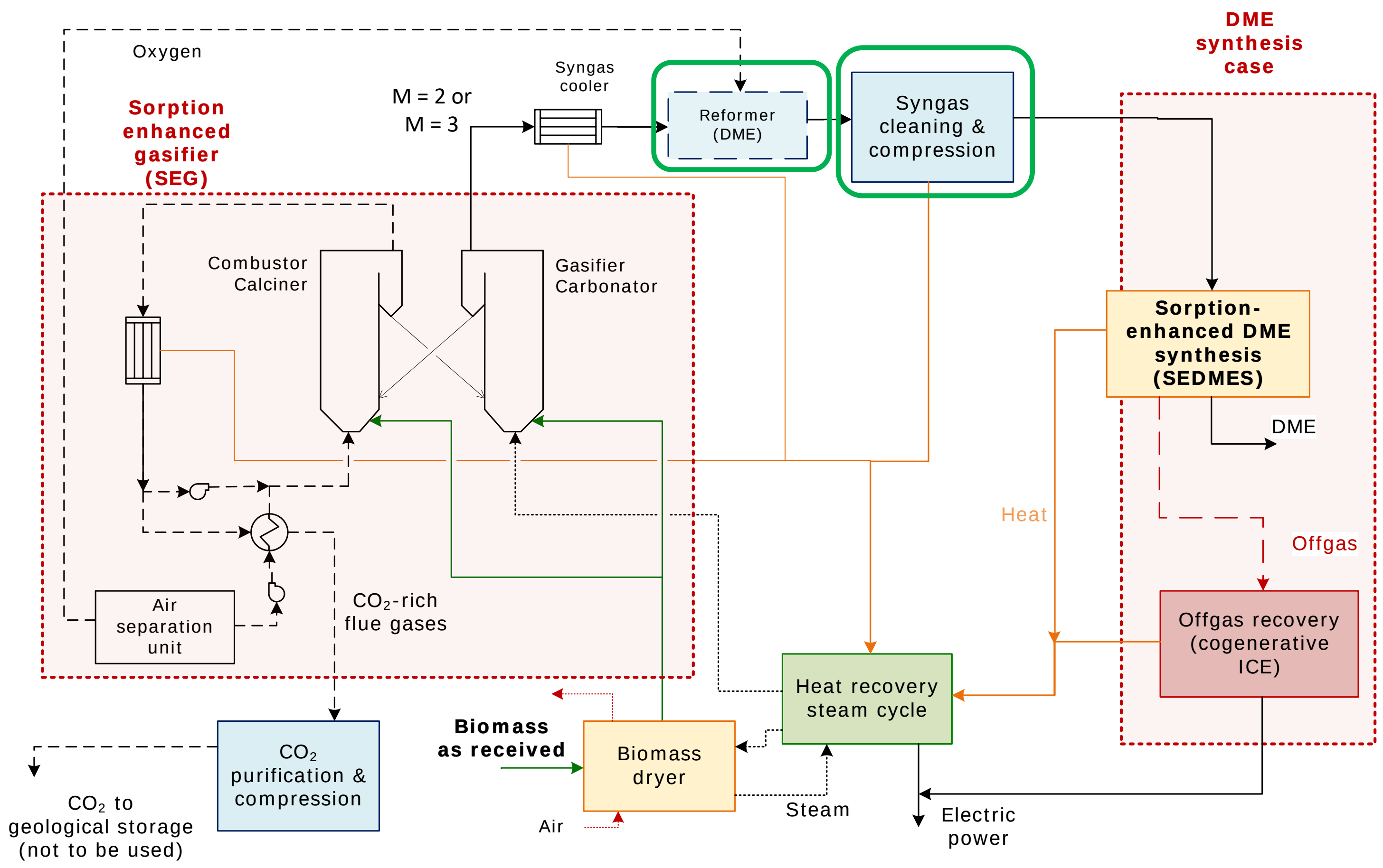


Objective**: M-module=2 (DME) and 3 (SNG)** after the cleaning and compression

$$M - module = \frac{N_{H2} - N_{CO2}}{N_{CO} + N_{CO2}}$$

Gasifier temperature modified through gas solid circulation (i.e., different amount of CO2 separated within the SEG) **for achieving the target M-module**

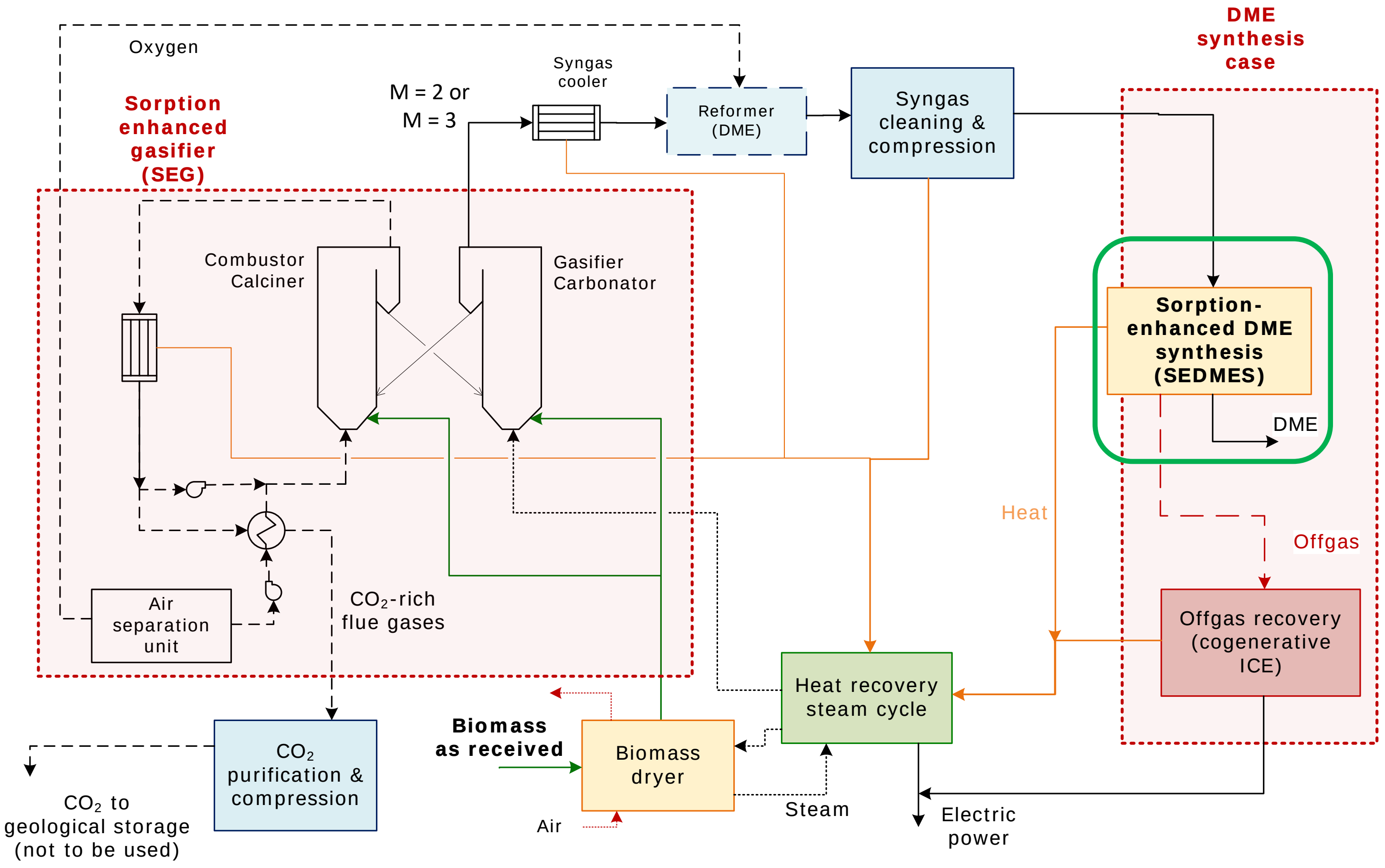
- **DME production plant**

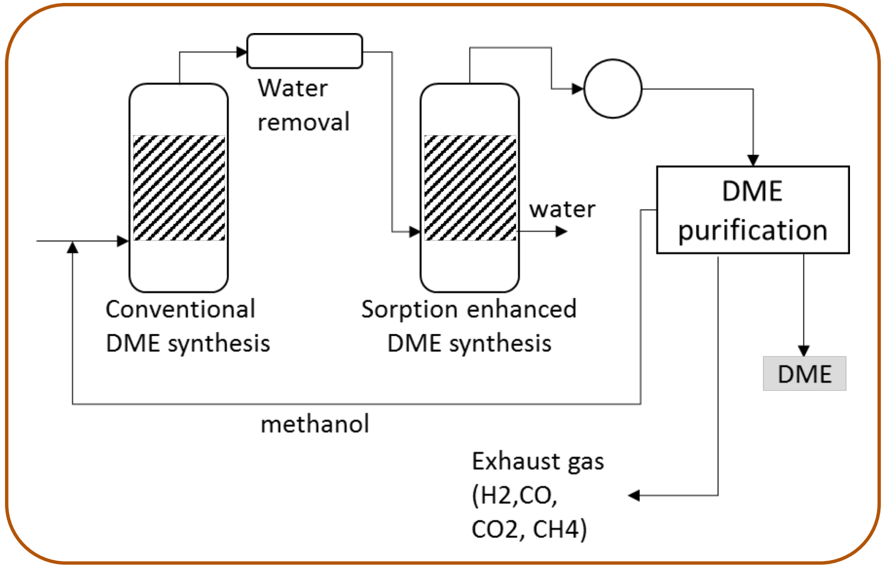


- **Reformer needed** before cleaning and conditioning **for reducing CH_4 content** (*dedicated unit for tar removal avoided*)

- **Syngas cleaning:**
- Syngas cooling (80°C)
- Water scrubber (40°C)
- H_2S removal: liquid redox process (Fe-based) $H_2S \rightarrow$ S and H_2O (LO-CAT® process)
- Compression up to 25 bar
- Cooling and water/H_2S traps

- **DME production plant**

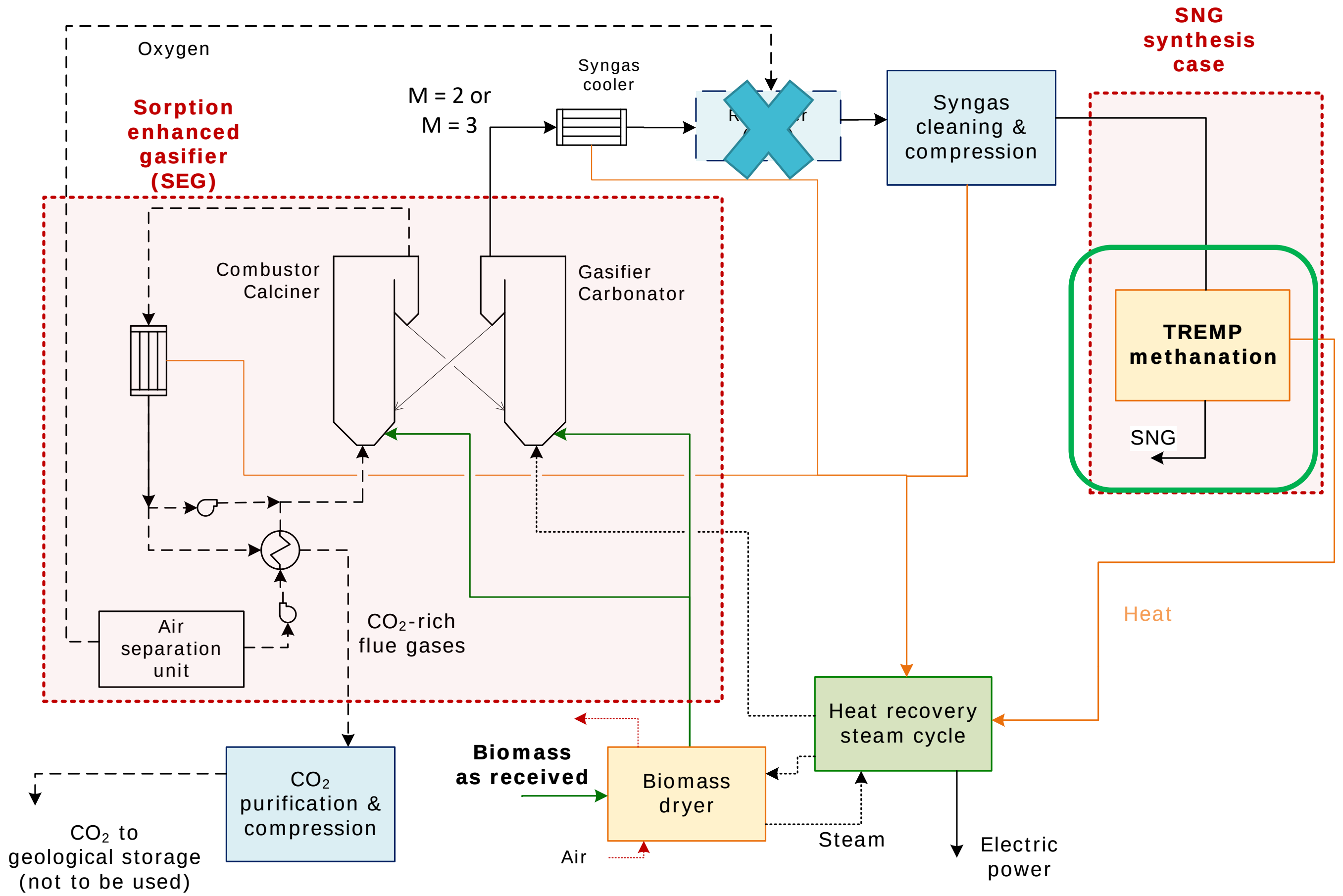




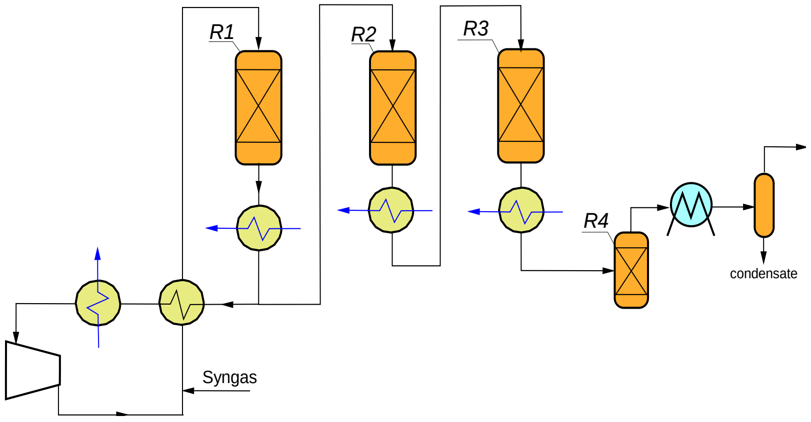
Two sequential reactors: conventional direct DME + SE-DME

- Exhaust gas (H_2, CO mainly) burnt in an engine (40 %) for additional power production
- Heat recovery steam cycle (480ºC, 28 bar)

- **SNG production plant**



- **Reformer not needed**
- **Syngas cleaning:**
  - Similar to that of the DME plant but including an OLGA process for tar removal
- **Methanation process:**
  - 3 adiabatic stages, 35 bar and 310/210ºC



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- Cold Gas Efficiency of the SEG process:

$$CGE_{SEG} = \frac{\dot{m}_{syngas} \cdot LHV_{syngas}}{\dot{m}_{bio,SEG\ in} \cdot LHV_{biomass}}$$

chemical energy of the syngas

chemical energy introduced with the biomass into SEG

- Global Cold Gas Efficiency:

$$CGE_{global} = \frac{\dot{m}_{DME/SNG} \cdot LHV_{DME/SNG}}{\dot{m}_{biomass,ar} \cdot LHV_{biomass,ar}}$$

chemical energy of the final product (DME/SNG)

- Equivalent Cold Gas Efficiency:

$$CGE_{eq} = \frac{\dot{m}_{DME/SNG} \cdot LHV_{DME/SNG}}{\dot{m}_{biomass} \cdot LHV_{biomass} - \frac{P_{el,net}}{\eta_{el,ref}}}$$

- If $P_{el,net}$<0 (import electricity) → additional fuel consumption

Fuel saving associated to the electric power output (34% for a biomass SC)

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Performance results

	SEG-DME production plant	SEG-SNG production plant
Gasifier temperature [ºC]	716.2	703.4
Biomass input to gasifier [%]	94.9	97.2
Biomass input to combustor-calciner [%]	5.1	2.8
CGE_{SEG} [%]	63.5	69.0
CGE_{global} [%]	53.7	60.1
Net electric output [MW_e] (**$P_{el,net}$**)	-1.6	-4.1
Steam turbine electric output [MW_e]	7.3	7.3
Electric consumption [MW_e]	12.2	11.4
Off gas engine electric output [MW_e]	3.4	--
CGE_{eq} [%]	51.3	53.7
CO_2 capture ratio [%]	63.0	67.7

- **Lower gasifier temperature** in the SNG plant **since more CO2 capture needed (M higher)**
- **Larger amount of unconverted char** → less biomass sent to the calciner → **CGE_{SEG} turns larger**
- **Global CGE larger for the SNG plant** (no reformer needed, CGE_{SEG} larger and no off-gas produced)
- SNG plant needs more electricity import → advantage still on CGE_{eq}

Results: Well to Wheel Analysis

	Primary source	Well-to-Tank (Fuel production)			TtW (fuel use)	Well-to-Wheel		
		MJ_P/MJ_F	$g_{CO2,eq}$ stored/MJ_F	$g_{CO2,eq}$ emitted/MJ_F	$g_{CO2,eq}$ /MJ_F	$g_{CO2,eq}$ emitted/MJ_F	$g_{CO2,eq}$ emitted/km	$g_{CO2,eq}$ stored/km
Diesel	Oil	0,2	--	15,1	73,6	89	106	--
Gasoline	Oil	0,19	--	14,0	73,9	88	132	--
Conventional CNG	Natural gas	0,16	--	13,2	57,3	71	107	--
Bio-CNG from SEG	Biomass	0,83	-119	-47	55,0	8,1	12,3	-181
Conventional bio-DME	Biomass	1,05	--	-65	67,3	2,4	2,9	--
Bio-DME from SEG	Biomass	1,01	-127	-62	67,3	5,2	6,3	-155

↑ Primary energy expended per MJ of final fuel produced

Fossil fuel based value chains are positive emitters, while conventional DME is almost neutral

SEG-based processes have the potential to store 155-181 gCO2/km → turns out into a **'carbon negative' mobility** (net C removal from the atmosphere)

Joint Research Centre-EUCAR-CONCAWE collaboration, "WELL-to-WHEELS Report", 2014

Concluding remarks

A process **assessment of two synthetic fuel production plants based on a flexible Sorption Enhanced Gasification process of biomass** has been carried out

Synthetic Natural Gas production plant yields biomass-to-fuel efficiency of almost 54% (CGE_{eq}), which is slightly higher than that of the DME production plant (52%)

Based on the WtW analysis: **a bio-DME vehicle emits around 100 gCO2/km less than a conventional diesel vehicle**, which is the same saving for the conventional CNG vehicle and the bio-CNG one

Assessed processes allow capturing between 63-67% of inlet C from biomass, which turn into 155-181 gCO2/km removed from the atmosphere and stored (‘carbon negative’ mobility)

Thanks for your attention

http://www.fledged.eu/

This project has received funding from the European Union's Horizon 2020 research and innovation Programme under grant agreement No 727600