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Bioenergy & Biofuels LAB

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Fuel flexibility of an open top pilot plant gasifier

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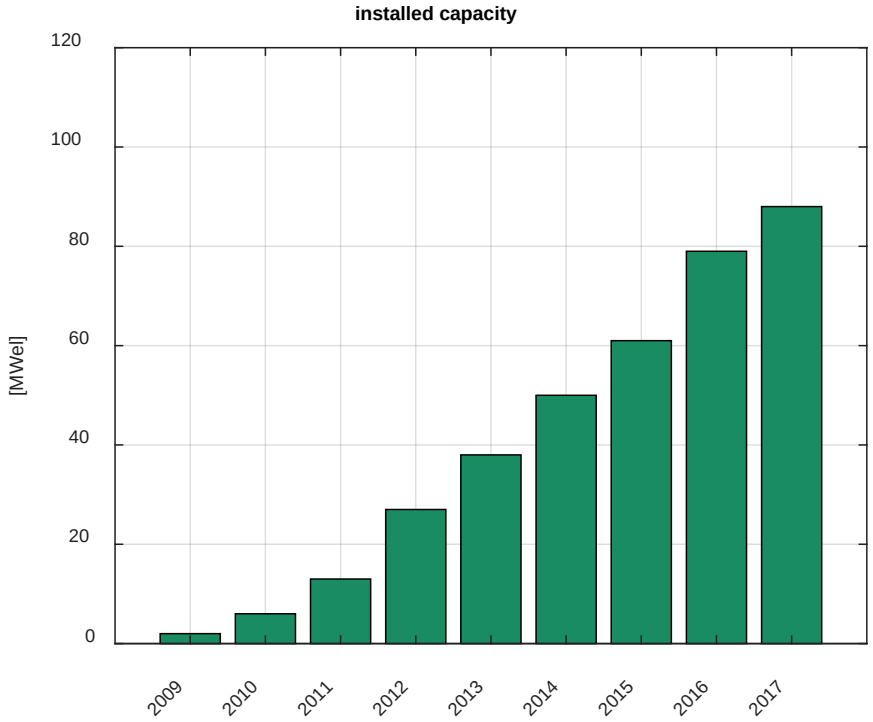
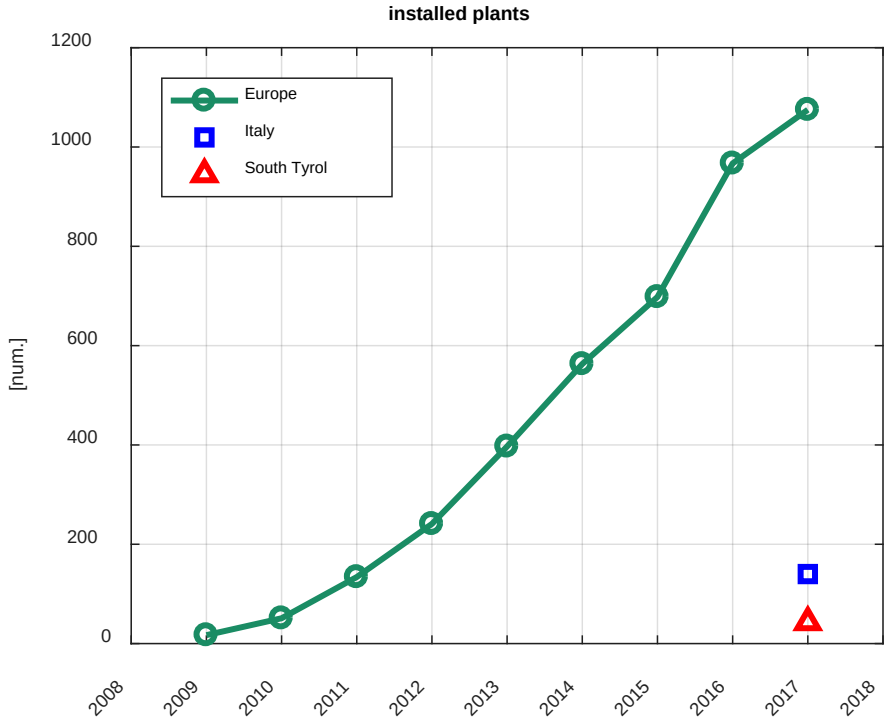
Small-scale biomass gasification in EU

Size of the plants < 0.5 MW_{el}
Number of installed plants > 1000

Application: CHP (feed in tariff)
Technology: fixed bed gasifiers

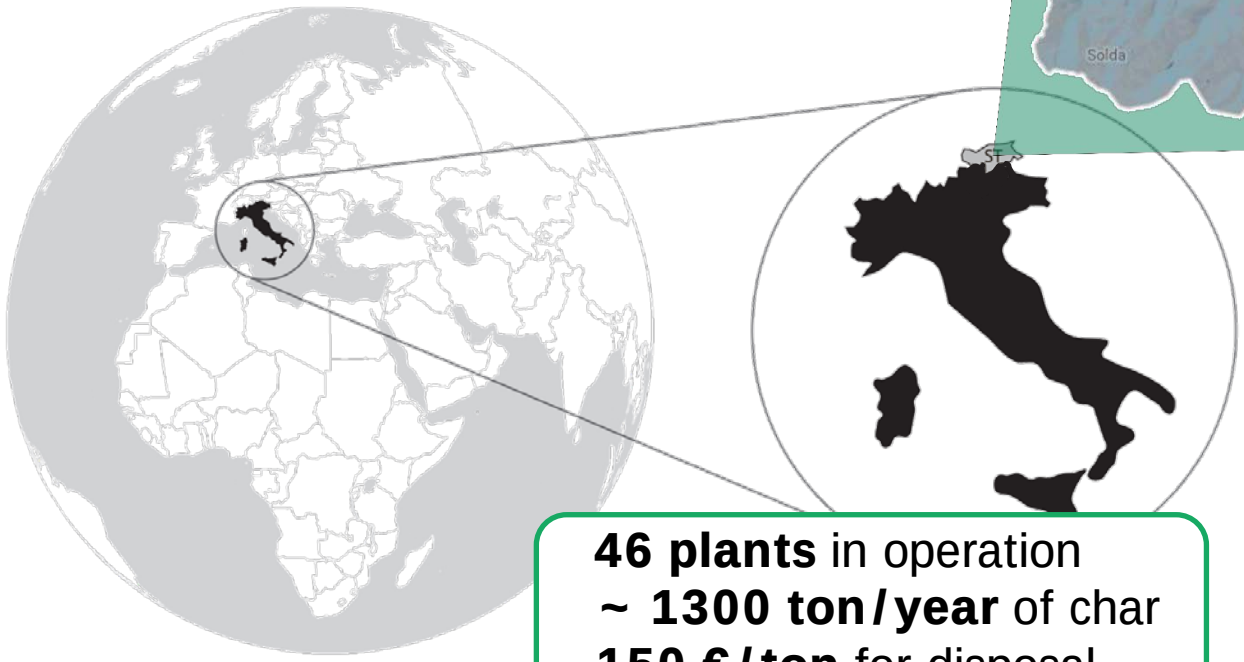




Source: 2018 - IEA bioenergy Task 33

The South Tyrol (Südtirol) region

Area: 7400 km²
Population: 511750 ab.
42% forest



46 plants in operation
~ 1300 ton/year of char
150 €/ton for disposal

Main limitations of commercial small-scale biomass gasification systems

- Pretty reliable systems when working at nominal conditions, but...
- ... limited:
  - fuel flexibility
  - partial load operation

THE AIM OF THIS WORK is to investigate the effect of **partial load** and **fuel flexibility** in fixed bed gasification systems

Open-top gasifier

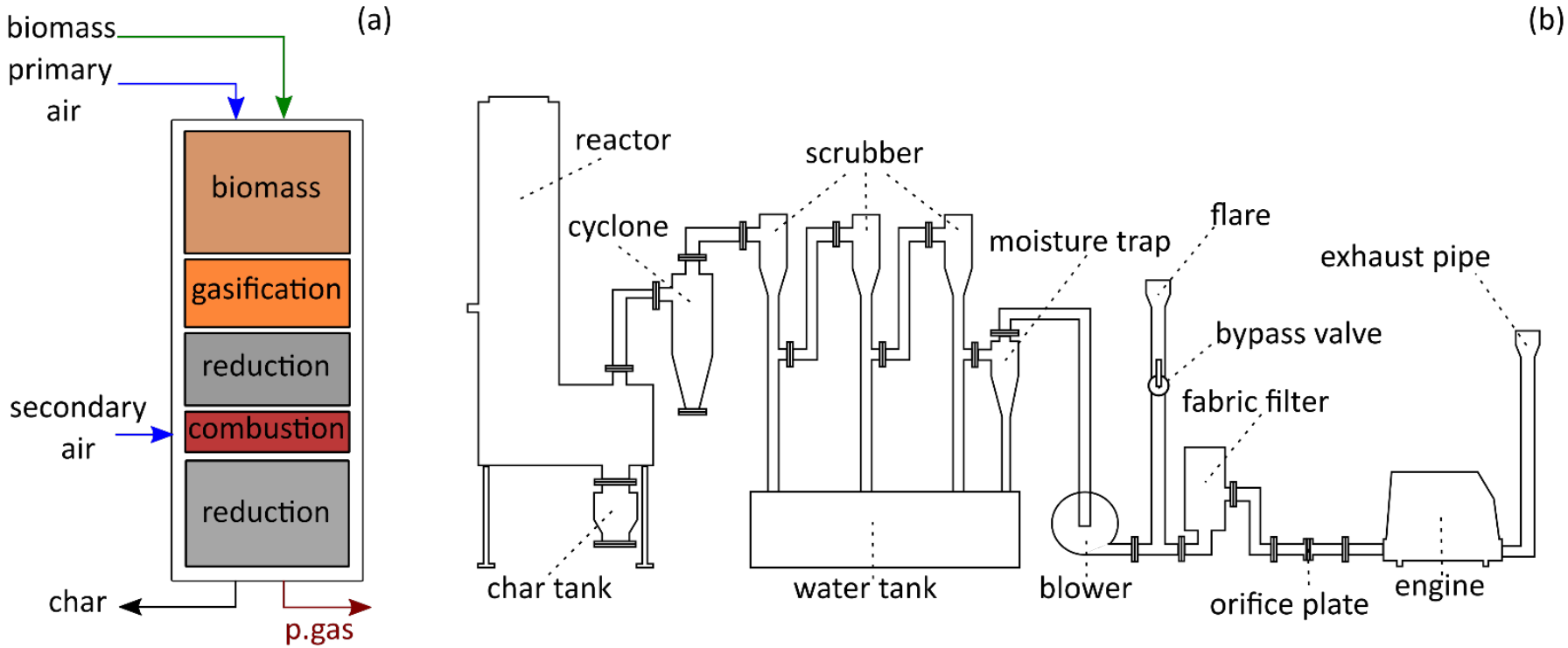
Fixed bed reactor – Nominal size: 4 kg_{biom}/h





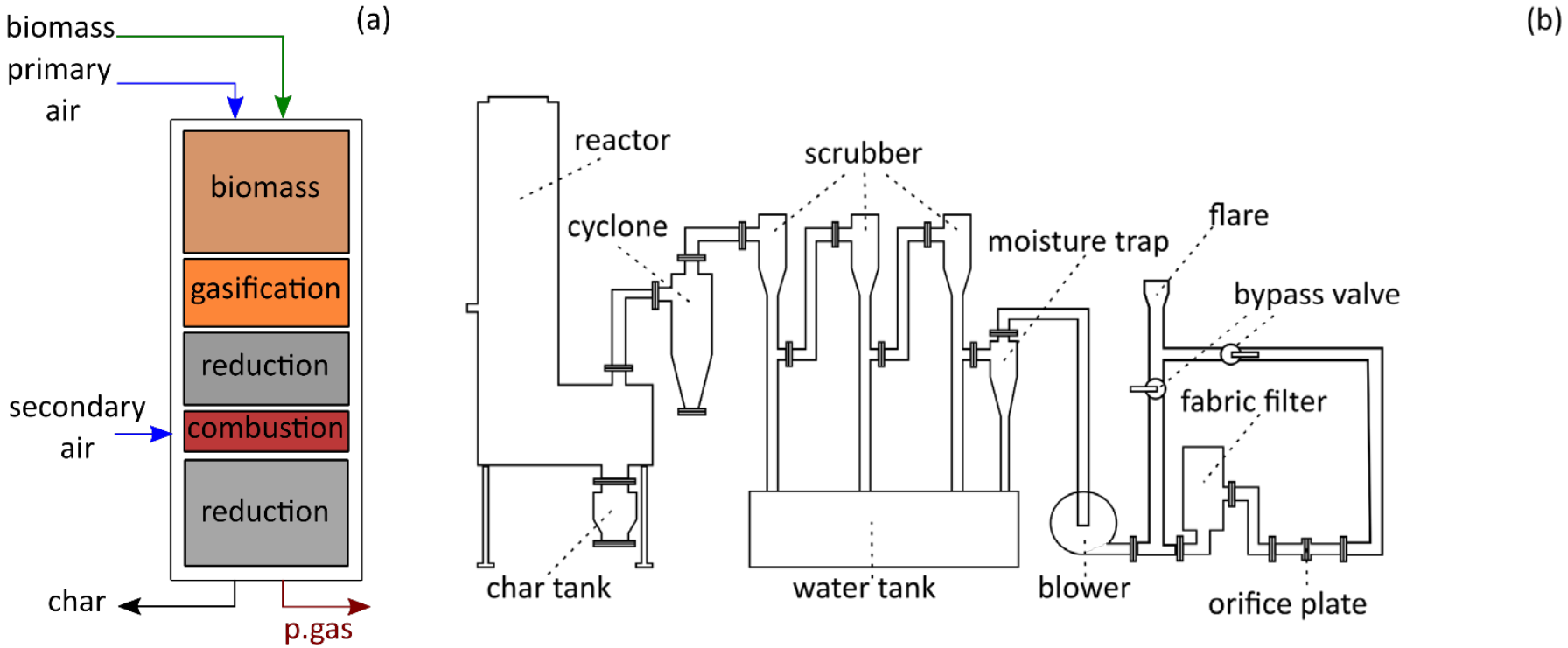
Open-top gasifier

CHP operation mode (coupled with a dual fuel diesel engine)



Open-top gasifier

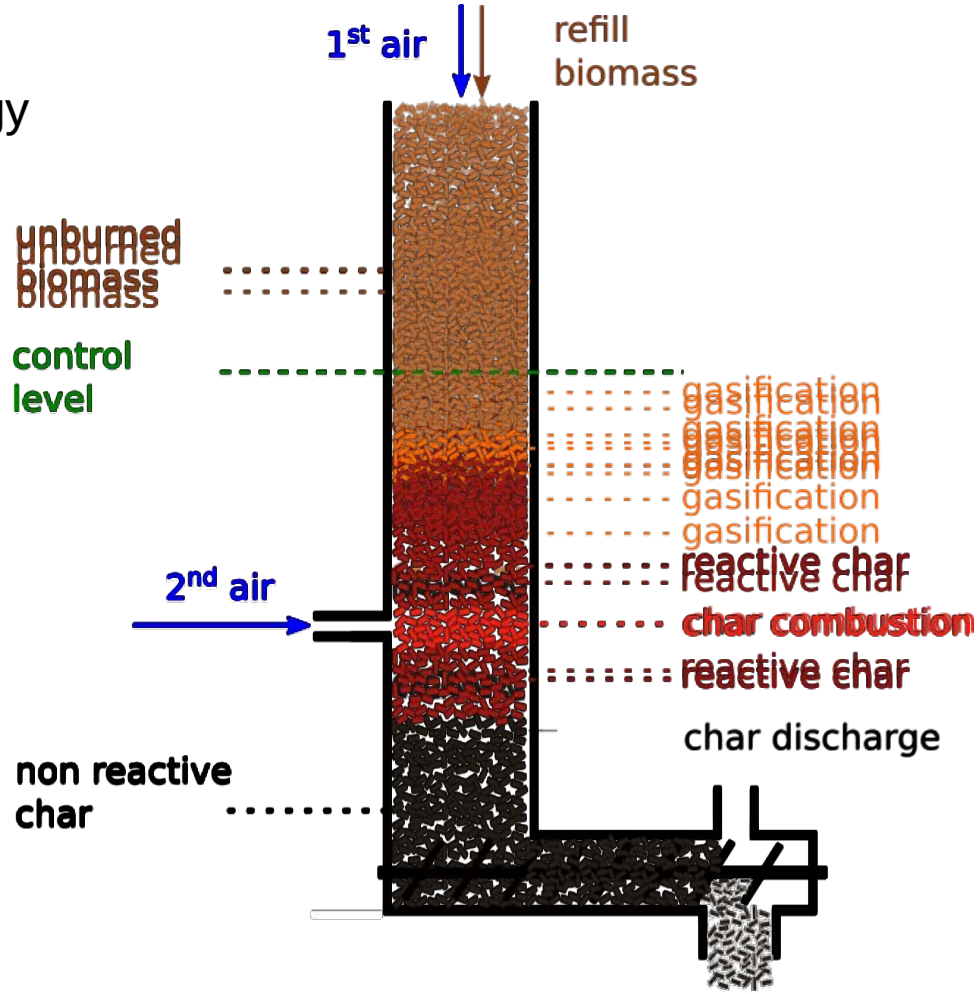
Gasification mode



Open-top gasifier

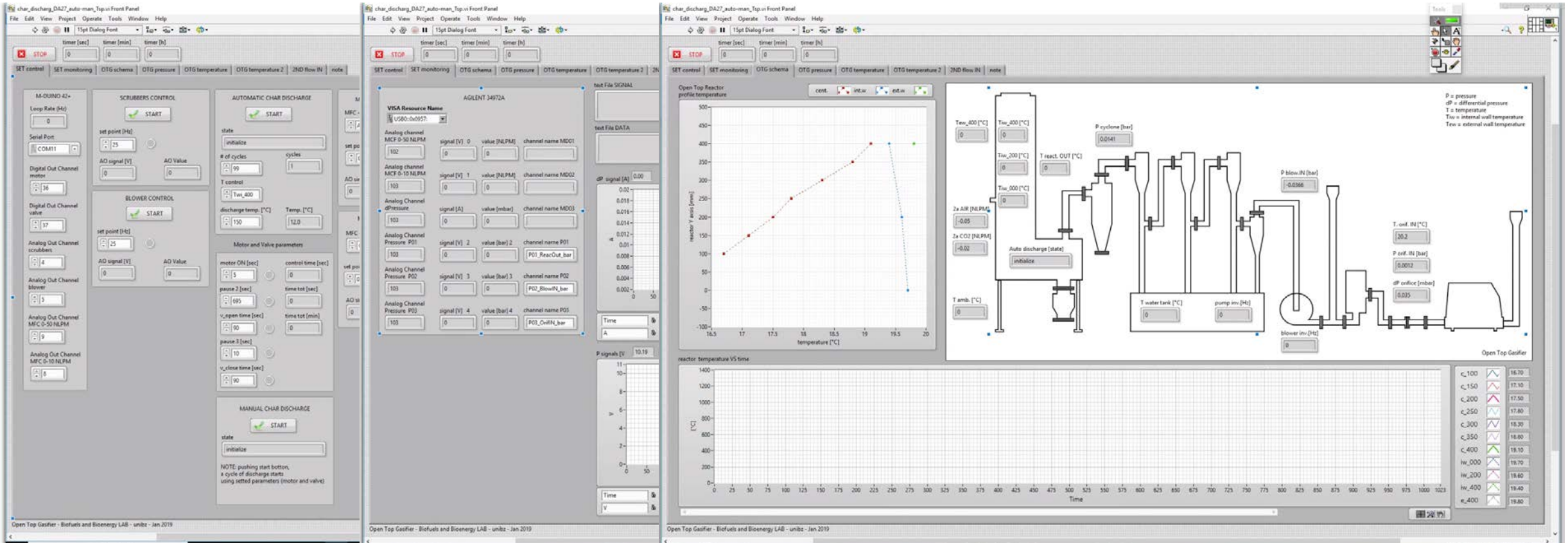
Reactor behavior and control strategy

- When the thermocouple reach a **temperature of 400 °C**, the discharge starts
- Each discharge cycle comprises **3 rotations of the screw conveyor**



Process control and data acquisition

by means of a Labview interface



Measured quantities and characterized properties

- Mass IN
- Mass OUT
- Charge and discharge time

- Secondary air mass flow rate (mass flow controller)
- Producer gas flow rate (differential pressure over a calibrated orifice)
- Gas composition (microGC)

Derived quantities and process parameters

- Biomass and char mass flow rates

- Total air IN (nitrogen balance)
- Equivalence Ratio

- Energy fluxes
- Cold Gas Efficiency

Fuel characterization

e.g. Standard spruce pellet EN plus A1 – 6 mm diameter

- moisture content
- ash content
- elemental analysis C,H,N,S (Vario MACRO Cube, Elementar)
- HHV - LHV (C 200 - IKA)

Moisture	Ash	C	H	N	S	O	LHV
[%wt$_{ar}$]			[%wt$_{dry}$]				[MJ/kg$_{dry}$]
7.1	0.3	49.8	5.6	0.1	0.4	43.8	16.9

Performed experimental campaigns

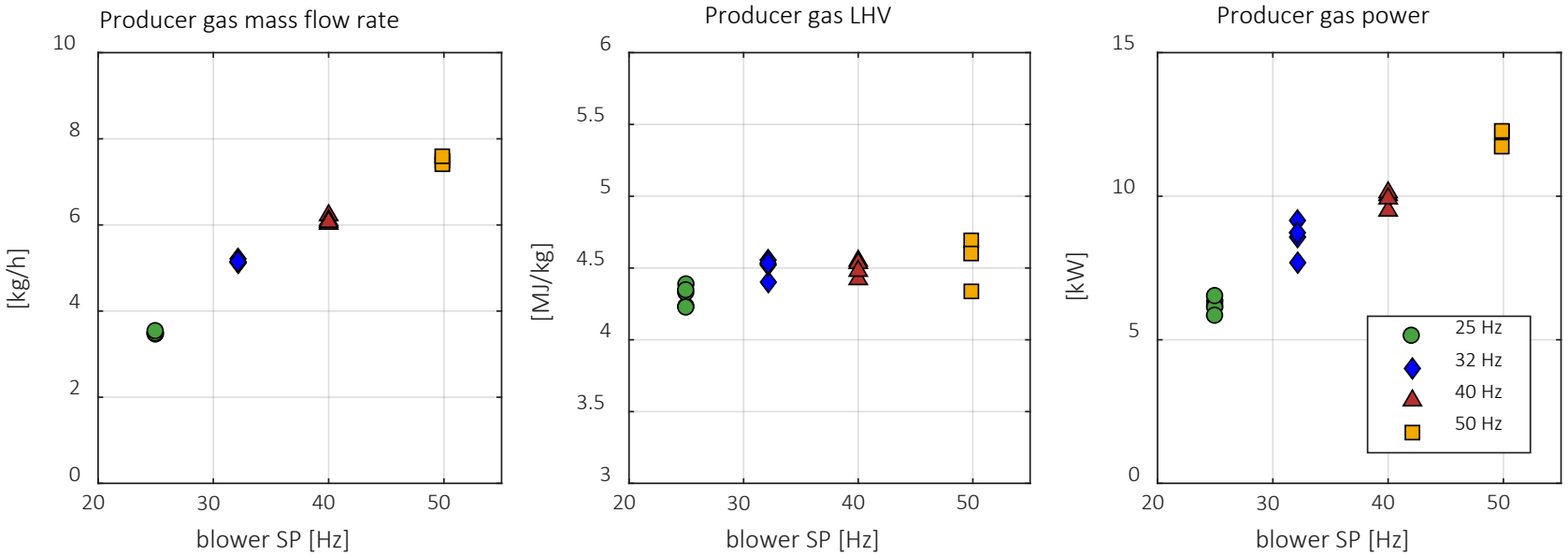
• **Load Modulation (LM):** in this campaign, the load of the gasifier, operated with standard wood pellet, has been modulated varying the blower set point, ranging from 44% to 69% to 82% to full load;	**Load modulation**
• **Char Recirculation (CR)**: in this campaign, char has been recirculated together with wood pellets, with shares ranging between about 5% to about 10%; • **Torrefied Pellets (TP):** in this campaign, three gasification experiments have been carried out using standard pellet, torrefied pellet at 250 °C and torrefied pellet at 270 °C, also varying the secondary air from 0 NLPM to about 38 NLPM; • **Bark and Chips (BC):** in this campaign, the gasifier has been operated with standard wood chips, also mixed with different shares of bark (ranging from 30 % to 80 %).	**(char valorization)** **Fuel flexibility**

Experimental campaign	Feedstock	Investigation - Aims
Load Modulation	Wood pellets EN plus A1	Load modulation capability

D. Antolini et al., Enhancement of the load modulation capability of a pilot plant gasifier by means of secondary air control. In: 27th European Biomass Conference and Exhibition. pp. 802–806. ETA-Florence Renewable Energies, Lisbon, Portugal (2019)

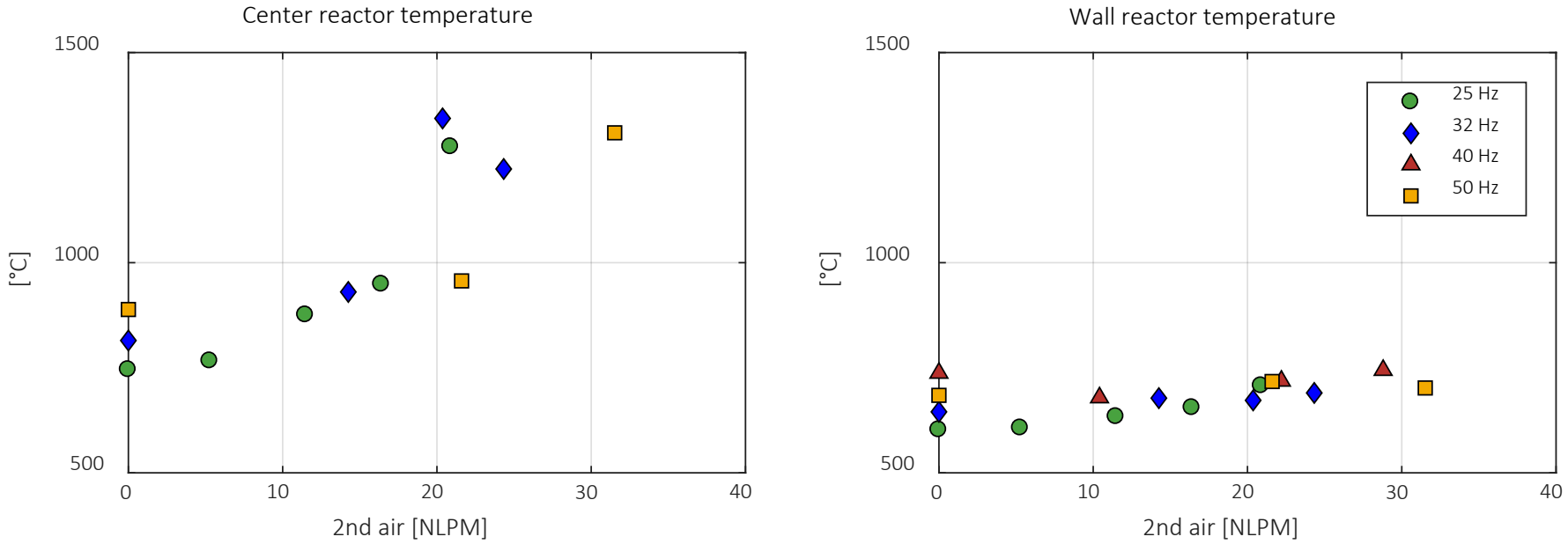
Load Modulation (LM)

- SP 50 Hz, gas power ≈ 12.0 kW, load 100%
- SP 40 Hz, gas power ≈ 9.9 kW, load 83%
- SP 32 Hz, gas power ≈ 8.5 kW, load 71%
- SP 25 Hz, gas power ≈ 6.2 kW, load 52%



Load Modulation (LM)

Effect of secondary air

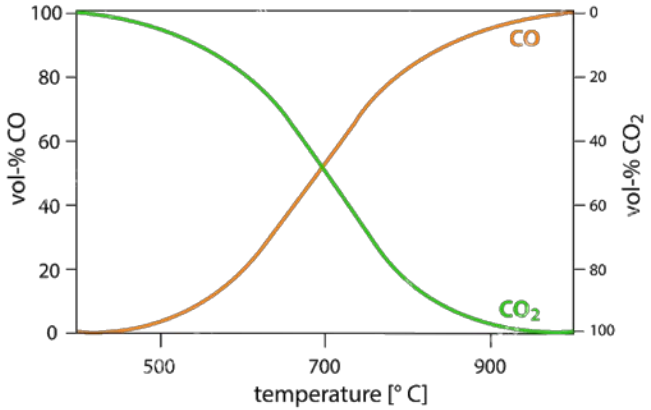


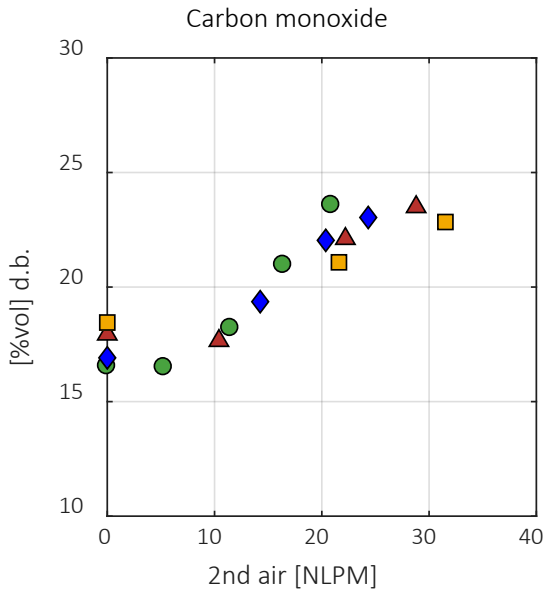
Load Modulation (LM)

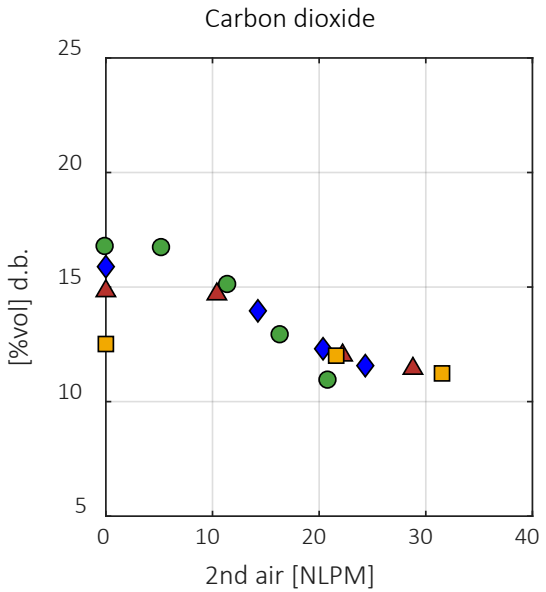
Effect of secondary air

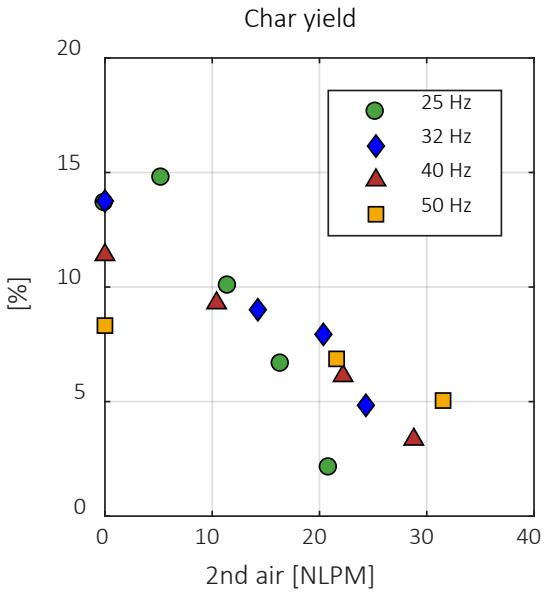
Boudouard reaction

$$C + CO_2 \rightleftharpoons 2\,CO$$









Experimental campaign	Feedstock	Investigation - Aims
Char Recirculation	Wood pellets and blend of wood and char pellets	Study the effect of char recirculation Automatic char discharge system development

F. Patuzzi et al., Char recirculation for improving the conversion yields in fixed bed gasification systems. In: 27th European Biomass Conference and Exhibition. pp. 527–532. ETA-Florence Renewable Energies, Lisbon, Portugal (2019)

Char Recirculation (CR)

Study cases

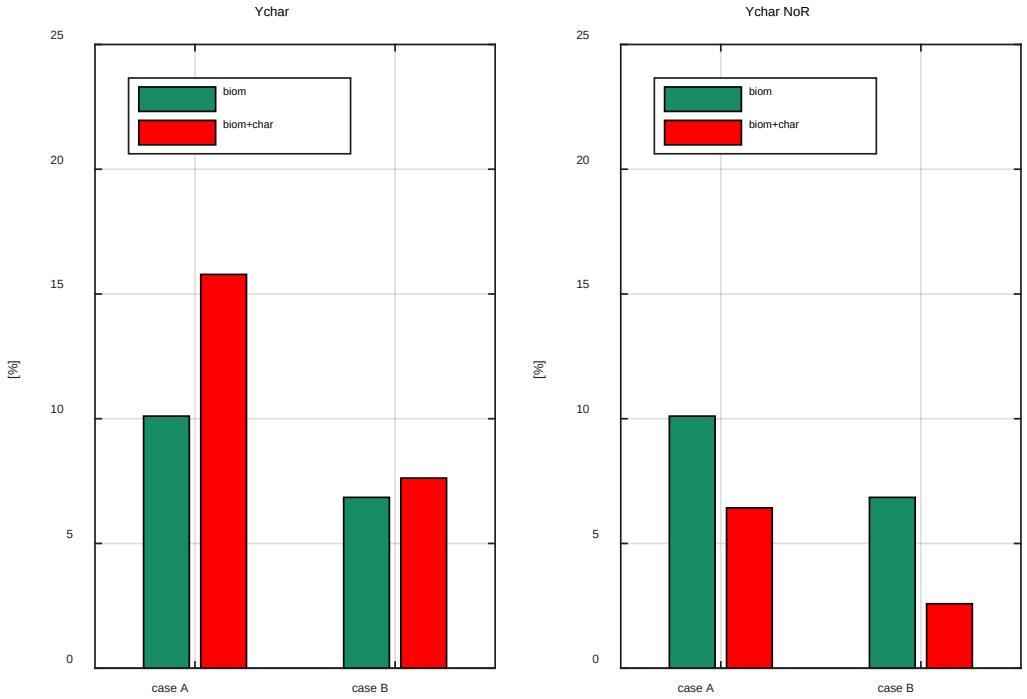
	char yield / recirc. share [%]	**2nd air injected** [NLPM]	**Blower SP** [Hz]	**ER** (when the fuel is only biomass) [-]
Case A	~ 10	10	40	< 0.25
Case B	~ 5	26	40	~ 0.25

Sub-cases

- **0:** fuel IN = standard pellet (biomass)
- **R:** fuel IN = standard pellet (biomass) + char (produced in the corresponding sub-case 0)

Char Recirculation (CR)

Conversion yields

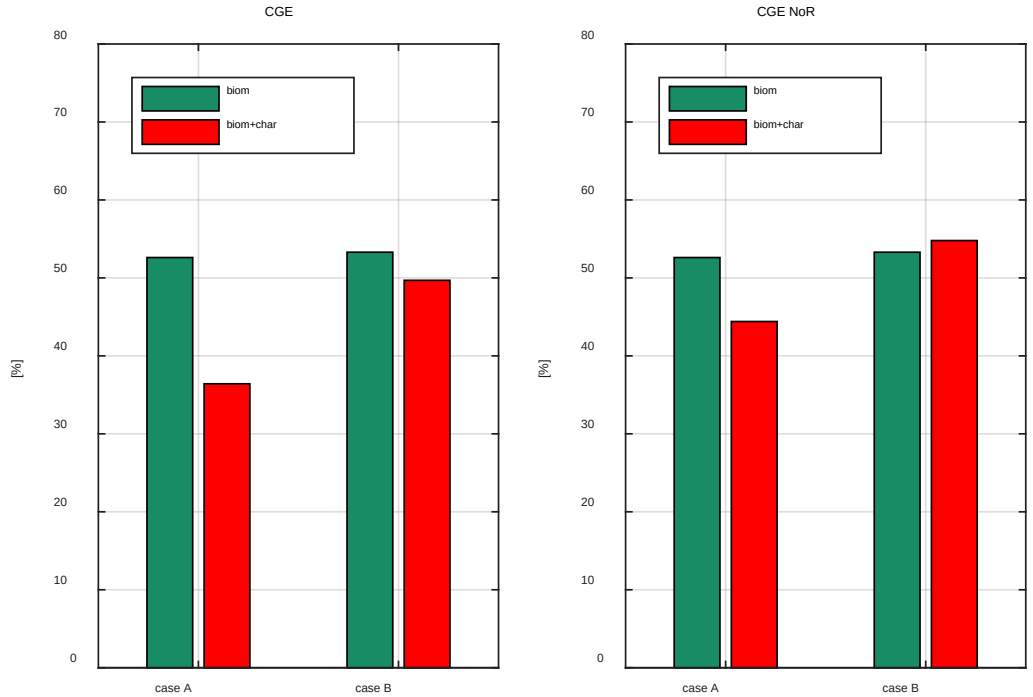


$$Y_{char} = \frac{\dot{m}_{char\ OUT}}{\dot{m}_{biom\ IN} + \dot{m}_{charIN}}$$

$$Y_{char\ NoR} = \frac{\dot{m}_{char\ OUT} - \dot{m}_{charIN}}{\dot{m}_{biom\ IN}}$$

Char Recirculation (CR)

Cold Gas Efficiency



$$CGE = \frac{\dot{m}_{pgas} \cdot LHV_{pgas}}{\dot{m}_{biom\,IN} \cdot LHV_{biom\,IN} + \dot{m}_{charIN} \cdot LHV_{charIN}}$$

$$CGE_{NoR} = \frac{\dot{m}_{pgas} \cdot LHV_{pgas}}{\dot{m}_{biom\,IN} \cdot LHV_{biom\,IN}}$$

Char Recirculation (CR)

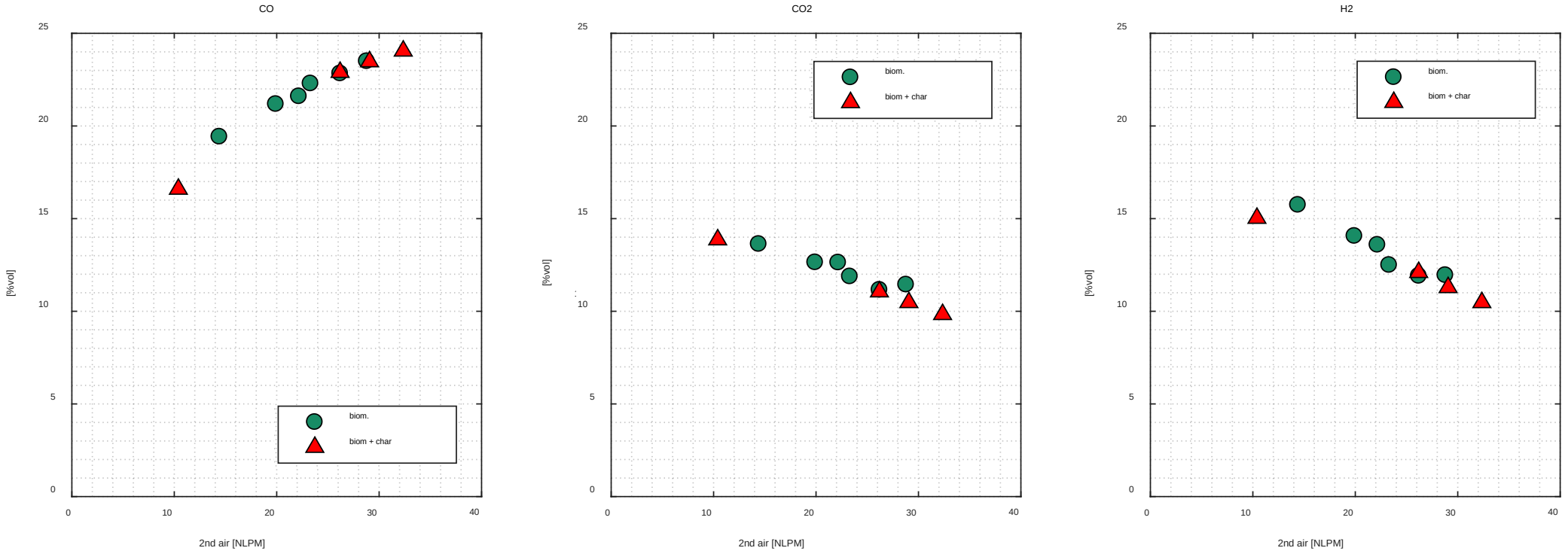
Effect of secondary air

- Can the process conditions be further tuned up to optimize the process for char recirculation?

	char yield / recirc. share	**2nd air injected**	**Blower SP**	**ER** (when the fuel is only biomass)
	[%]	[NLPM]	[Hz]	[-]
Case C	3 - 10	14 - 32	40	0.19 - 0.25

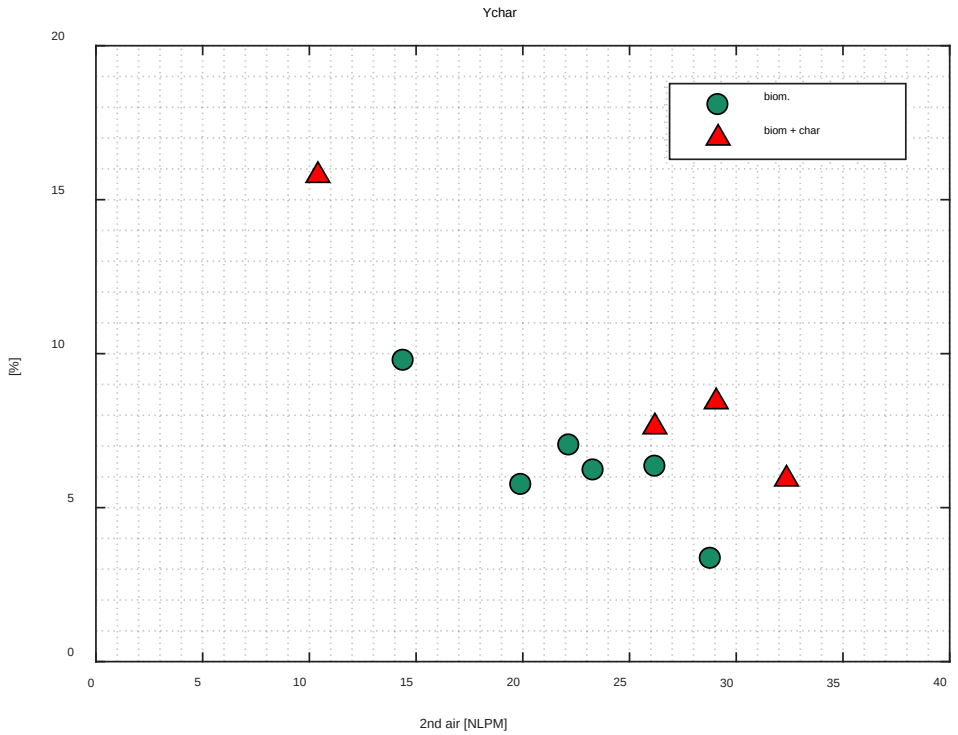
Char Recirculation (CR)

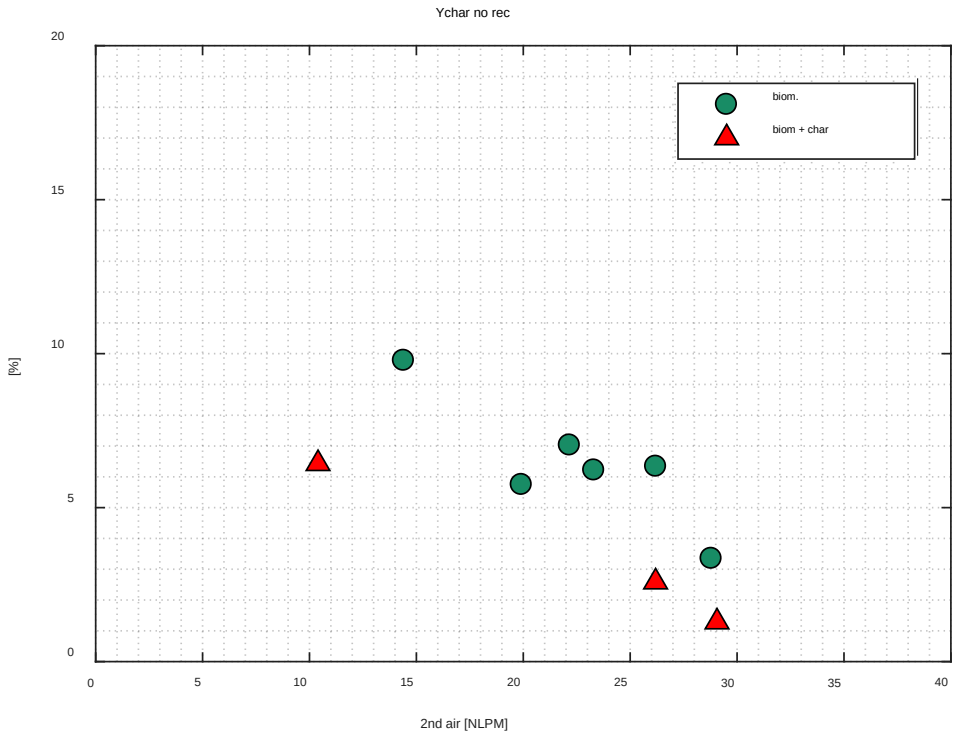
Effect of secondary air



Char Recirculation (CR)

Effect of secondary air



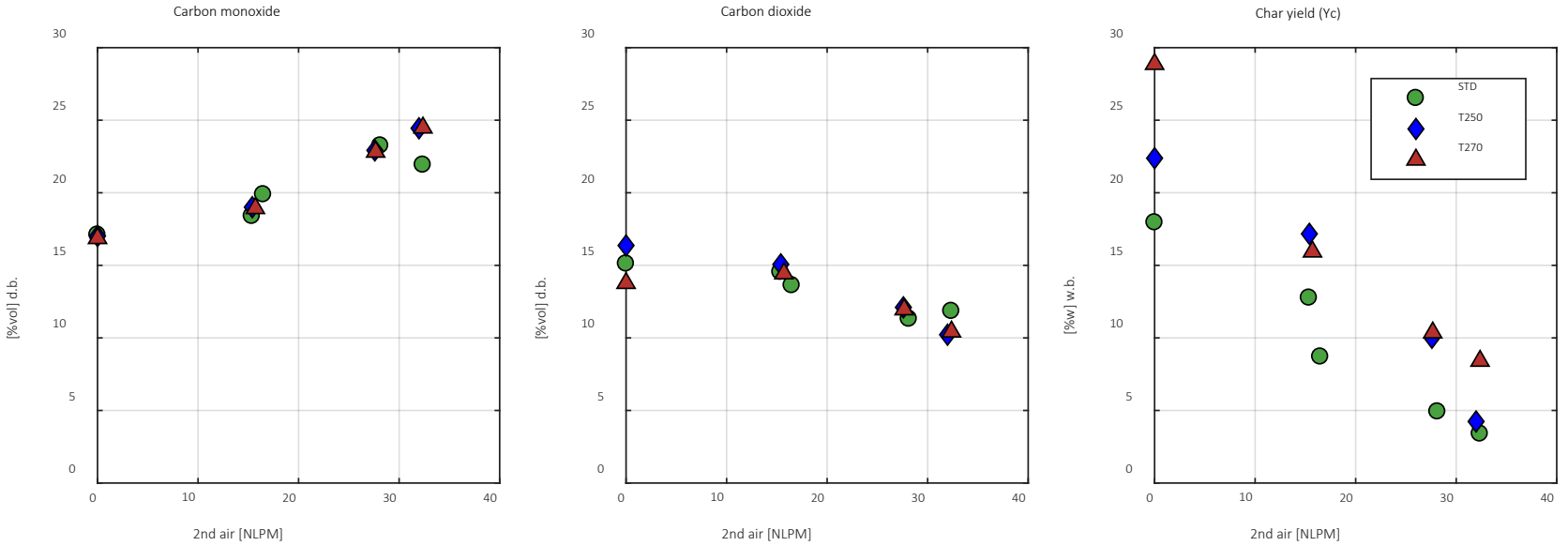


Experimental campaign	Feedstock	Investigation - Aims
Torrefied Pellets	Wood pellets and Torrefied pellets	Comparison between wood and wood torrefied pellets gasification

D. Antolini et al., Fuel flexibility of a pilot plant gasifier using torrefied pellets as feedstock. In: 28th European Biomass Conference and Exhibition. pp. 403–406. ETA-Florence Renewable Energies (2020)

Torrefied pellets (TP)

Effect of secondary air



Experimental campaign	Feedstock	Investigation - Aims
Bark and Chips	Chips with different percentage of bark	Study the gasification of wood chips with increasing amount of bark for forestry residues valorization

bark content:

B08 – wood chips 8% bark content

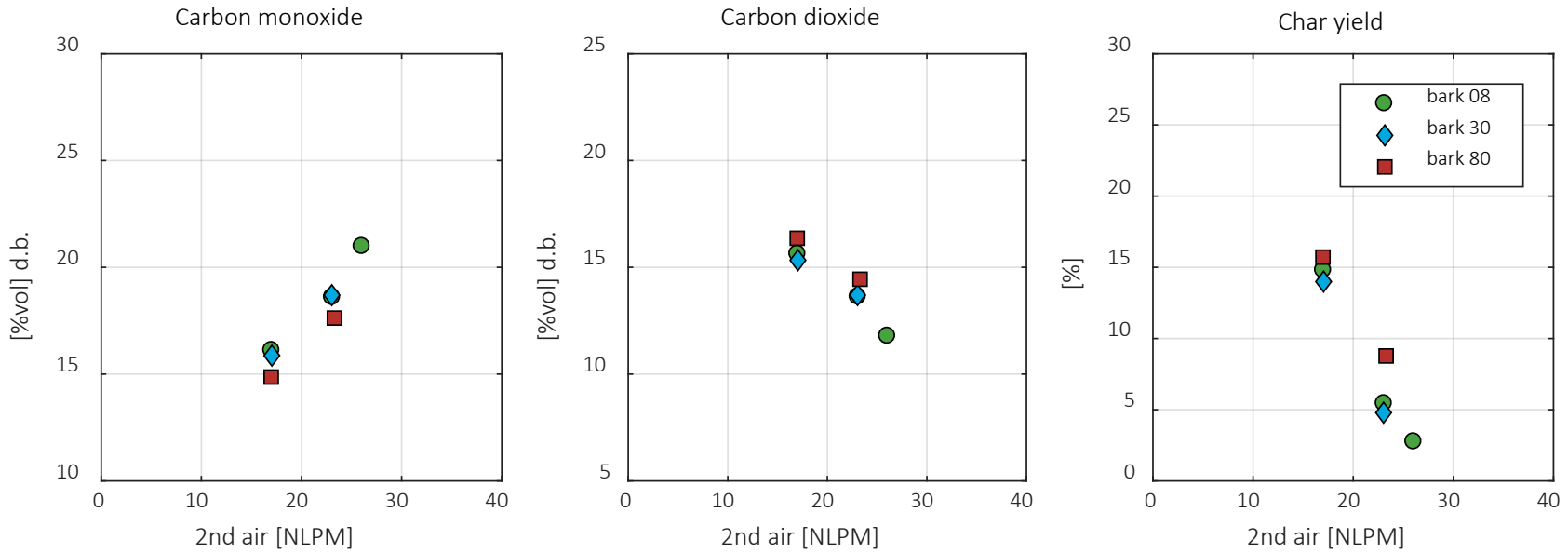
B30 – wood chips 30% bark content

B80 – wood chips 80% bark content

D. Antolini et al., Energy Valorization of Forestry Residues through a Small-Scale Open Top Gasifier. In: 28th European Biomass Conference and Exhibition. pp. 407–410. ETA-Florence Renewable Energies (2020)

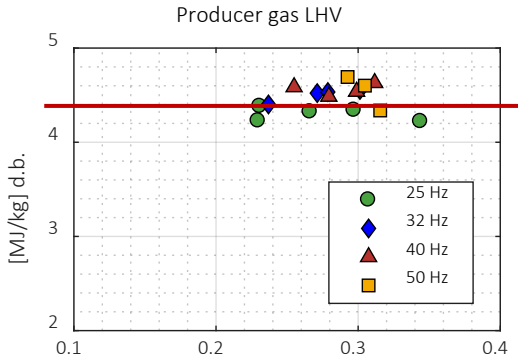
Bark and Chips (BC)

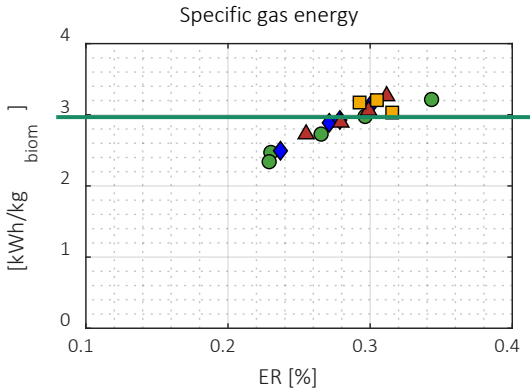
Effect of secondary air



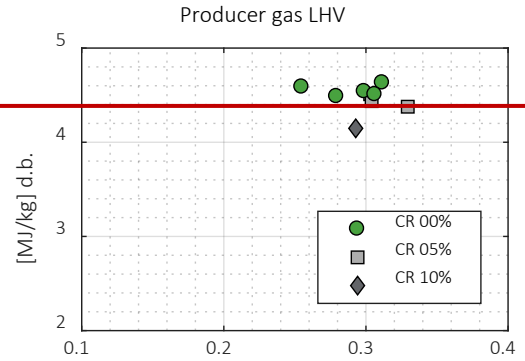
Comparison vs ER

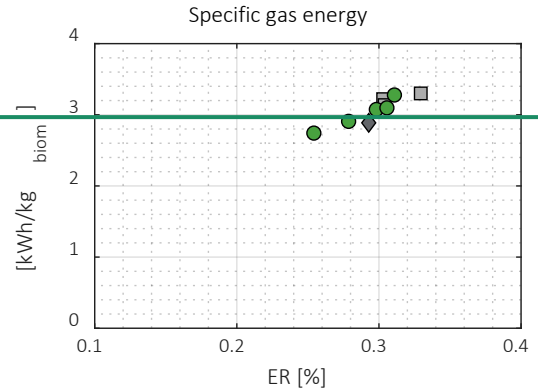
Load Modulation (LM)



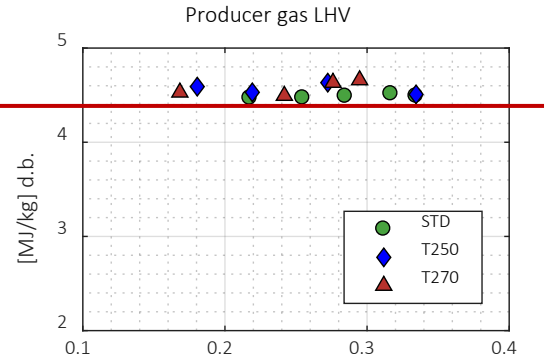


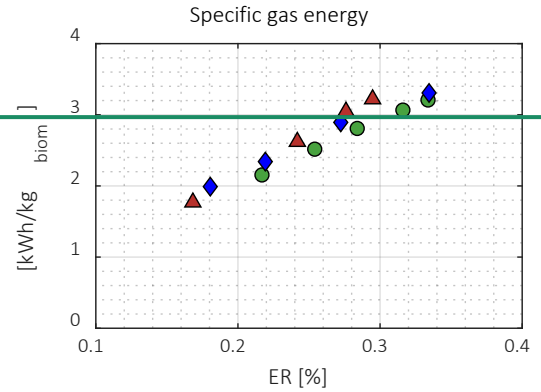
Char Recirculation (CR)



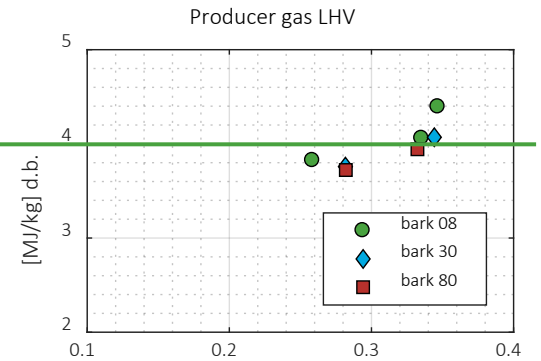


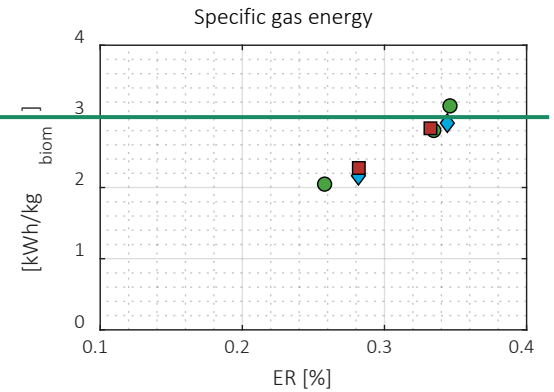
Torrefied Pellets (TP)





Bark and Chips (BC)





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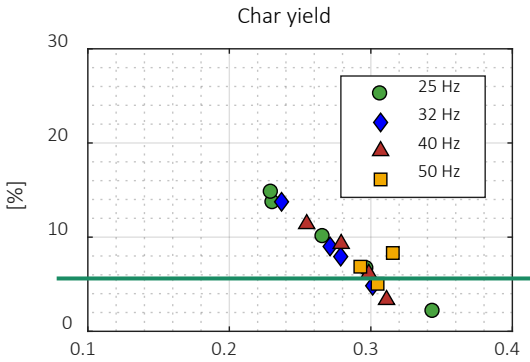
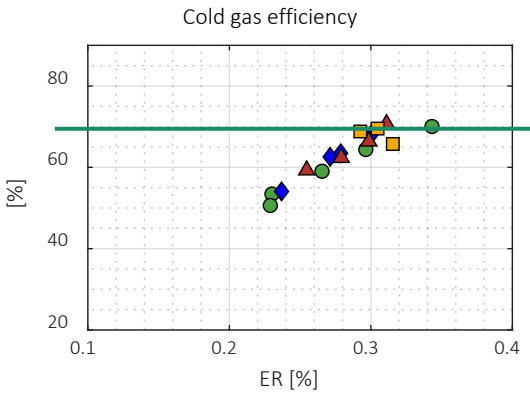
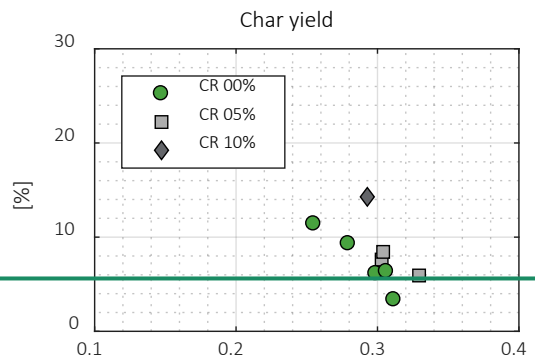
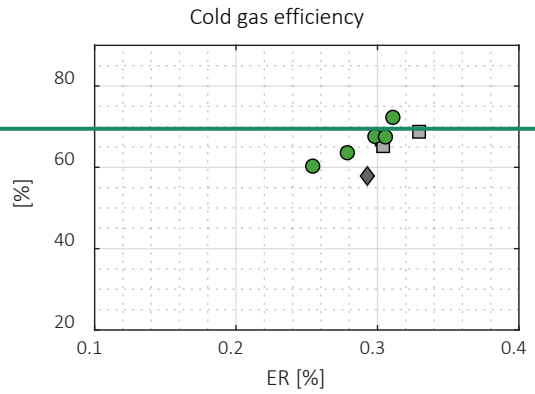
Load Modulation (LM)



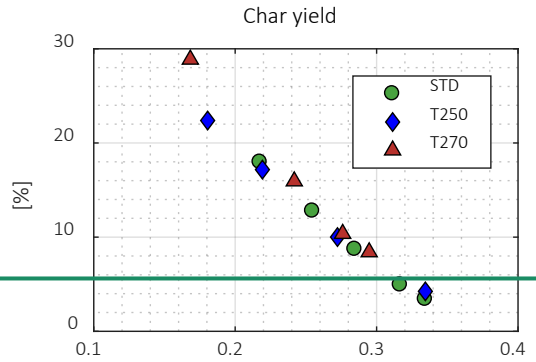


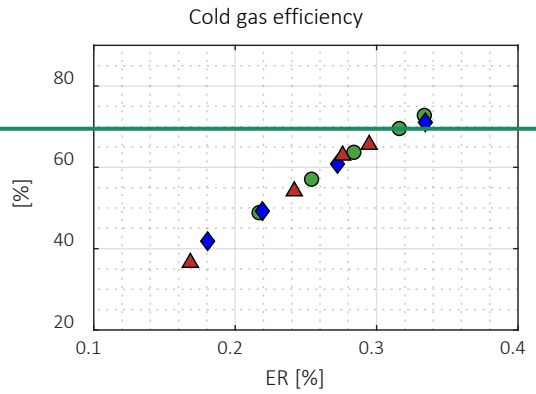
Char Recirculation (CR)



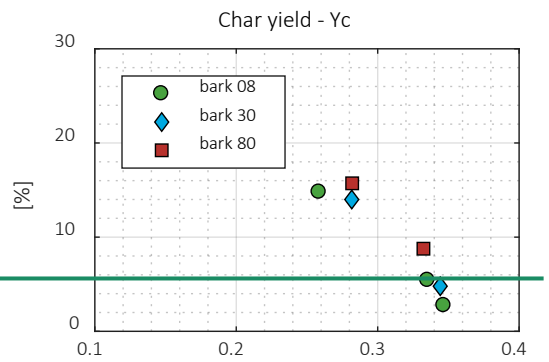


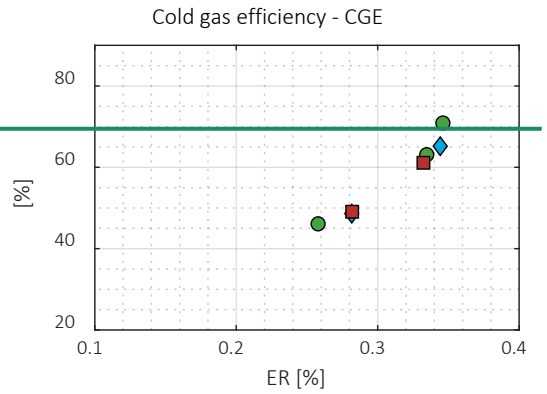
Torrefied Pellets (TP)





Bark and Chips (BC)





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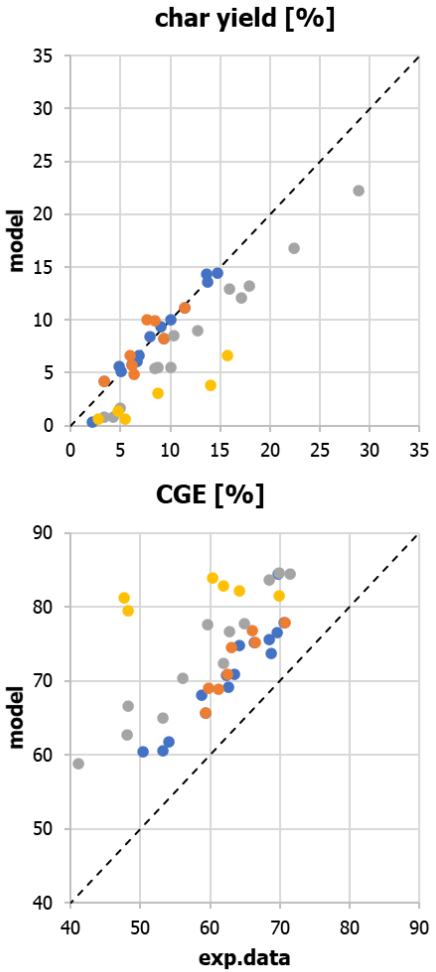
Model calibration

Adiabatic formulation

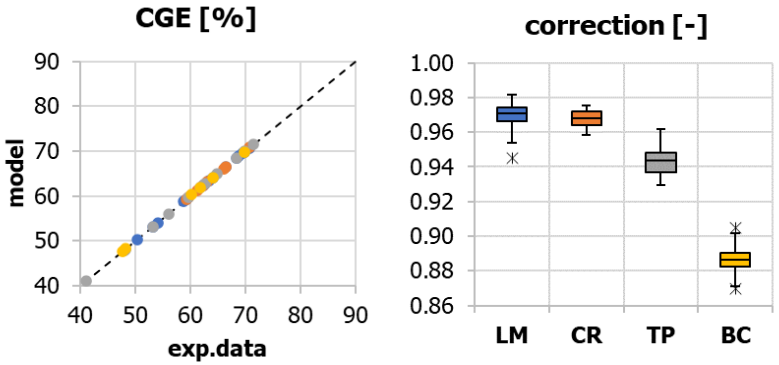


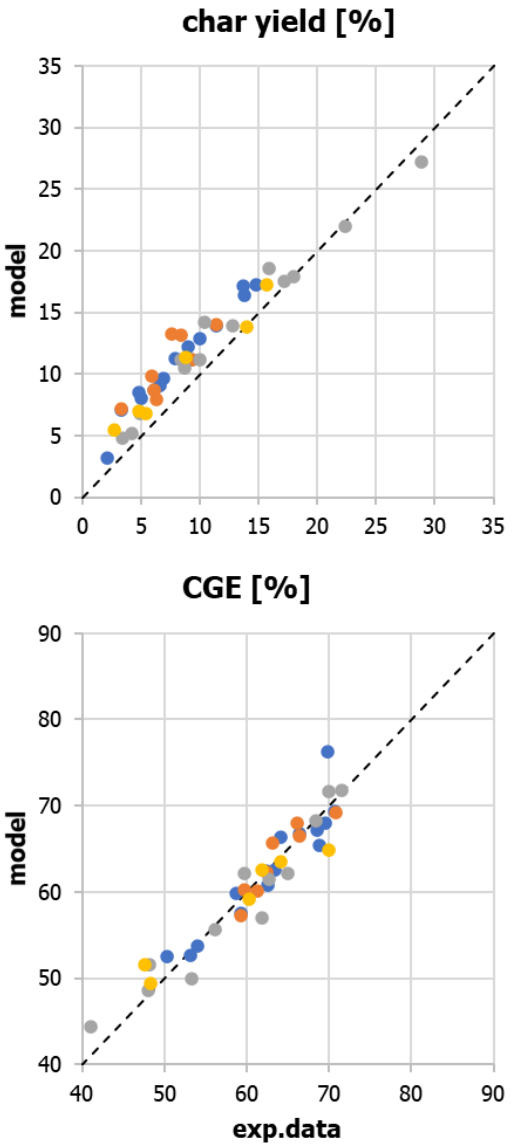
Four different exp. campaigns

- LOAD MODULATION (LM)
- CHAR RECIRCULATION (CR)
- TORREFIED PELLETS (TP)
- BARK AND CHIPS (BC)

Calibration to match the experimental CGE

$$\text{correction} = \frac{\Delta H_{OUT}}{\Delta H_{IN}}$$





Conclusions

- The gasification process can be optimized (at different load in terms of producer gas power) using secondary air in order to:
  - control the equivalent ratio
  - enhance the carbon conversion (increasing CO and decreasing char production) due to the highest temperature in the char reduction zone
  - increase the cold gas efficiency of the gasification system

- At the same time, the control of ER due to the secondary air modulation can help on fuel flexibility achieving:
  - producer gas LHV higher than 4.5 MJ/kg with pellets and approximately equal to 4 MJ/kg with woodchips
  - specific gas energy higher than 3 kWh/kg
  - CGE approximately equal to 70%
  - char production lower than 5%

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24 June 2021

Thank you very much for your kind attention!

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