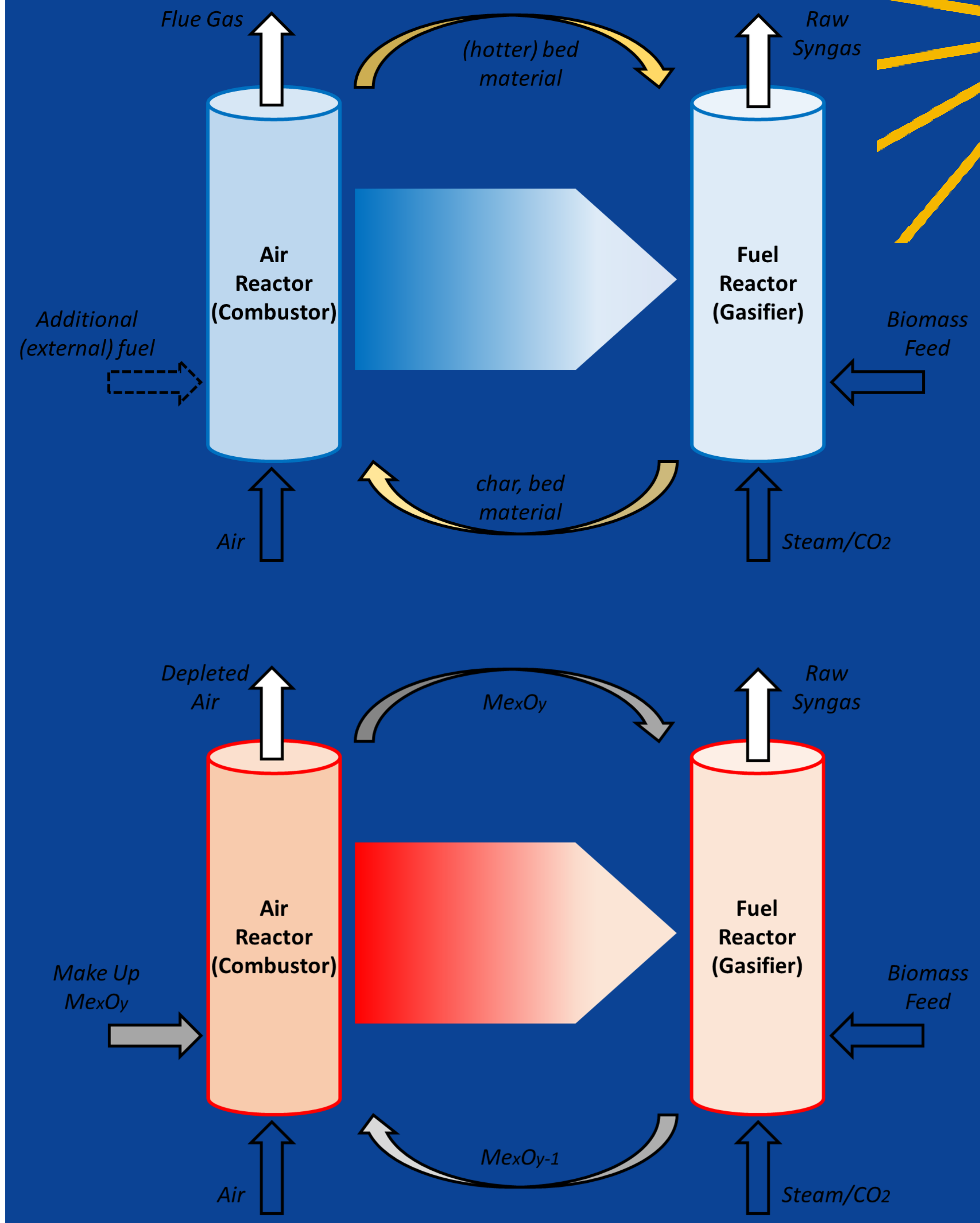
A comparative analysis and assessment of Dual Fluidized Bed and Chemical Looping Gasification: Design considerations for commercial use and applicability in BtL schemes

Nikolaos Detsios[1], Konstantinos Atsonios[1], Panagiotis Grammelis[1], Paul Dieringer[2], Jochen Ströhle[2], Ville Nikkanen[3], Nikolaos G. Orfanoudakis[4]

[1]Centre for Research & Technology Hellas/Chemical Process and Energy Resources Institute, Athens, Greece
[2]Technical University of Darmstadt, Energy Systems and Technology, Darmstadt, Germany
[3]Technical Research Center of Finland Ltd-VTT, Espoo, Finland
[4]Laboratory for Technical Study, Design, Supervision, Efficiency and Evaluation of Thermal and Environmental Installations, National & Kapodistrian University of Athens, Athens, Greece

EUBCE
31st European Biomass Conference & Exhibition
IN PERSON, ONLINE
Bologna 2023

5 – 8 June | Conference & Exhibition
9 June | Technical Tours



Introduction – General Information

IN PERSON, ONLINE
EUBCE 31st European Biomass Conference & Exhibition
Bologna 2023

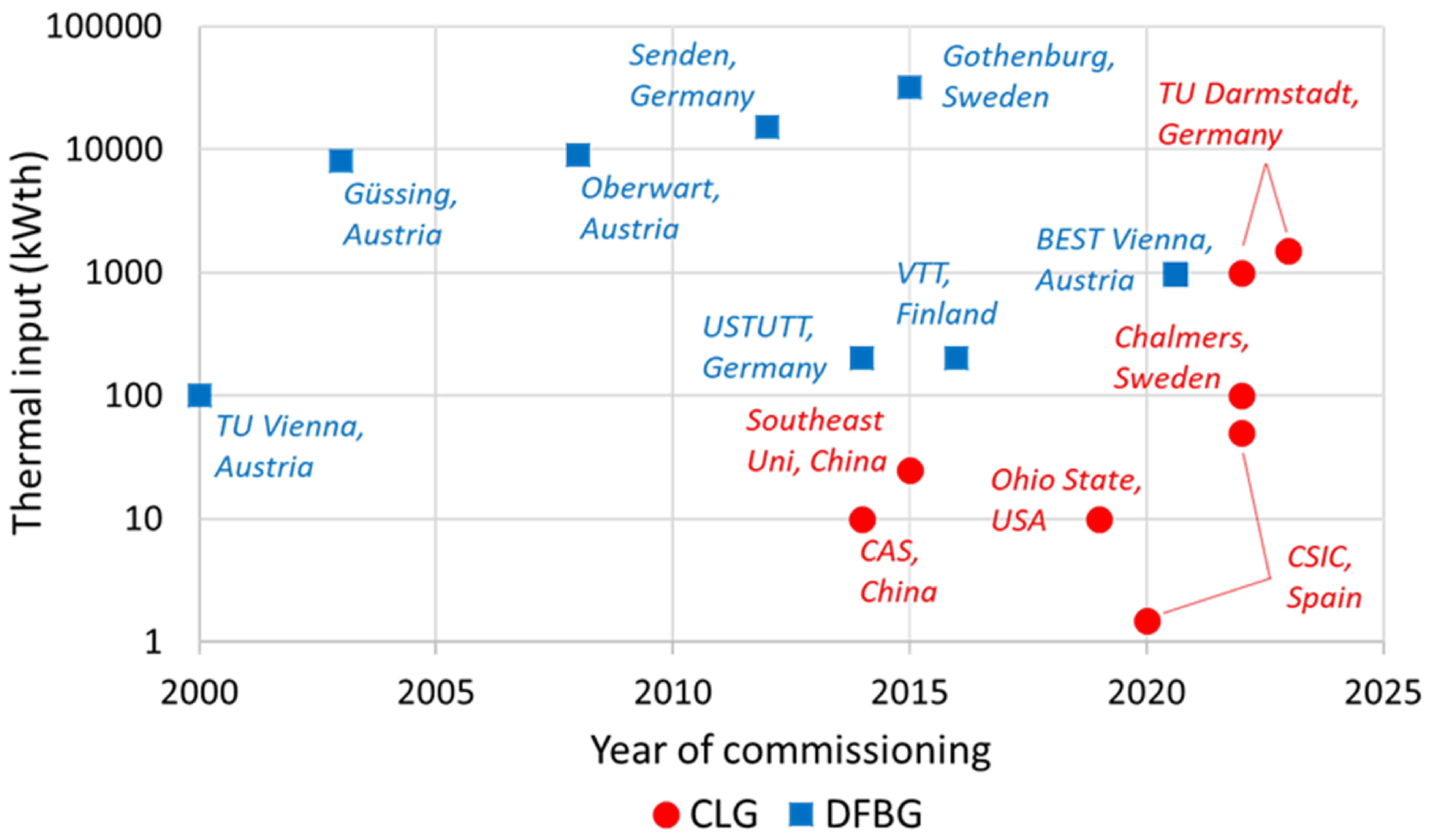
- In sectors where electrification or hydrogen are not easily and directly applicable, such as aviation, **biofuels have started to attract great interest**. The International Energy Agency (IEA) claims that **biofuels could provide 27% of total transport fuel by 2050, mainly replacing diesel, kerosene and jet fuel**.[1]
- At the same time, the **EU's biofuels policy**, as documented, in the latest directives (e.g. **RED II, ReFuelEU Aviation**), mentions the **promotion of residue-based biofuels (or so-called advanced biofuels)**.[2]
- The low energy density (due to high oxygen content) and the corrosive nature of pyrolysis bio-oil or the high costs (catalysts, high pressures) of liquefaction have established **biomass gasification as the most cost-effective and efficient technology for lignocellulosic biomass conversion**.[3]
- **Dual Fluidized Bed Gasification**[4] **(DFBG)** and **Chemical Looping Gasification**[5] **(CLG)** (indirect gasification systems) are considered an attractive option for syngas production due to their extended **fuel flexibility**, **high quality syngas (nitrogen-free)**, and the **avoidance of costly/energy demanding oxygen production units** (e.g. Air Separation Unit).

[1] Detsios, N. et al. Recent Advances on Alternative Aviation Fuels/Pathways: A Critical Review. Energies 2023, 16, 1904. https://doi.org/10.3390/en16041904
[2] ReFuelEU Aviation iniative: Sustainable aviation fuels and the fit for 55 package. 2022, European Commission: Brussels.
[3] Detsios, N. et al. Design considerations of an integrated thermochemical/ biochemical route for aviation and maritime biofuel production. Biomass Conversion and Biorefinery, 2023. https://doi.org/10.1007/s13399-023-03754-4
[4] Naresh Hanchate et al. Biomass gasification using dual fluidized bed gasification systems: A review. Cleaner Production, 2021,280:p. 123148, https://doi.org/10.1016/j.jclepro.2020.123148
[5] D. Xu, A, A. Tong, and LS. Fan, State of Scale-Up Development in Chemical Looping Technology for Biomass Conversions: A Review and Perspectives. Waste and Biomass Valorization, 2022. 13(3): p. 1363-1383. https://doi.org/10.1007/s12649-021-01563-2

Introduction – DFBG & CLG (Background)

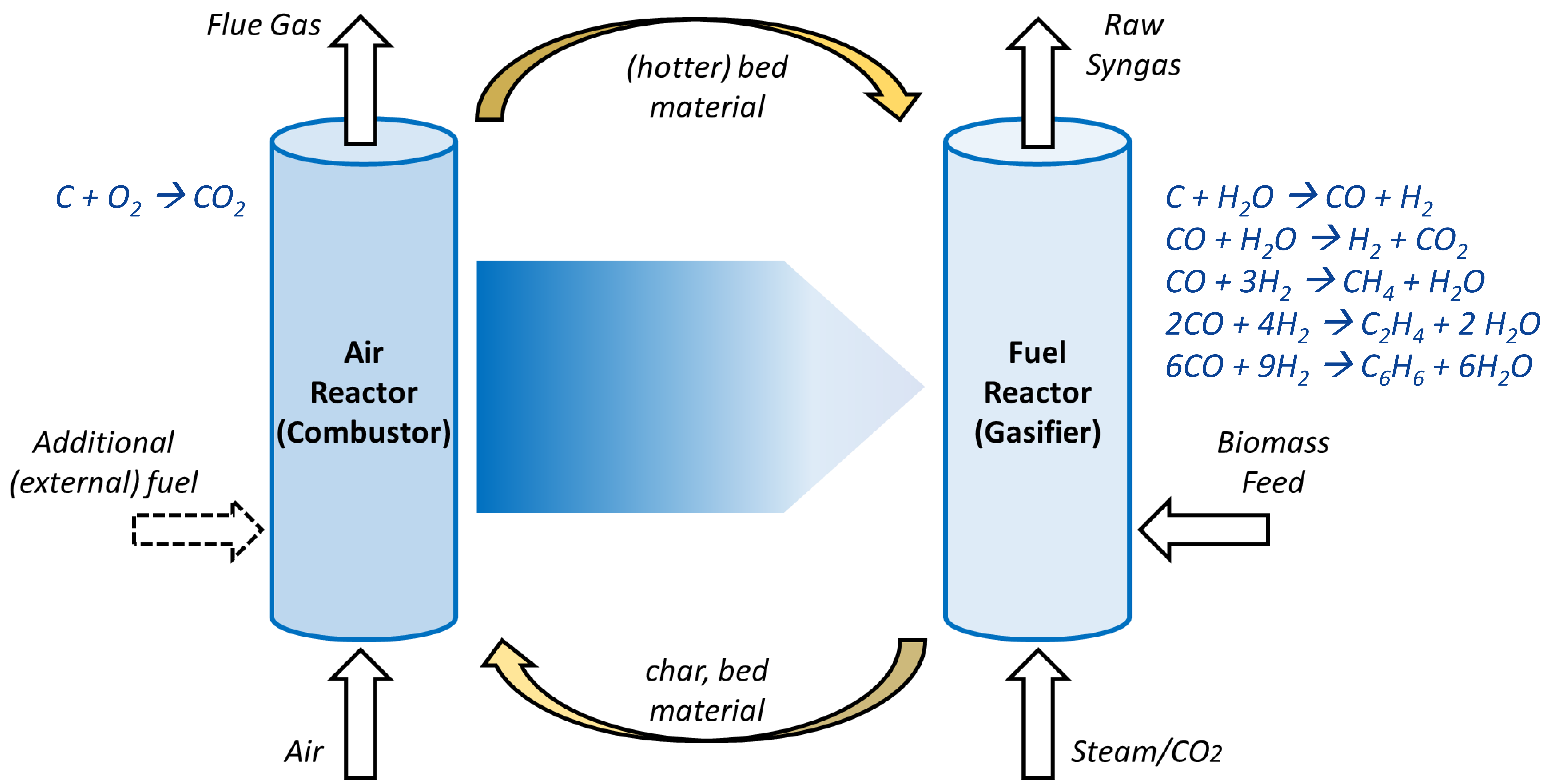
- **DFBG is a semi-commercially proven technology.** The technological functionality that the **Güssing plant (8 MWth)** proved, led to the development of other large-scale DFBG applications like **Oberwart (9 MWth), Senden (15 MWth)**, and the **Gothenburg – GoBiGas plant (32 MWth).**

- **CLG has just been demonstrated at pilot scale.** The synergy of **CSIC (Spain), Chalmers (Sweden)**, and **TU Darmstadt (Germany)**, within the framework of the **CLARA project** (https://clara-h2020.eu/), led to the **successful pilot CLG operation in the facilities of the latter (1-1.5 MWth).**



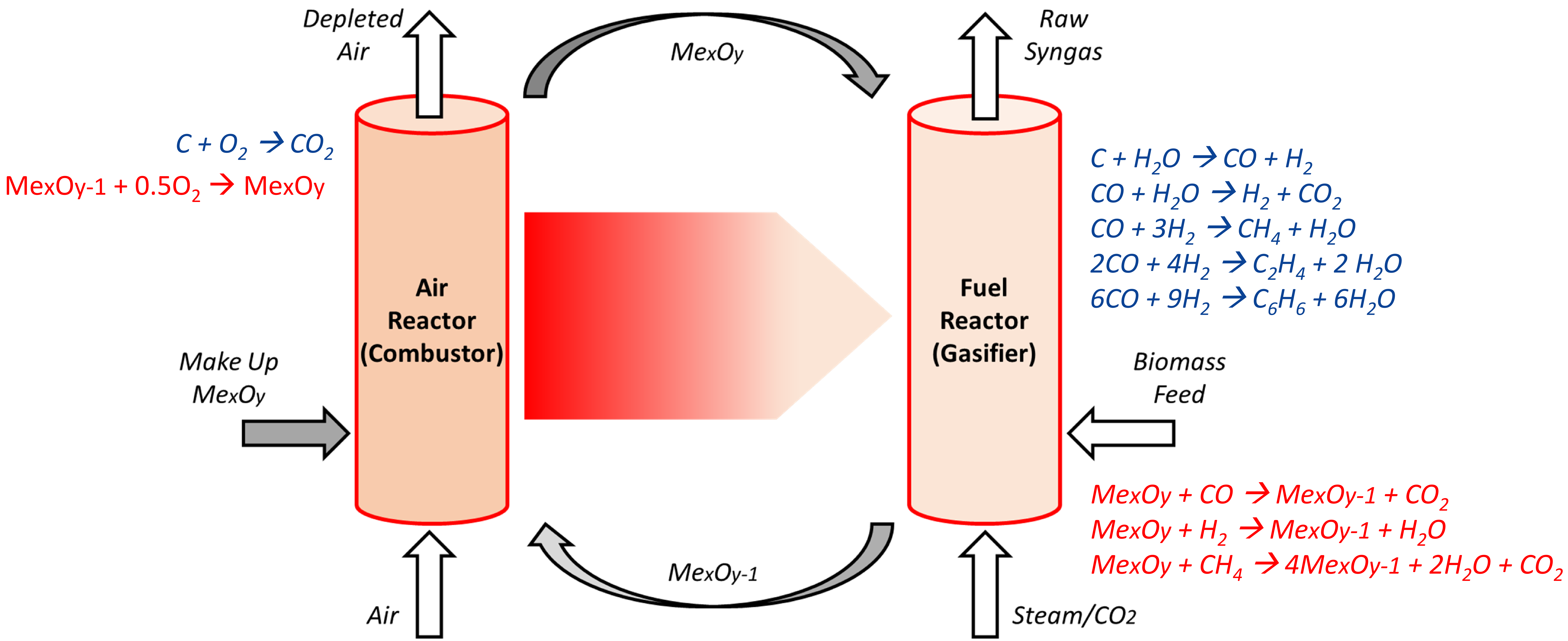
- The major difference between the two similar technologies is that in opposition to **DFBG, where the required heat for gasification is provided by partial char combustion**, in **CLG the required lattice oxygen is introduced by a solid oxygen carrier (OC) that is circulated between the two reactors.**

DFBG (Operating principle)



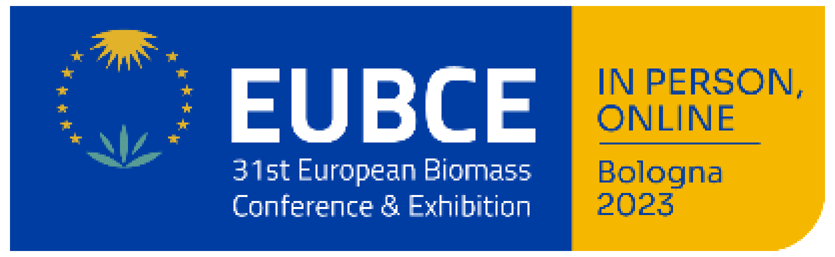
The produced char, other residues (i.e. ash) and part of the bed material are transported to the combustor where they react with the oxidizing medium (air) to produce heat. The (hotter) bed material returns to the gasifier, serving as an external heat source for the endothermic steam gasification reactions.

CLG (Operating principle)



A solid oxygen carrier (e.g. ilmenite) that is circulated between the two reactors provides the oxygen required for the endothermic gasification reaction. Unconverted char leaving the fuel reactor may also be transferred to the air reactor and combusted there (carbon 'slip').

Gasification pilot tests and selected feedstock



- Within the framework of the **BioSFerA** (https://biosfera-project.eu/) and **CLARA** (https://clara-h2020.eu/) projects, **VTT and TU Darmstadt (TUDA)** provided experimental data from **pilot DFBG (200 kWth)** and **CLG operation (1.5 MWth)**, respectively.
- **CERTH utilized these data for the proper model development and validation of these two gasification processes**. The rationale is to **form reliable models** for both processes that will be able to serve comparative full-scale simulations and upscaling considerations.
- In order to secure the consistency of the comparative analysis, operational points with **similar feedstock (forest residues) were selected for the pilot model validation as well as the full-scale simulations**.

Biomass Feed	Forest residues (DFBG)	Forest residues (CLG)
Proximate analysis (%)		
Moisture	7.40	4.40
Fixed Carbon (d.b)	19.60	17.40
Volatile Matter (d.b)	77.80	80.30
Ash (d.b.)	2.60	2.30
Ultimate analysis (% d.b.)		
Ash	2.60	2.30
Carbon	52.50	51.15
Hydrogen	6.10	6.07
Nitrogen	0.30	0.44
Chlorine	0.01	0.01
Sulphur	0.02	0.02
Oxygen	38.47	40.01
Net Calorific Value a.r. (LHV) (MJ/kg)	18.10	18.30

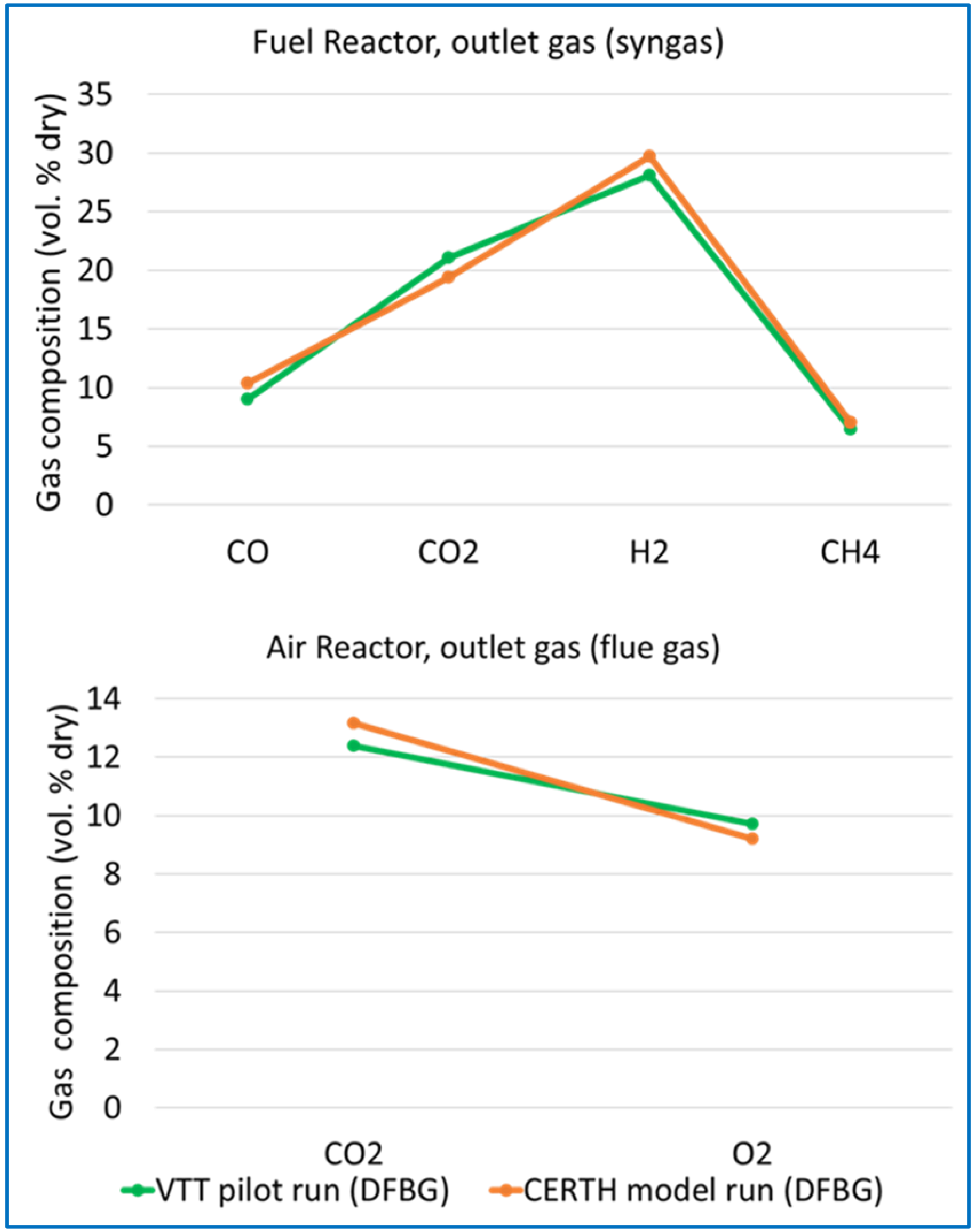
DFBG (200 kWth) pilot tests and model validation

EUBCE 31st European Biomass Conference & Exhibition
IN PERSON, ONLINE
Bologna 2023

- The **VTT** pilot DFBG configuration consists of **two CFBs** (Circulating Fluidized-Beds) and can support **a thermal input up to 200 kWth**.
- **Stable and efficient DFBG operation** was secured for a total of **400 hours**.
- **A good agreement is achieved between the model results and the experimental measurements.**

VTT

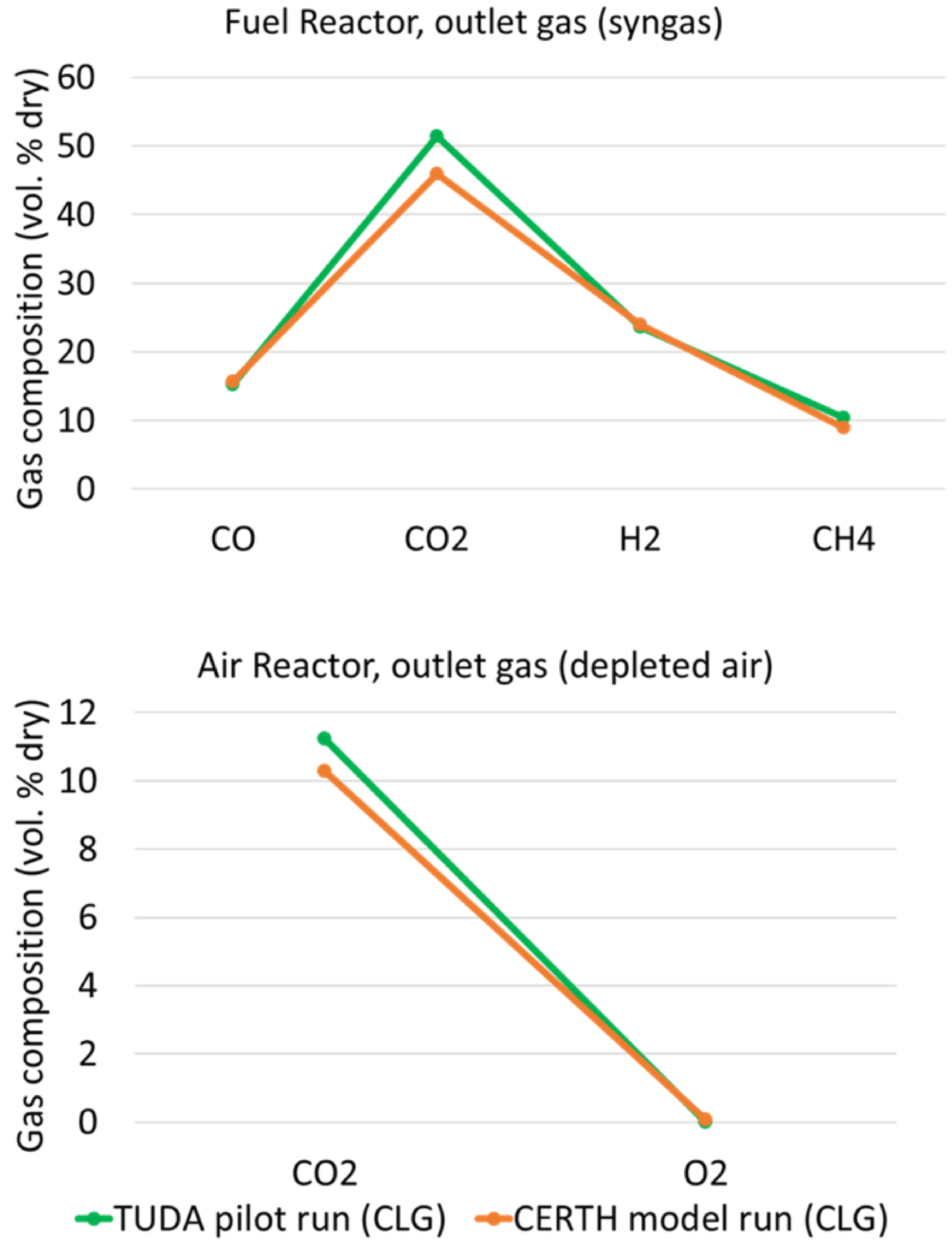
DFBG



CLG (1.5 MWth) pilot tests and model validation

- The **TUDA** pilot CLG configuration consists of **two CFBs** and can support **a thermal input up to 1.5 MWth**.
- **Stable GLC operation** was accomplished for **more than 100 hours. TUDA's pilot test campaign is the largest CLG application** up to now.
- The **inherent major heat losses** of the TUDA pilot plant as well as other **plant-specific restrictions** led to lower process efficiencies than those obtainable in an industrial (optimized) unit.
- **A good agreement is achieved between the model results and the experimental measurements.**

CLG



EST
TECHNISCHE UNIVERSITÄT DARMSTADT

Full-scale (200 MWth) DFBG/CLG simulations – Input

- The **target** is to identify the operational characteristics for both gasification technologies in a **potential industrial (optimized) setup** and **evaluate their appropriateness for commercial BtL applications**.

- **Autothermal system operation** (both reactors are in heat balance) is considered for the full-scale simulations of both technologies. **Inherent heat losses equal to 1%** (2 MWth) of the total thermal input are set for both cases as well.

Parameter	DFBG	CLG
Thermal input (MWth)	200	200
Feedstock inlet in FR (kg/s)	11.05	10.93
Steam/Biomass ratio (kg/kg)	0.70	0.60
Air inlet in AR (kg/s)	18.60	19.30
OC flow in FR (kg/s)	-	506
Air pre-heating temperature in AR (°C)	400	400
Steam pre-heating temperature in FR (°C)	350	350
AR Temperature (°C)	900	1000
FR Temperature (°C)	800	900

Full-scale (200 MWth) DFBG/CLG simulations – Output (stream results)

- The relatively **large steam flow required for DFBG** technology leads to extended water-gas shift effect and subsequent **dominance of H_2 over CO in the produced syngas**.

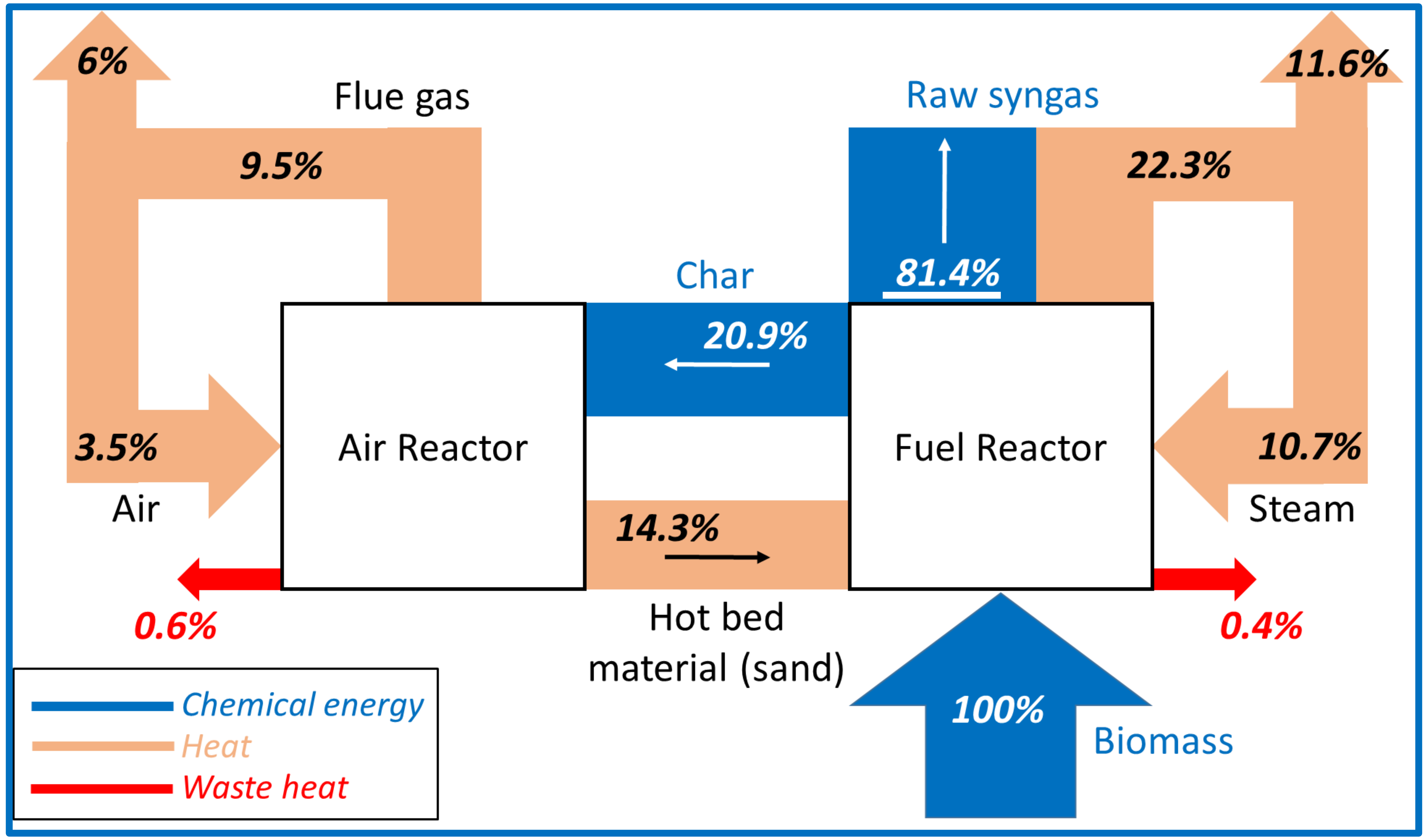
- In both cases, **the remarkable content of light hydrocarbons** along with the **non-negligible tars production** indicate **the need of catalytic reforming** in the downstream process of BtL applications in order to **avoid tar-related operational problems** and **enhance the H_2, CO syngas content**.

DFBG				CLG		
Component (vol. %)	FR, syngas	AR, flue gas		Component (vol. %)	FR, syngas	AR, depl. air
H2O	39.15	-		H2O	35.93	-
CO	**9.95**	-		CO	**15.16**	-
H2	**27.90**	-		H2	**23.08**	-
CO2	**14.77**	16.90		CO2	**17.48**	9.01
CH4	**5.56**	-		CH4	**5.84**	-
O2	-	4.10		O2	-	**0.83**
N2	-	79.00		N2	-	90.16
C2H4	**1.83**	-		C2H4	**2.14**	-
C6H6, other tars	**0.50**	-		C6H6, other tars	**0.10**	-
H2S, COS	188 ppm	-		H2S, COS	145 ppm	-
NH3, HCl	0.20	-		NH3, HCl	0.26	-

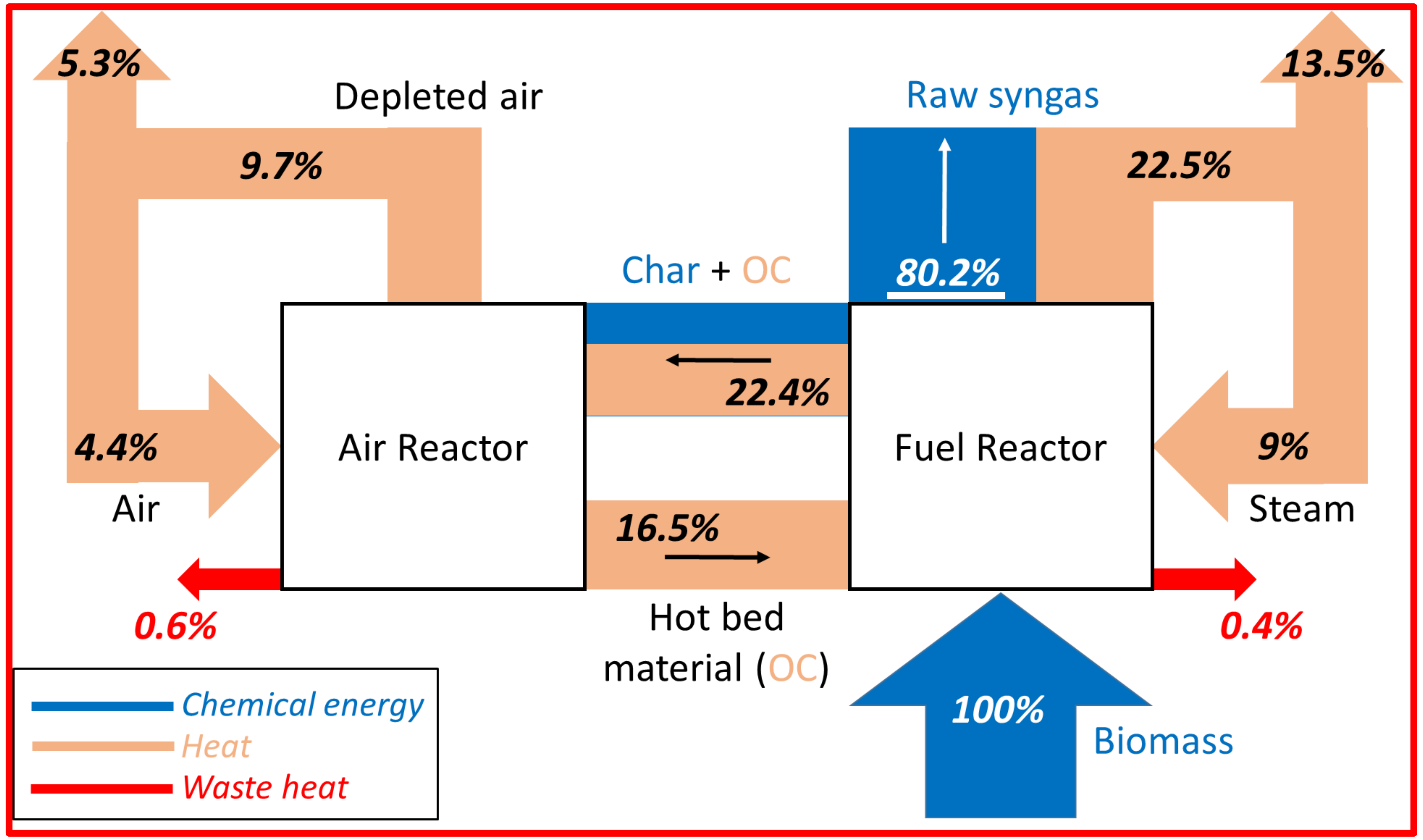
Full-scale (200 MWth) DFBG/CLG simulations – Output (Energy balance)

Cold Gas Efficiency (CGE) is the fraction of the chemical energy in the initial feedstock that is transferred to syngas in the gasifier

DFBG

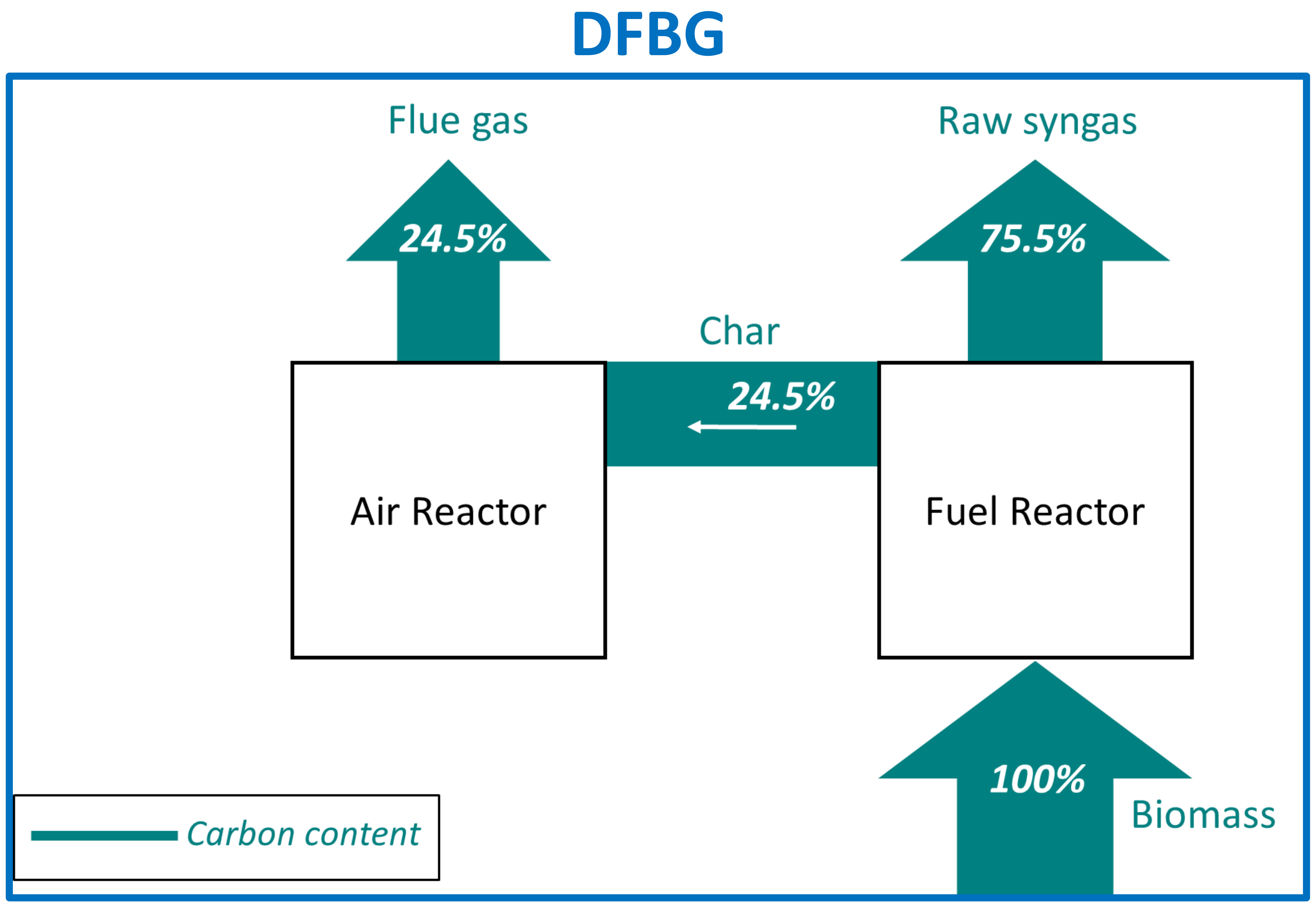


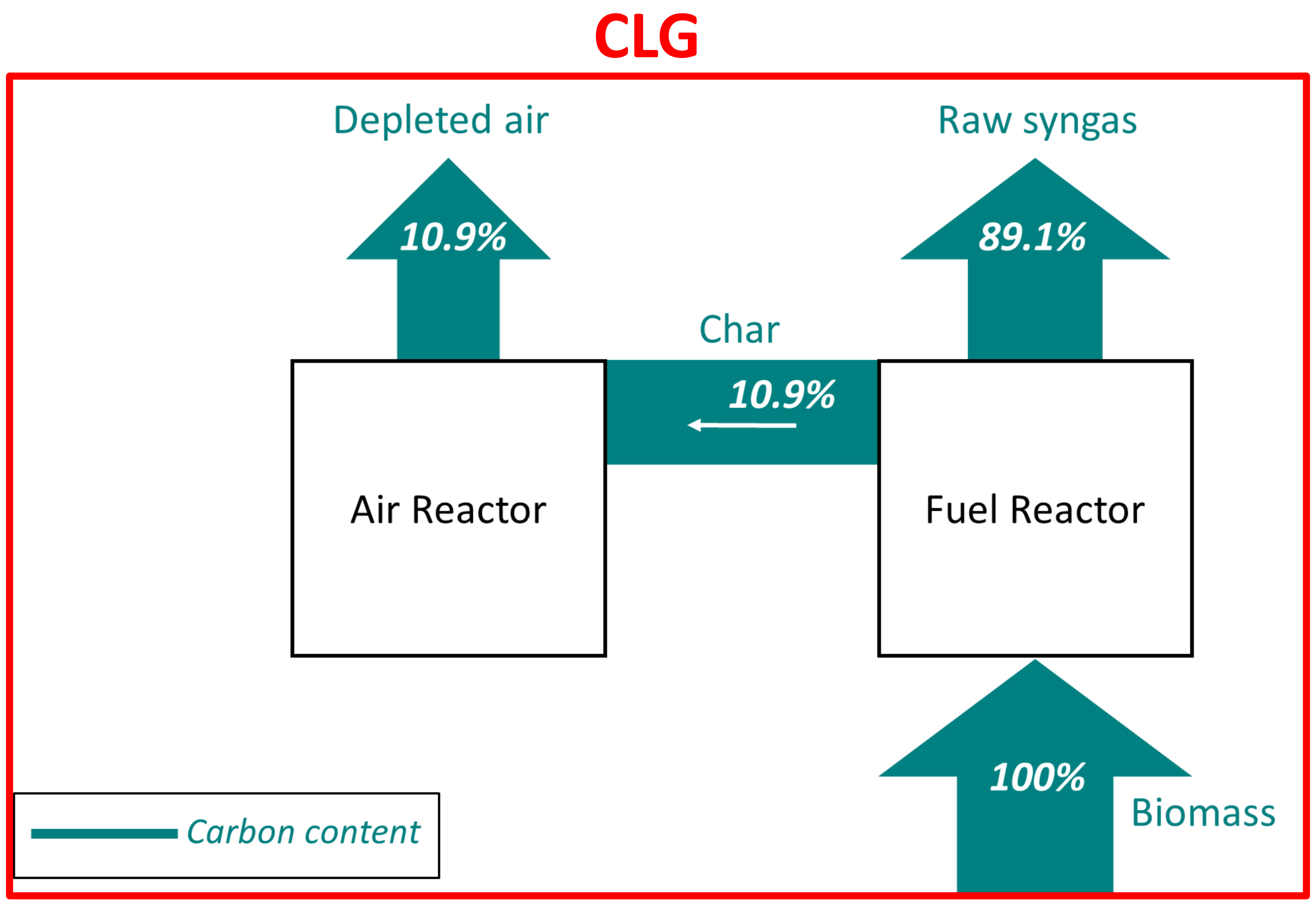
CLG



Full-scale (200 MWth) DFBG/CLG simulations – Output (Carbon balance)

Carbon Conversion (CC) is the fraction of carbon in the initial feedstock that is transferred to syngas in the gasifier



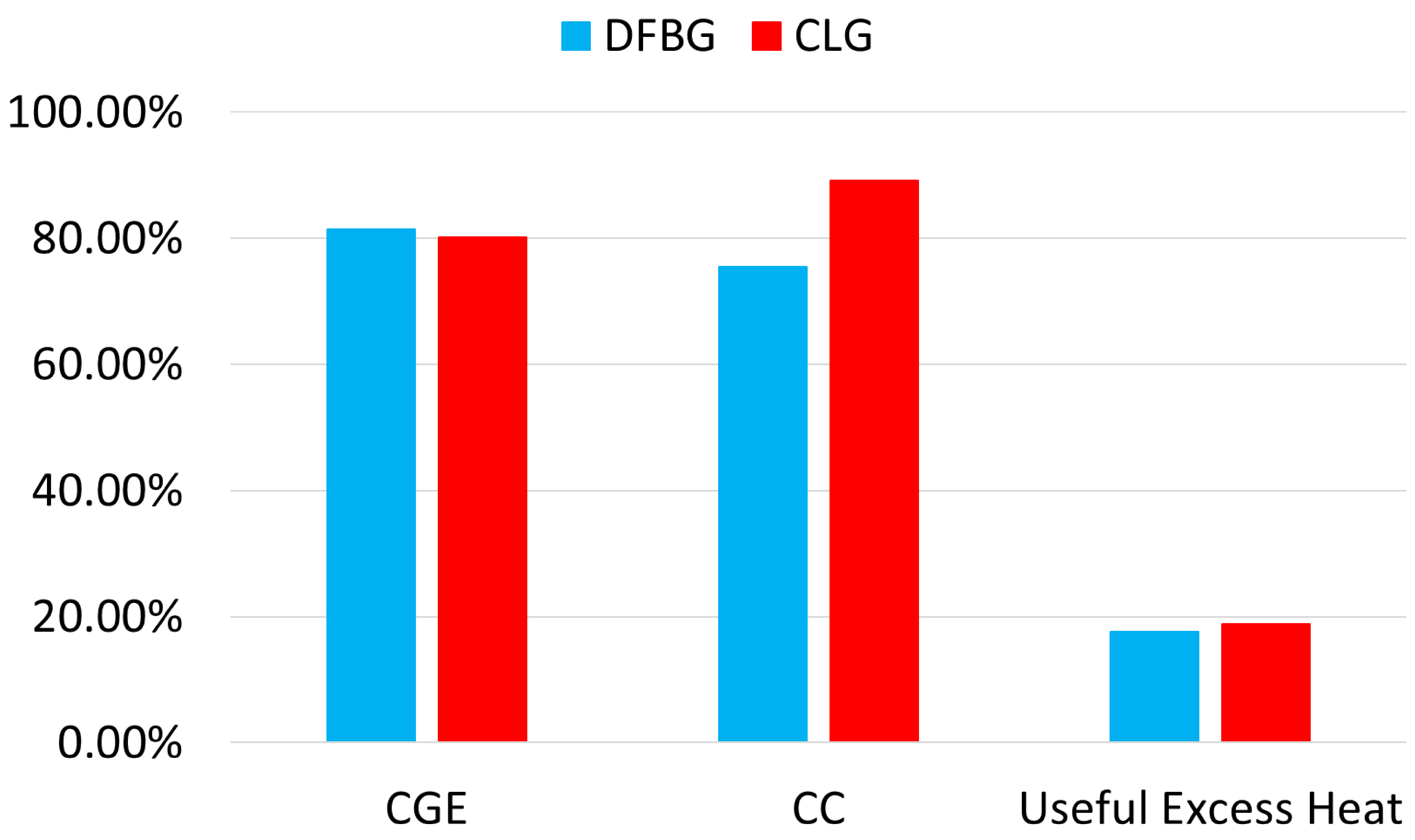


Full-scale (200 MWth) DFBG/CLG simulations – Comparative analysis (Discussion)

- **Both technologies**, in their potential commercial and optimized version, are capable of providing **a high quality syngas (CGE > 80%)** and **optimal heat integration (useful excess heat ~20%)**.

- The main differentiation lies on the ability of **CLG** to achieve higher carbon conversions in the gasifier **(CC ~90%)** and subsequently **higher carbon capture/ utilization potential in BtL concepts (negative CO_2 emissions)**.

- While the **CAPEX requirements are estimated more or less the same for both technologies** (i.e. feedstock feeding system, FR, AR, cyclones & interconnecting ducts, ash removal and handling), the **additional OPEX for the OC make-up** are present only in **CLG** applications.



- Within the TUDA CLG pilot tests, encouraging make-up rates equal to 0.15-0.25% of the OC circulation rates were required. In potential commercial applications, when **using ilmenite with a perfectly tailored particle size distribution**, even **lower OC make-up rates (0.05-0.1%)** could be attainable, ensuring that OC related costs will account **for less than 5% (low influence) of the annual OPEX of a BtL plant**.

Conclusions - Summary

EUBCE 31st European Biomass Conference & Exhibition
IN PERSON, ONLINE
Bologna 2023

- ✓ DFBG is a semi-commercially proven technology, while CLG has just been demonstrated at pilot scale.

- ✓ Both examined indirect gasification processes (DFBG, CLG) come up with great performance indicators and seem able to outperform the conventional gasification technologies in terms of feedstock flexibility, scalability, syngas quality and heat integration for BtL applications. No insurmountable barriers towards their scaling up were detected.

- ✓ CLG can be considered as a slightly improved variant of the DFBG technology that enables higher carbon capture/utilization with affordable additional costs.

On the one hand, DFBG can be considered a sufficiently mature (tested up to 32 MWth) and solid technology that is able to support large-scale gasification-based biorefineries. On the other hand, the favorable aspects of the emerging CLG technology (just tested up to 1.5 MWth) should be exploited in large-scale applications as well, only after further maturation of the technology that will decisively mitigate any technical (e.g. agglomeration) and financial (OC make-up costs) risks.

This work has been carried out in the framework of the European Union's Horizon 2020 research and innovation programs under Grant Agreement No 817841 (Chemical Looping gAsification foR sustainAble production of biofuels – CLARA, https://clara-h2020.eu/) and Grant Agreement No 884208 (BIOfuels production from Syngas FERmentation for Aviation and maritime use – BioSFerA, https://biosfera-project.eu/)

Thank you

BioSFerA
Biofuel for biotravels

EUBCE
31st European Biomass Conference & Exhibition
IN PERSON, ONLINE 2023 | BOLOGNA. ITALY.

Clara

eubce.com

Contact: detsios@certh.gr