Freie Universität Bozen
Libera Università di Bolzano
Free University of Bolzano

Forest residues valorisation for energy purposes through a small-scale CHP system

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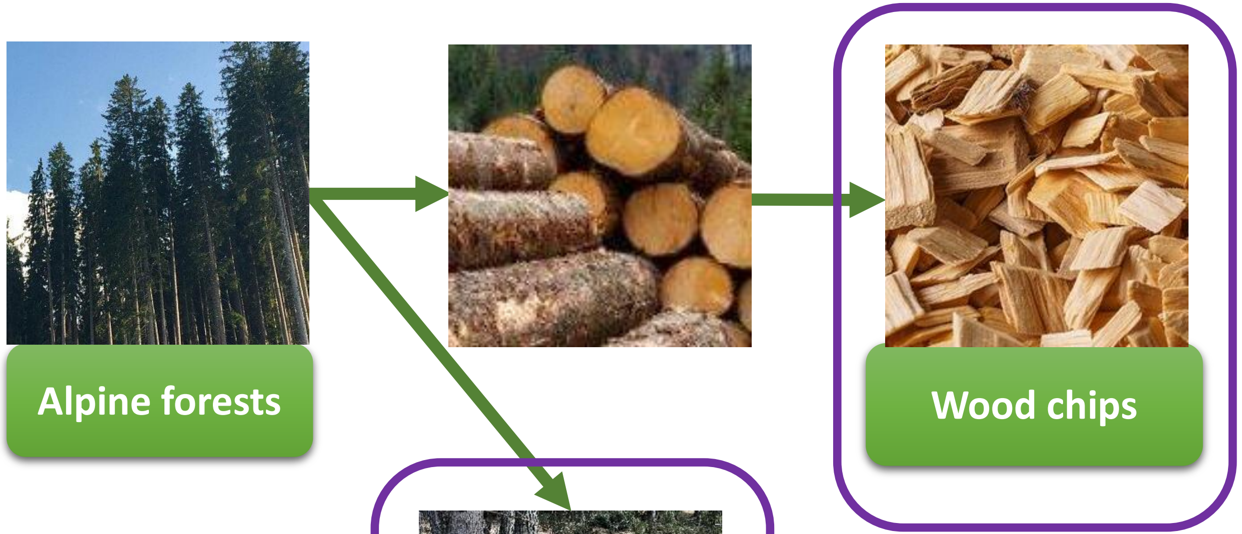
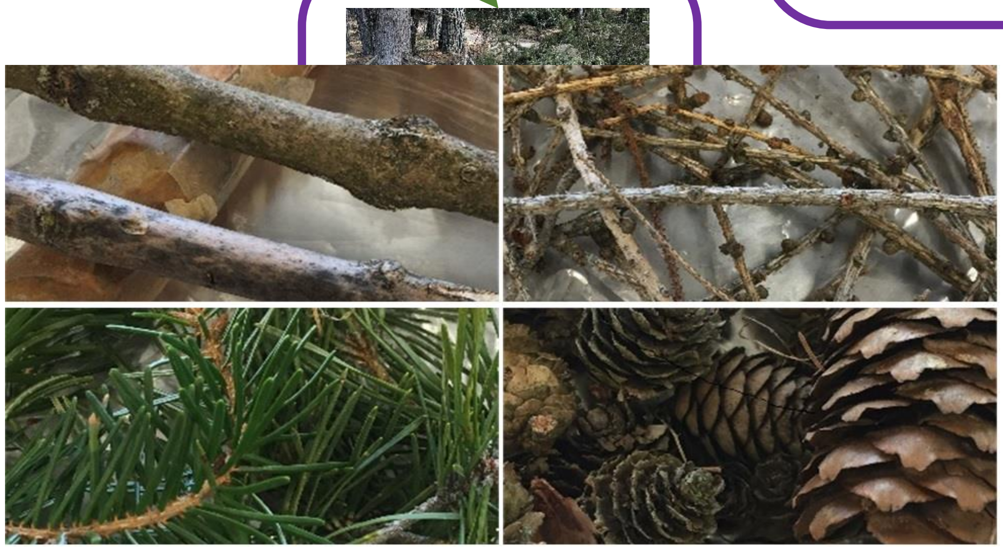
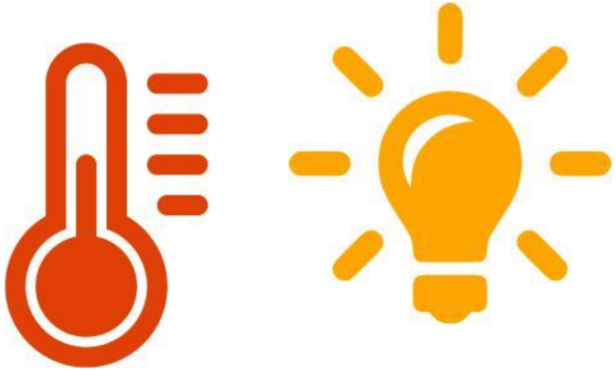
Introduction: Energy from woody residues management





Biomass → Producer Gas

Producer Gas → CHP

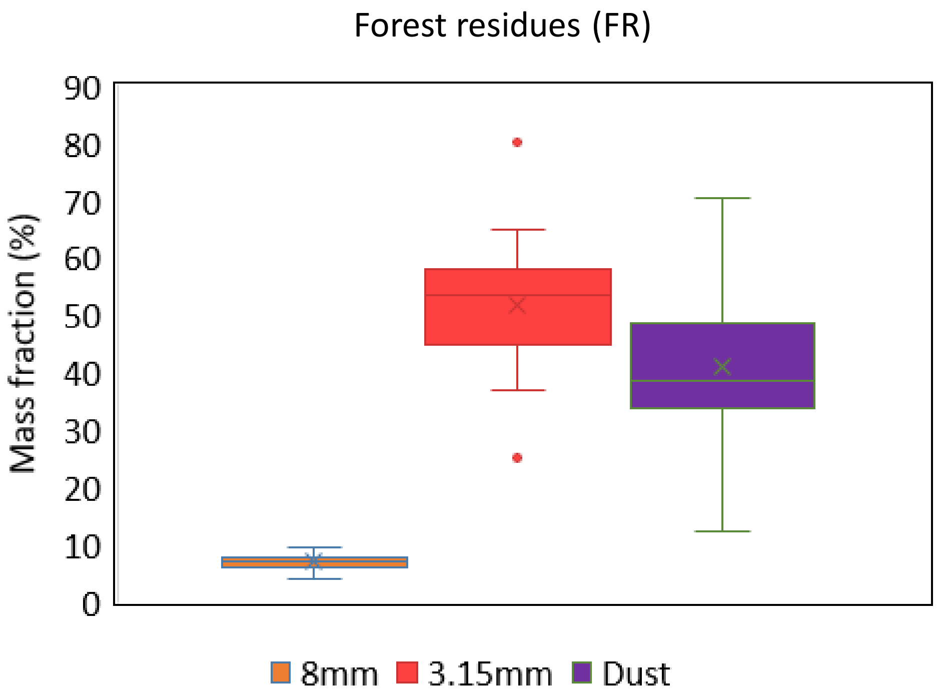


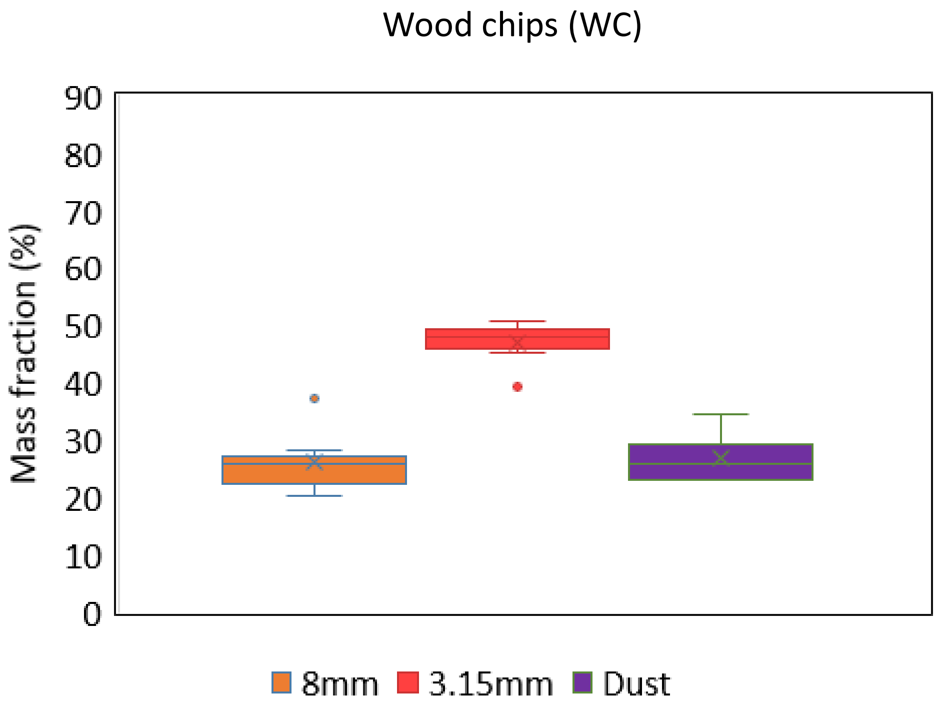
Feedstock: forest residues

- They can be effectively used as additional energy resource and,
  - ✓ **avoid safety problems in the forest**, such as the spreading of tree diseases, pests, and forest fires
  - ✓ provide an economic advantage of operating the plant
  - ✓ a strategy to increase the local clean energy production.
  - ✓ a buffer material in the seasons in which the maintenance activities are not performed – can feed gasifier throughout the year regardless of the seasonal changes

reduction of operational costs of plants and valorisation of a resource which is currently unused

Sieve test analysis

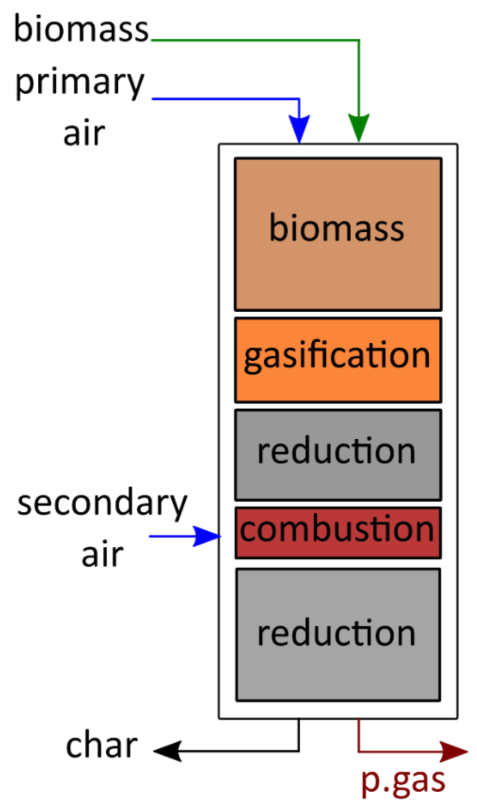


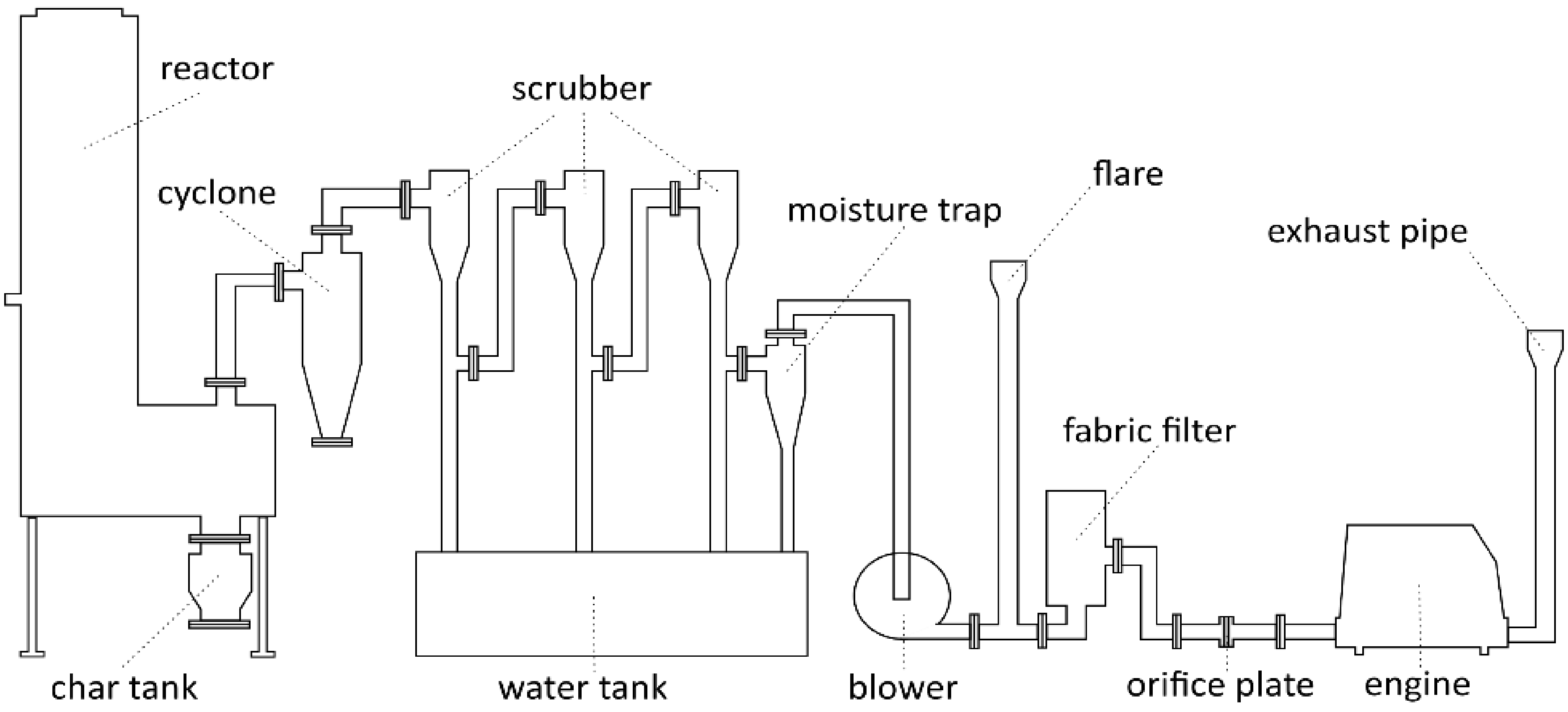


After sieving both feedstock (**FR** and **WC**), three different fractions were obtained:

1. **8 mm** – feedstock collected on sieve of aperture size 8 mm (range 16 mm – 8 mm)
2. **3.15 mm** – feedstock collected on sieve of aperture size 3.15 mm (range 8 mm – 3.15 mm)
3. **Dust** – feedstock collected on the bottom plate (i.e., < 3.15 mm)

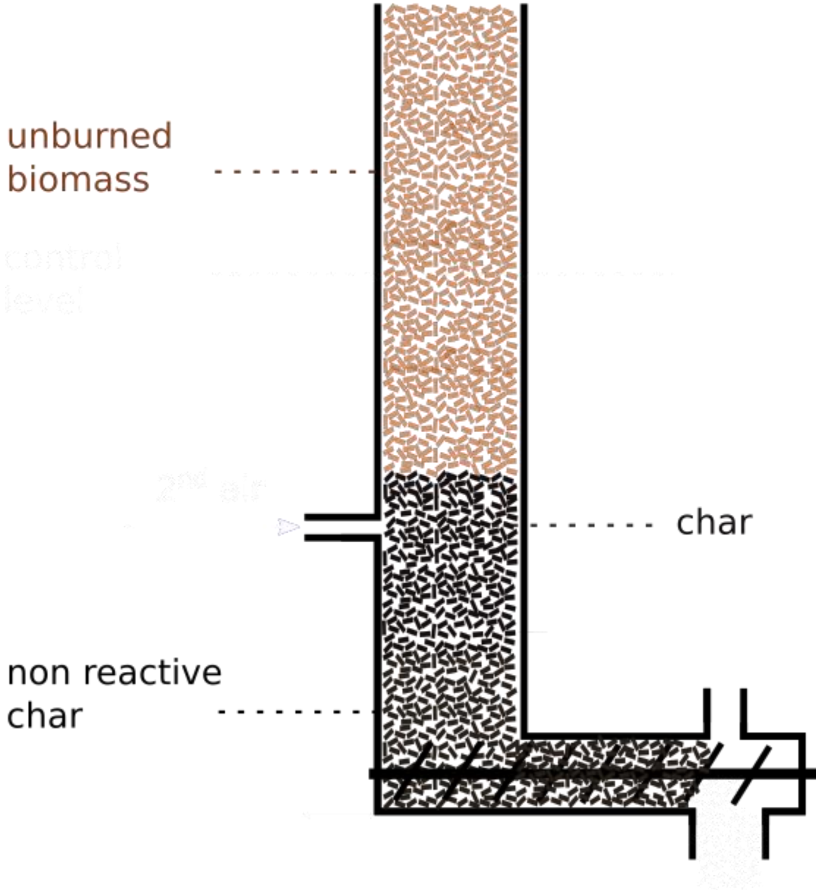
CHP system setup: open-top gasifier + dual fuel engine



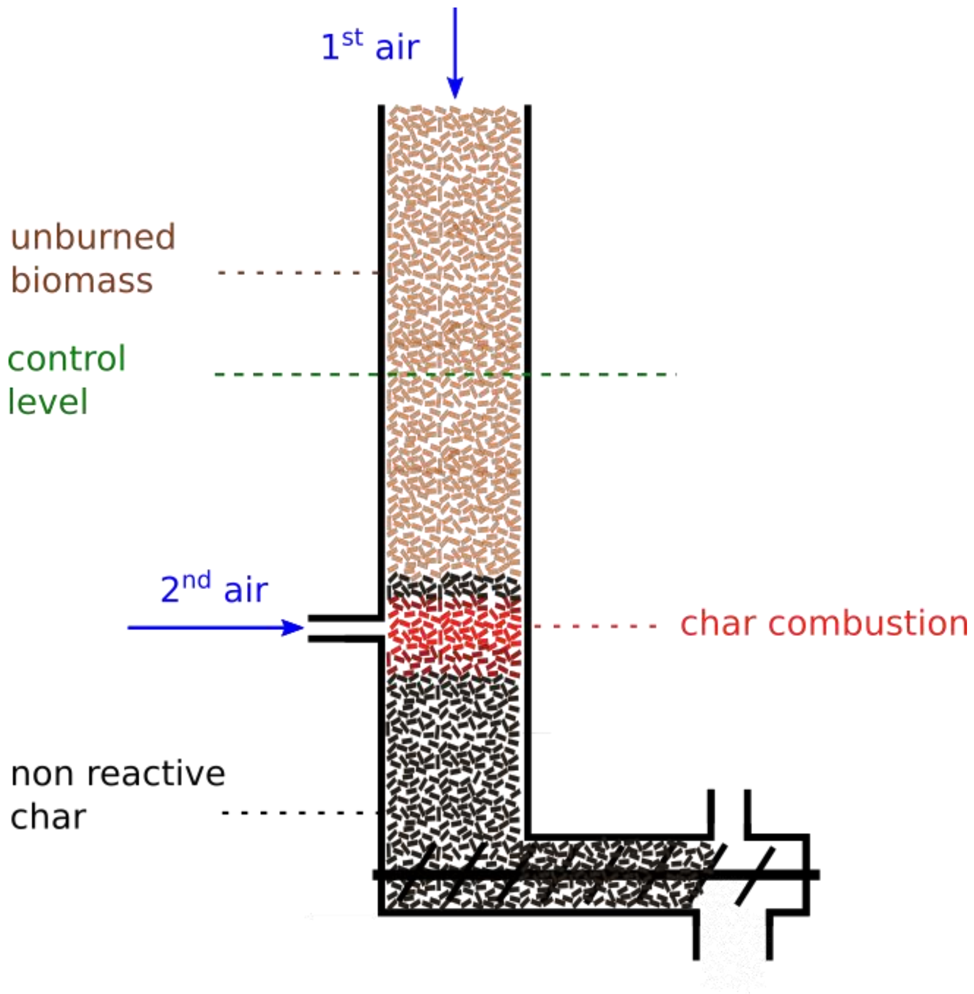


small-scale CHP system – dual fuel engine + gasifier

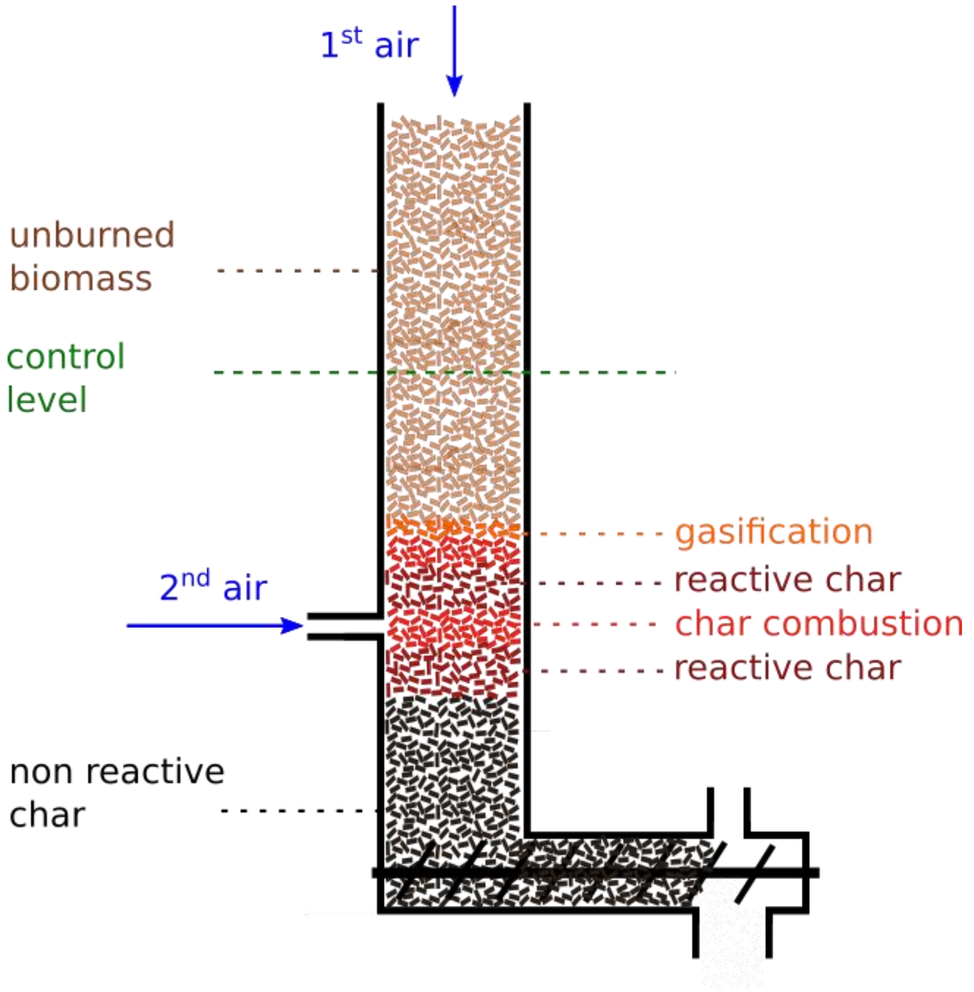
Open-top gasifier behavior



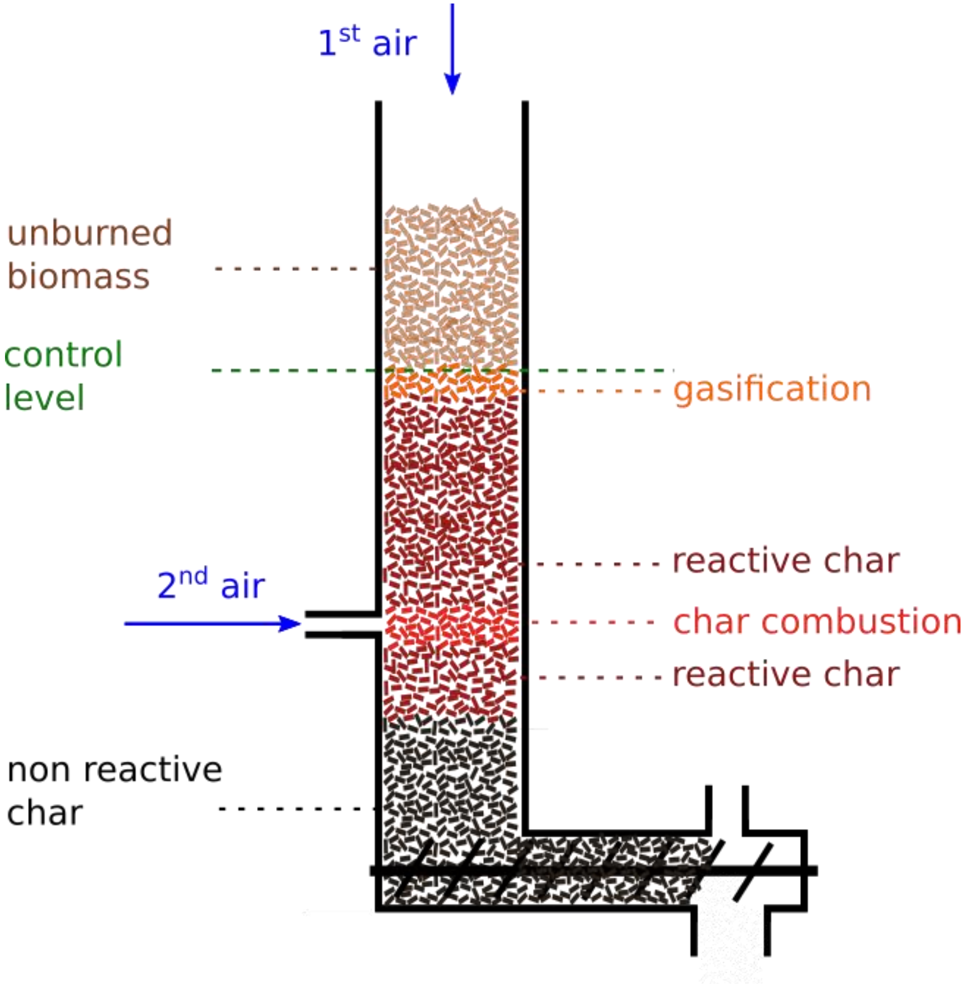
Open-top gasifier behavior



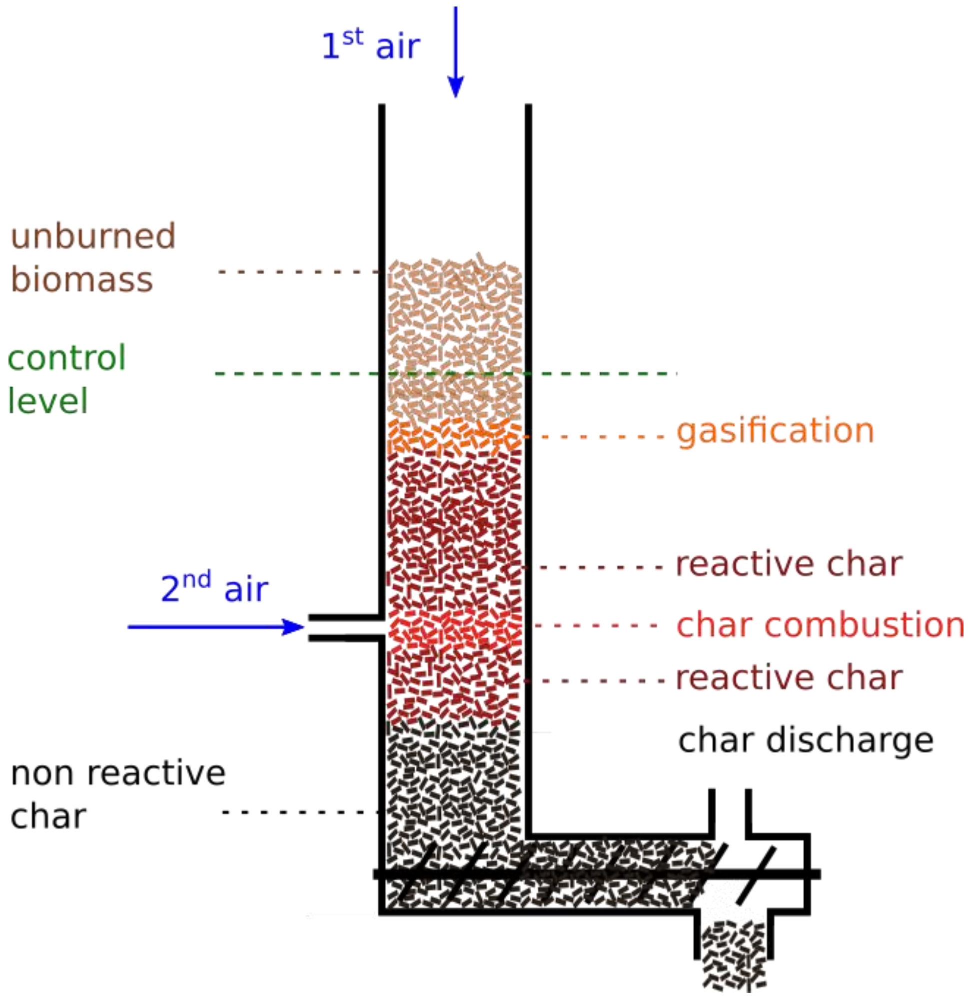
Open-top gasifier behavior



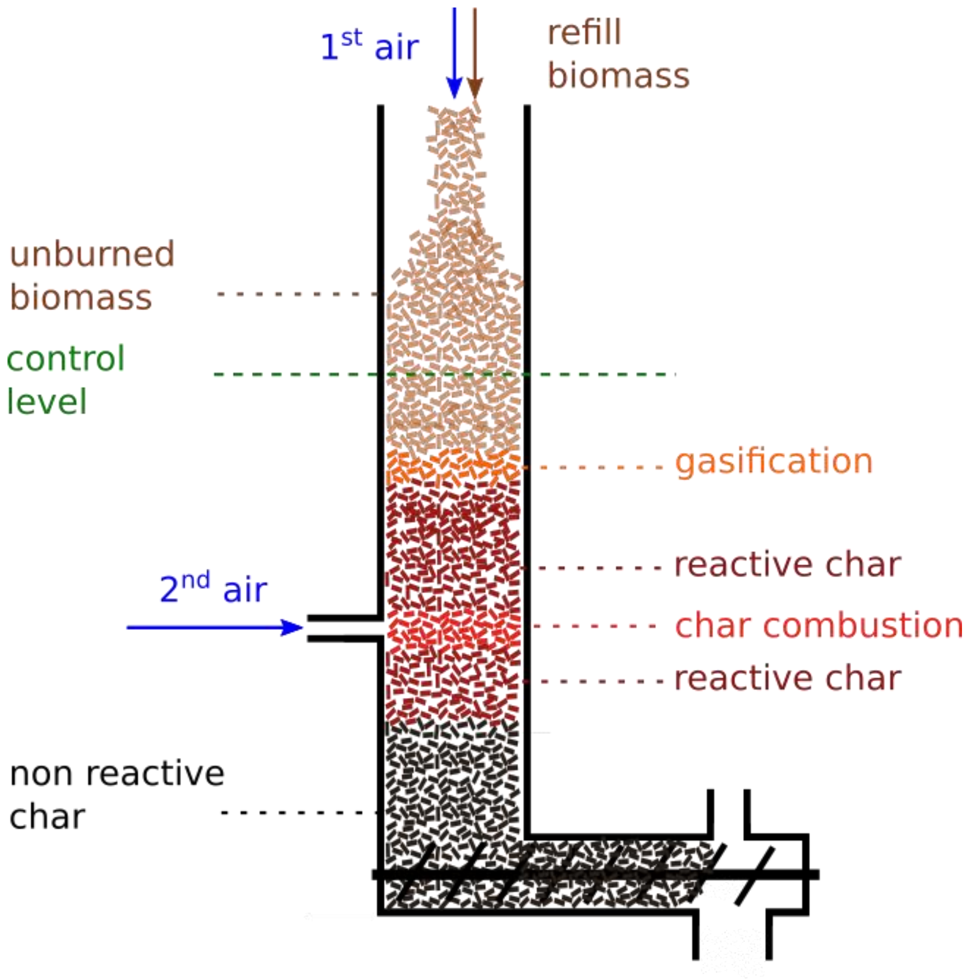
Open-top gasifier behavior



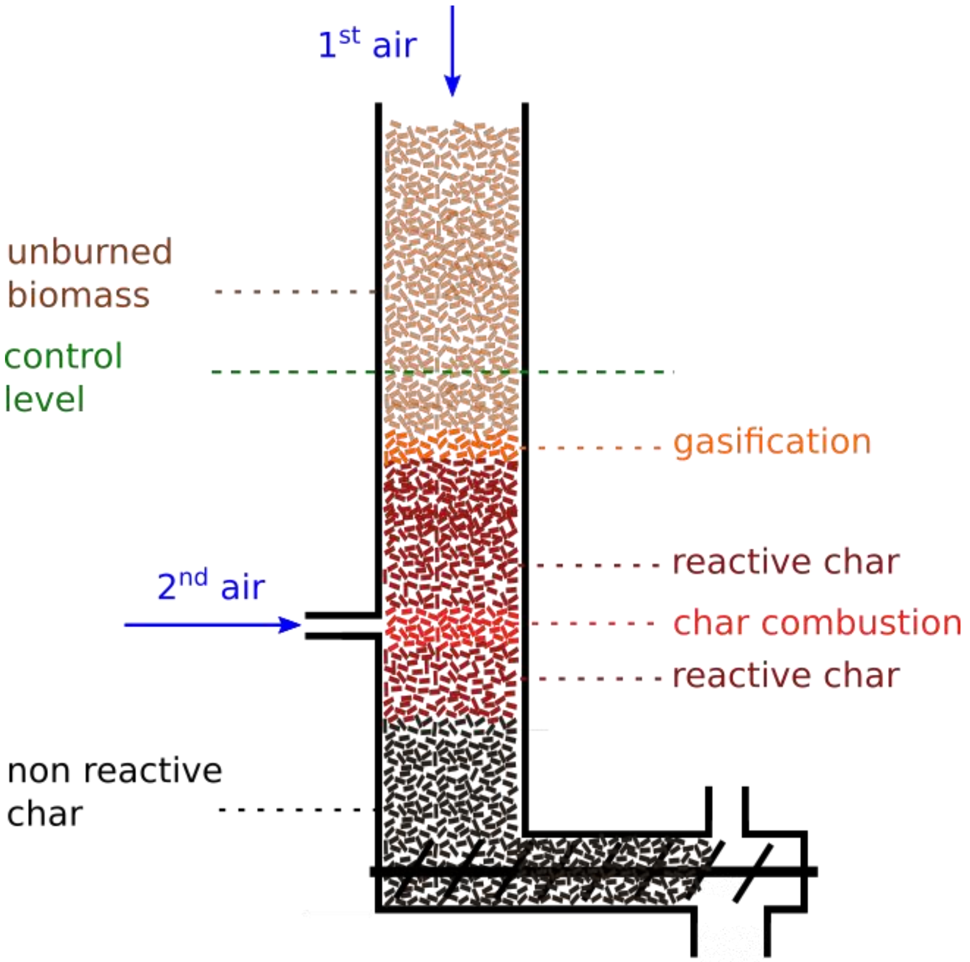
Open-top gasifier behavior



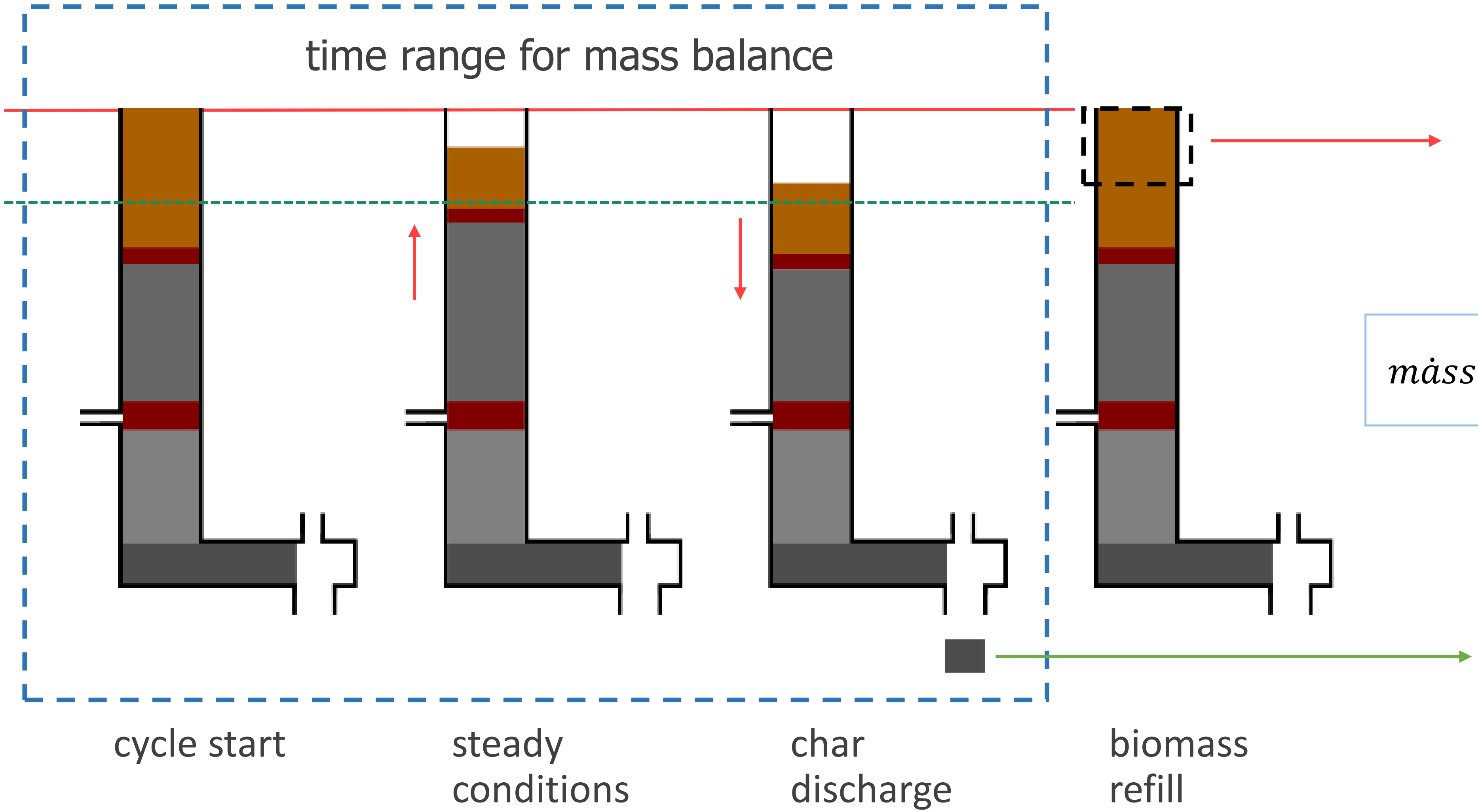
Open-top gasifier behavior



Open-top gasifier behavior



cycle of fuel charge and char discharge



biomass weight

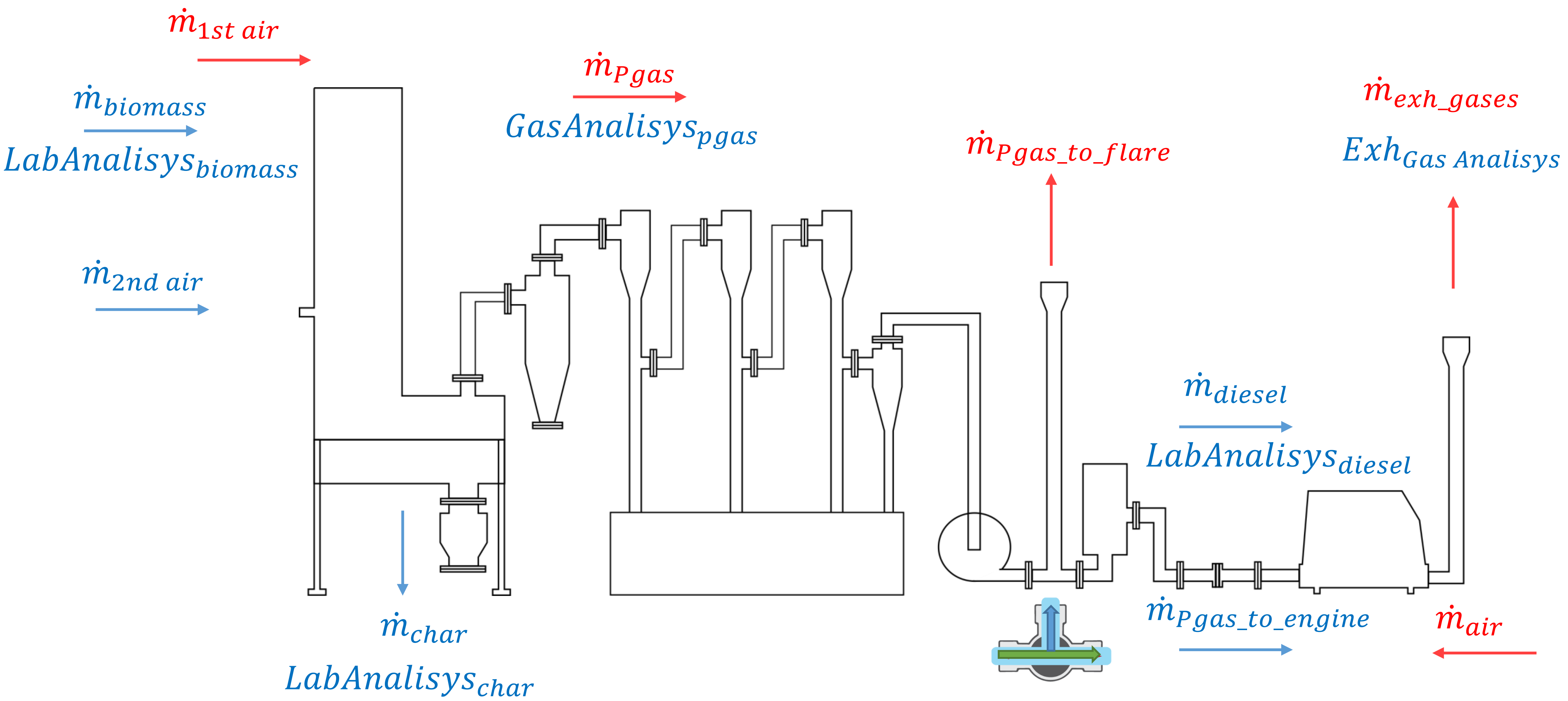
$\dot{m}_{biom}$

$$\dot{mass} = \frac{weight}{(time_{end} - time_{start})}$$

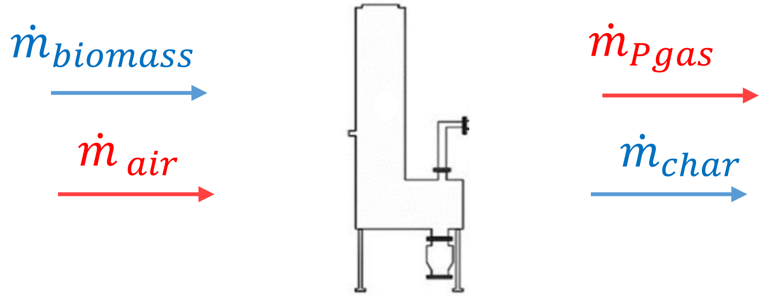
char weight

$\dot{m}_{char}$

CHP system mass balance



Methods



Data acquisition and mass balances

$$\dot{m}_{biomass\_wet} + \dot{m}_{air} = \dot{m}_{pgas\_dry} + \dot{m}_{pgas\_H_2O} + \dot{m}_{char\_dry}$$

OVERALL MASS BALANCE

$$\dot{m}_{biomass\_wet} \cdot [N]_{biomass\_wet} + \dot{m}_{air} \cdot [N]_{air} = \dot{m}_{Pgas\_dry} \cdot [N]_{Pgas\_dry}$$

NITROGEN BALANCE

$$\dot{m}_{biomass\_wet} \cdot [C]_{biomass\_wet} = \dot{m}_{Pgas\_dry} \cdot [C]_{Pgas\_dry} + \dot{m}_{char\_dry} \cdot [C]_{char\_dry}$$

CARBON BALANCE

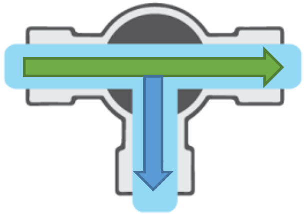
Specific Gas Energy

$$SGE \left[\frac{MJ}{kg}\right] = \frac{\dot{m}_{pgas\_dry} \cdot LHV_{pg}}{\dot{m}_{biomass}}$$

Cold Gas Efficiency

$$CGE\ [\%] = \frac{\dot{m}_{pgas\_dry} \cdot LHV_{pgas}}{\dot{m}_{biomass} \cdot LHV_{biomass}}$$

Experiments



- Feedstocks:

1. 100WC
2. 75WC25FR
3. 50WC50FR
4. 25WC75FR

Three different Producer gas mass flows rate to engine

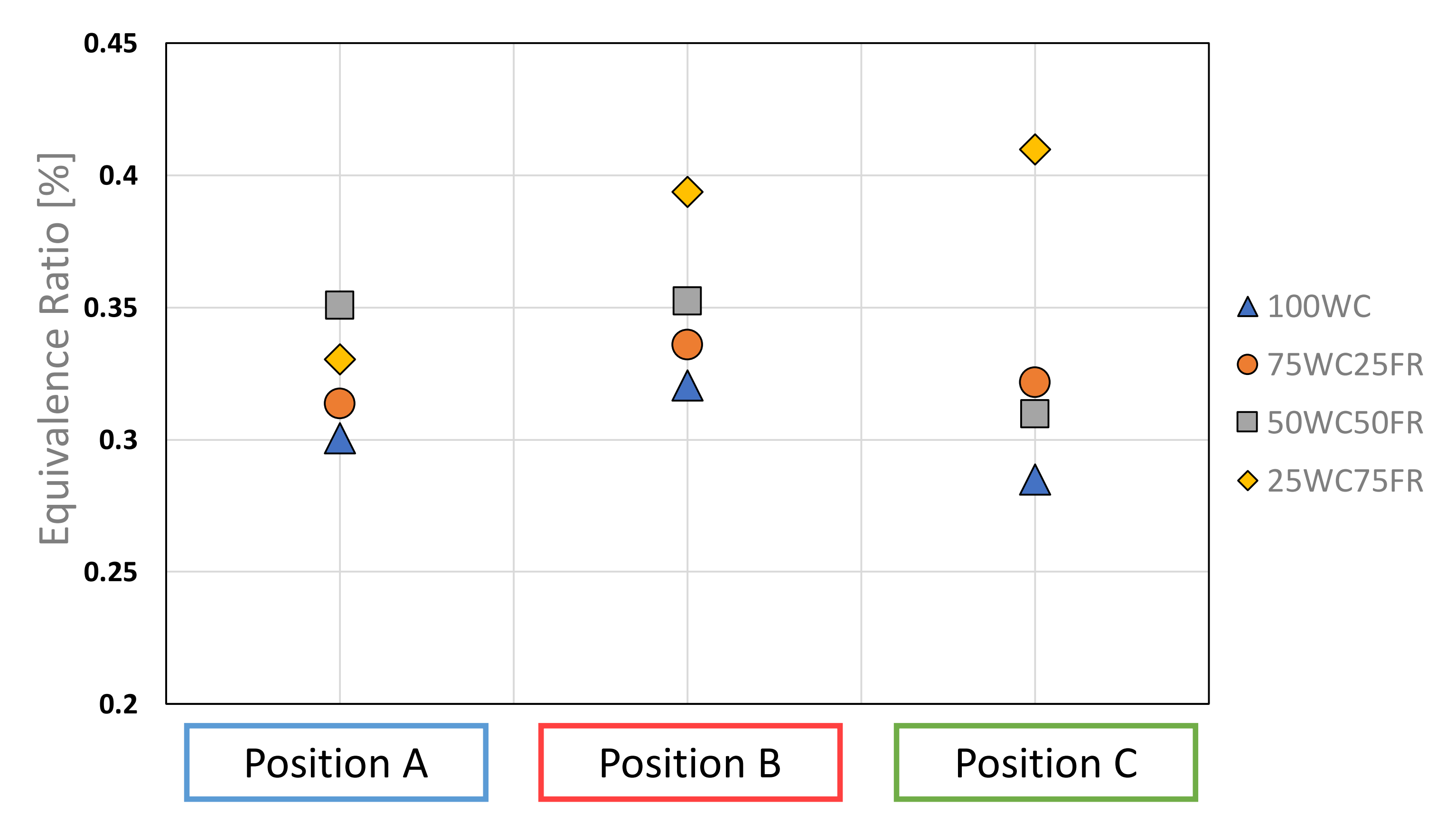
Position A: 3.92 ± 0.06 kg/h
Position B: 4.78 ± 0.03 kg/h
Position C: 5.57 ± 0.04 kg/h

Two different Electrical load of engine

- Position A: 2 kw, 3 kw
- Position B: 2 kw, 3 kw
- Position C: 2 kw, 3 kw

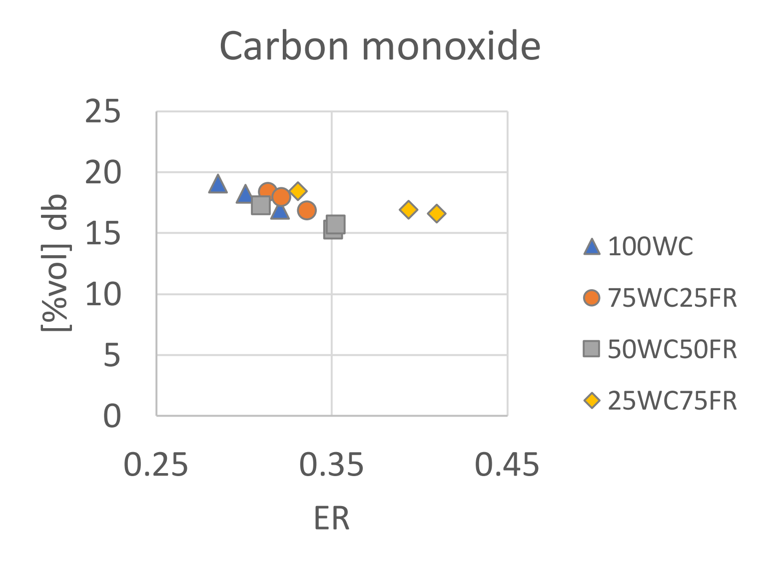
Feedstock	C (%)	H (%)	N (%)	S (%)	O* (%)	Moisture (%)	Ash (%)	LHV (MJ/kg)
100WC	48.21	6.17	0.41	0.22	40.87	3.84	0.28	17.69
75WC25FR	49.09	6.26	0.52	0.13	39.56	4.00	0.44	17.68
50WC50FR	48.59	6.13	0.41	0.19	39.89	4.17	0.62	17.60
25WC75FR	50.08	6.20	0.47	0.15	36.41	5.45	1.24	17.09

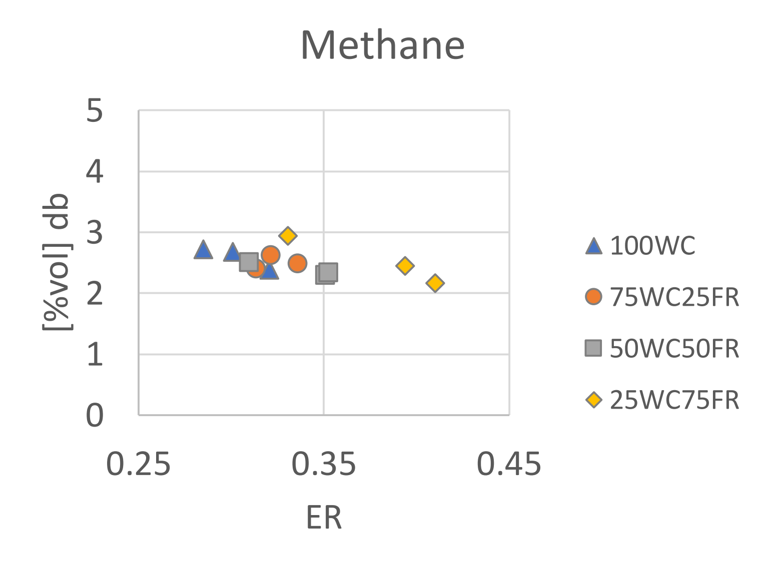
$$ER = \frac{\dot{m}_{O2}}{\dot{m}_{stoic.O2}} = \frac{\dot{m}_{air}}{\dot{m}_{stoic.air}}$$

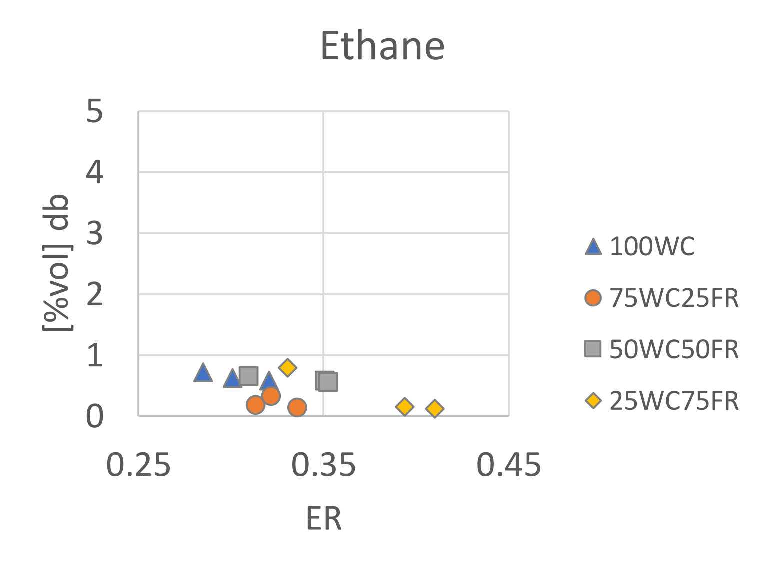


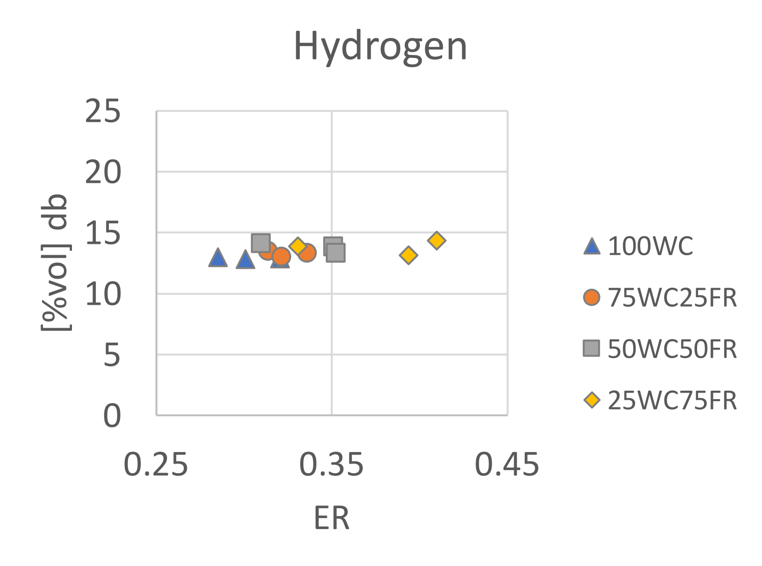
High variability was observed in the ER for feedstocks with higher FR

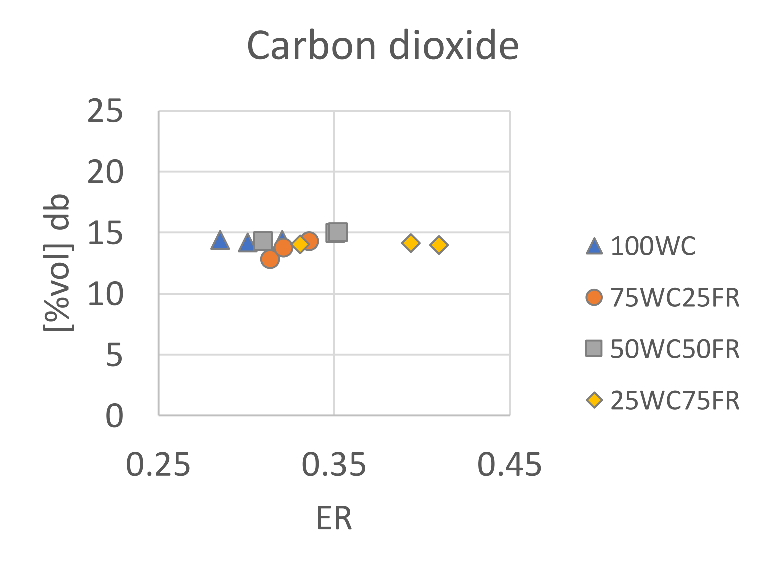
- The non-uniform particle size and non-homogeneity of different components
- The influence of the valve position to the pression drop of the gasifier gas line

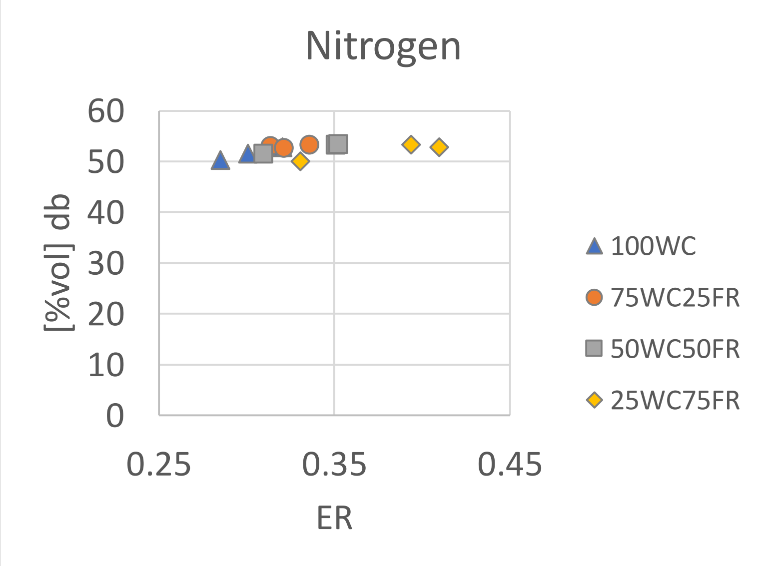

Carbon monoxide
[%vol] db
ER
100WC
75WC25FR
50WC50FR
25WC75FR

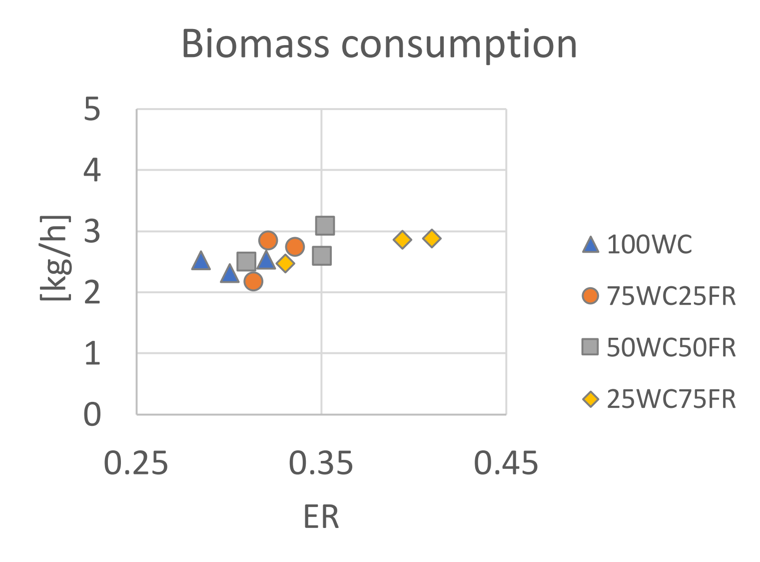

Methane
[%vol] db
ER
100WC
75WC25FR
50WC50FR
25WC75FR

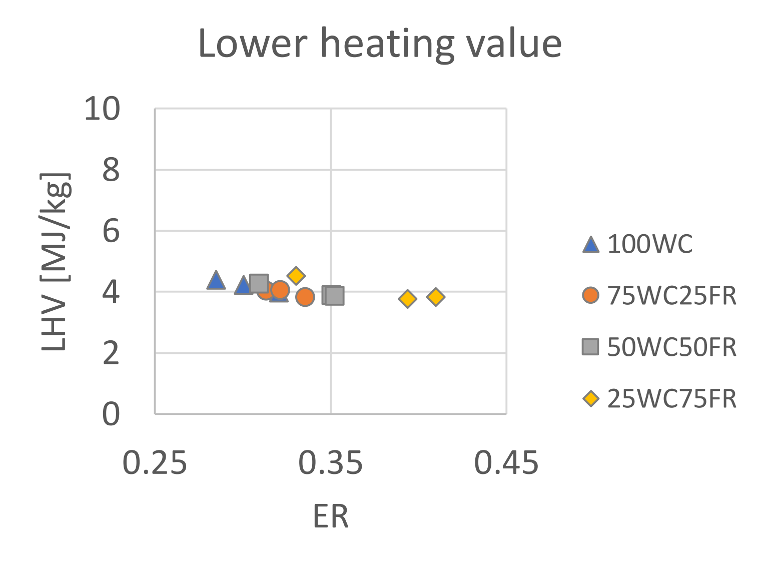

Ethane
[%vol] db
ER
100WC
75WC25FR
50WC50FR
25WC75FR

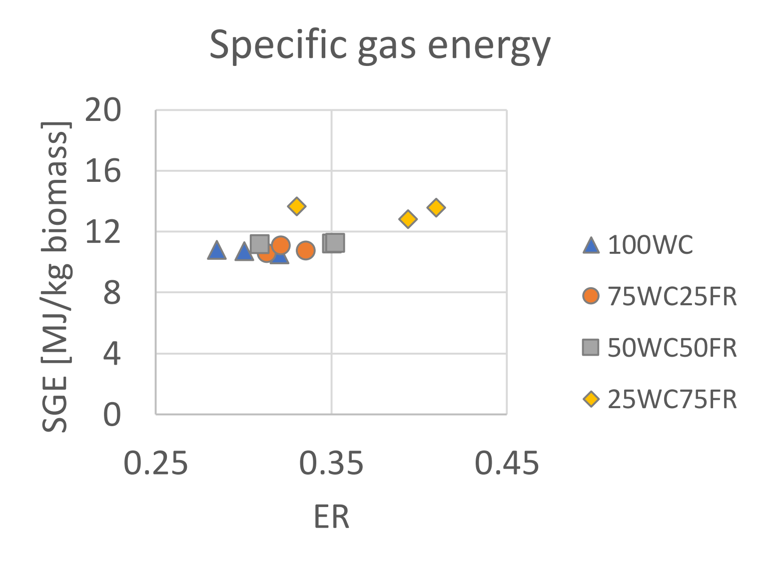

Hydrogen
[%vol] db
ER
100WC
75WC25FR
50WC50FR
25WC75FR

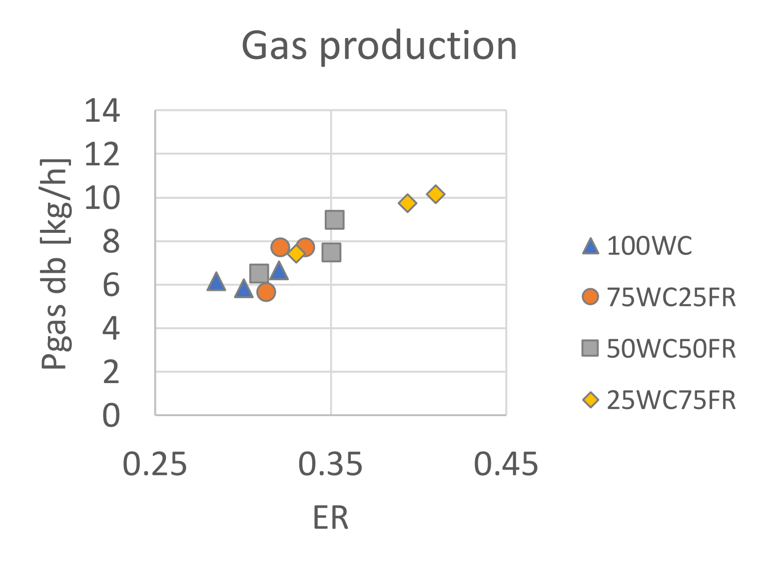

Carbon dioxide
[%vol] db
ER
100WC
75WC25FR
50WC50FR
25WC75FR

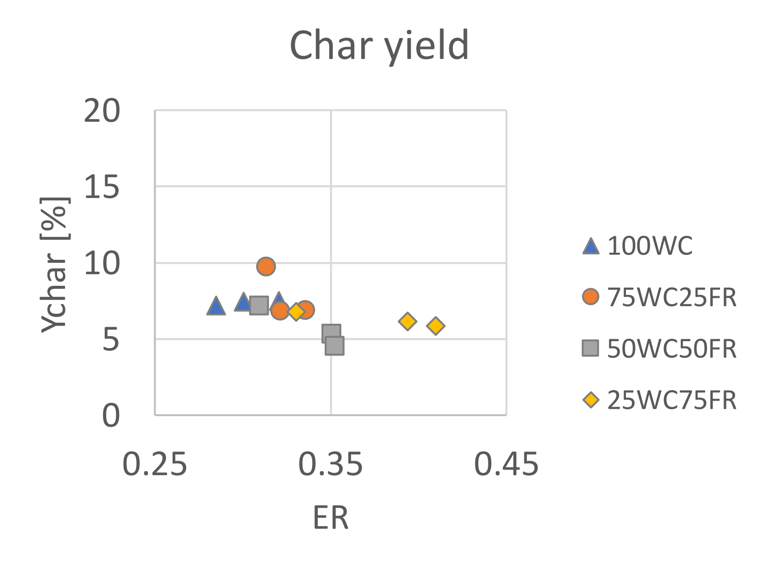

Nitrogen
[%vol] db
ER
100WC
75WC25FR
50WC50FR
25WC75FR

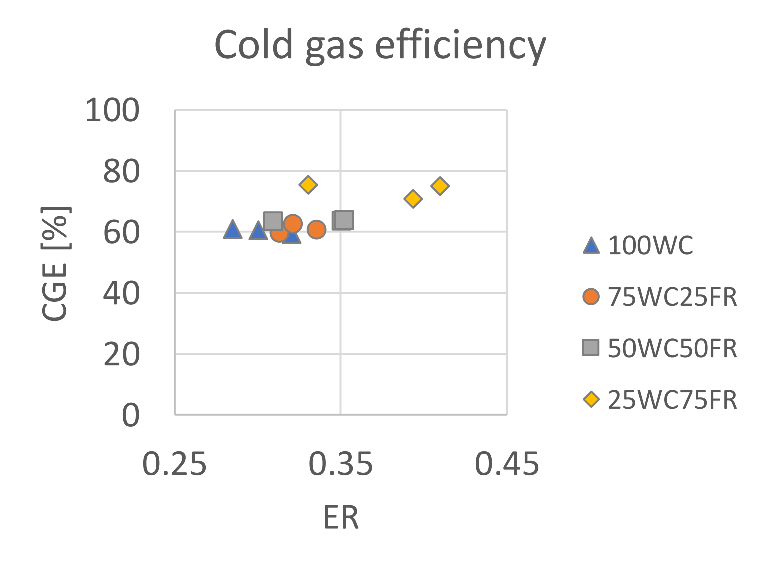

Biomass consumption
[kg/h]
5
4
3
2
1
0
0.25
0.35
0.45
ER
100WC
75WC25FR
50WC50FR
25WC75FR


Lower heating value
LHV [MJ/kg]
10
8
6
4
2
0
0.25
0.35
0.45
ER
100WC
75WC25FR
50WC50FR
25WC75FR

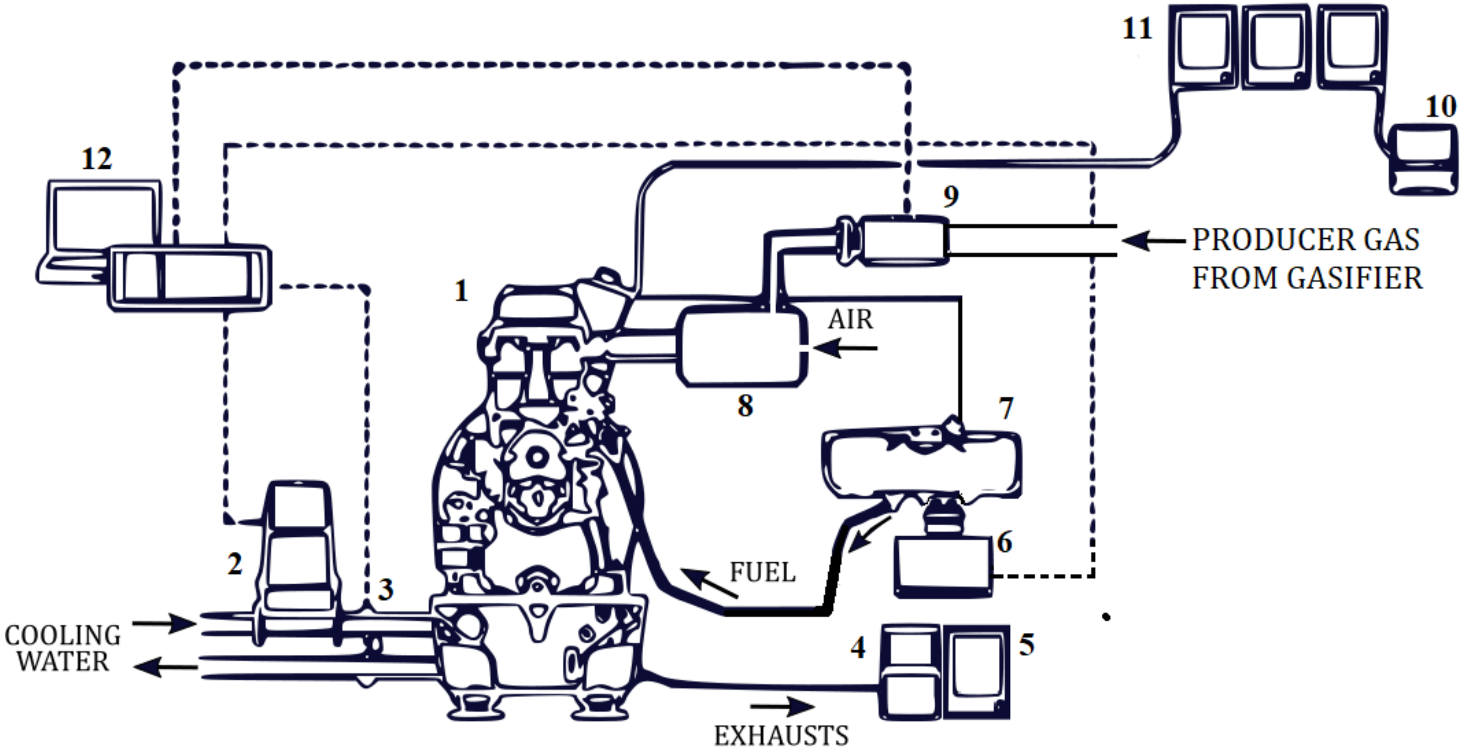

Specific gas energy
SGE [MJ/kg biomass]
20
16
12
8
4
0
0.25
0.35
0.45
ER
100WC
75WC25FR
50WC50FR
25WC75FR


Gas production
Pgas db [kg/h]
14
12
10
8
6
4
2
0
0.25
0.35
0.45
ER
100WC
75WC25FR
50WC50FR
25WC75FR


Char yield
Ychar [%]
20
15
10
5
0
0.25
0.35
0.45
ER
100WC
75WC25FR
50WC50FR
25WC75FR

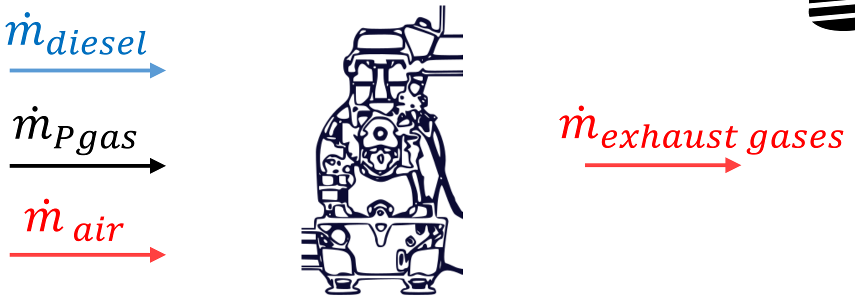

Cold gas efficiency
CGE [%]
100
80
60
40
20
0
0.25
0.35
0.45
ER
100WC
75WC25FR
50WC50FR
25WC75FR

Setup – *Engine*



1. Paguro 4000 engine-generator set
2. Siemens Sitrans MAG 1100 flow sensor
3. K-type thermocouples in cooling water line
4. MRU Vario Plus exhaust gas analyzer
5. Grimm Mini-WRAS 1371PM analyzer particel counter (diameter 10 nm - 35 µm)
6. Load cell
7. Fuel tank
8. PG-Air mixing chamber
9. PG control valve with orifice meter,
10. HT PQA820 power meter
11. Electrical loads
12. Data acquisition in PC.

Methods



Data acquisition and mass balances

$$\dot{m}_{Pgas} + \dot{m}_{diesel} + \dot{m}_{air} = \dot{m}_{exh\_dry} + \dot{m}_{exh\_H_2O}$$

OVERALL MASS BALANCE

$$\dot{m}_{Pgas} \cdot [N]_{Pgas} + \dot{m}_{air} \cdot [N]_{air} = \dot{m}_{exh\_dry} \cdot [N]_{exh\_dry}$$

NITROGEN BALANCE

$$\dot{m}_{Pgas} \cdot [C]_{Pgas} = \dot{m}_{exh\_dry} \cdot [C]_{exh\_dry}$$

CARBON BALANCE

Electrical efficiency

$$\text{efficiency [\%]} = \frac{Power_{electrical}}{\dot{m}_{pgas} \cdot LHV_{pgas} + \dot{m}_{diesel} \cdot LHV_{pgas}}$$

Thermal Efficiency

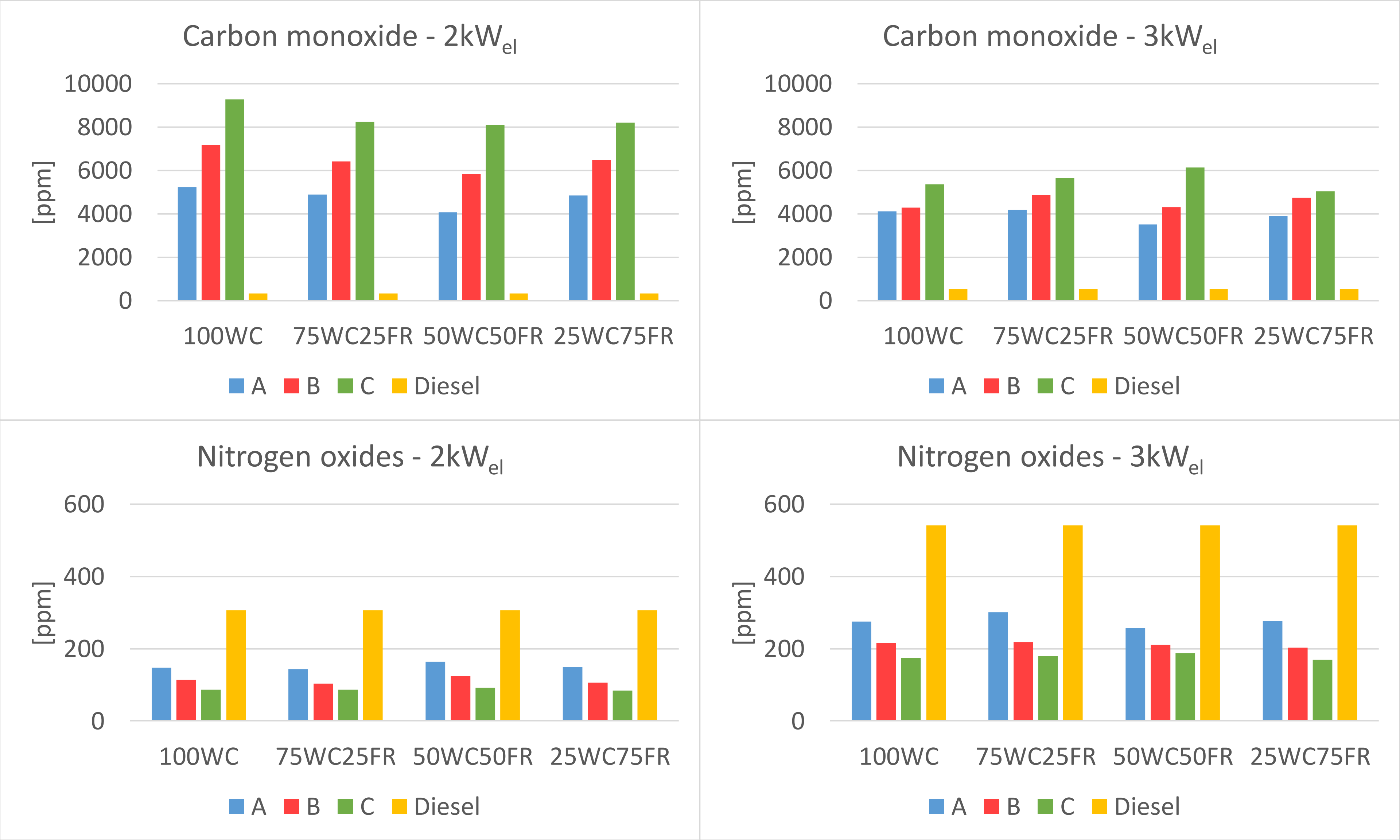
$$\text{efficiency [\%]} = \frac{\dot{m}_{water} \cdot Cp_{water} \cdot \Delta T}{\dot{m}_{pgas} \cdot LHV_{pgas} + \dot{m}_{diesel} \cdot LHV_{pgas}}$$

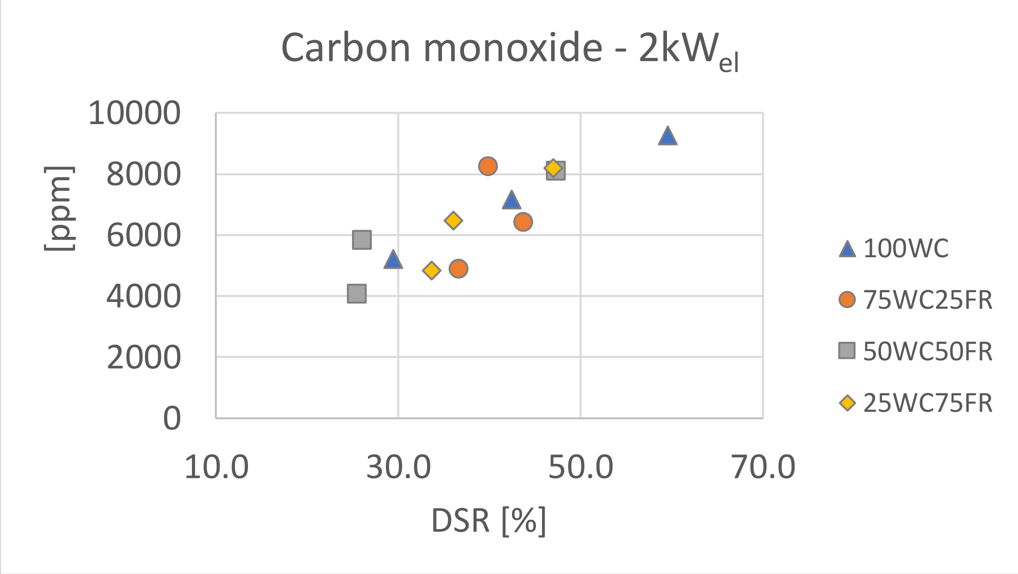
Diesel Substitution Rate

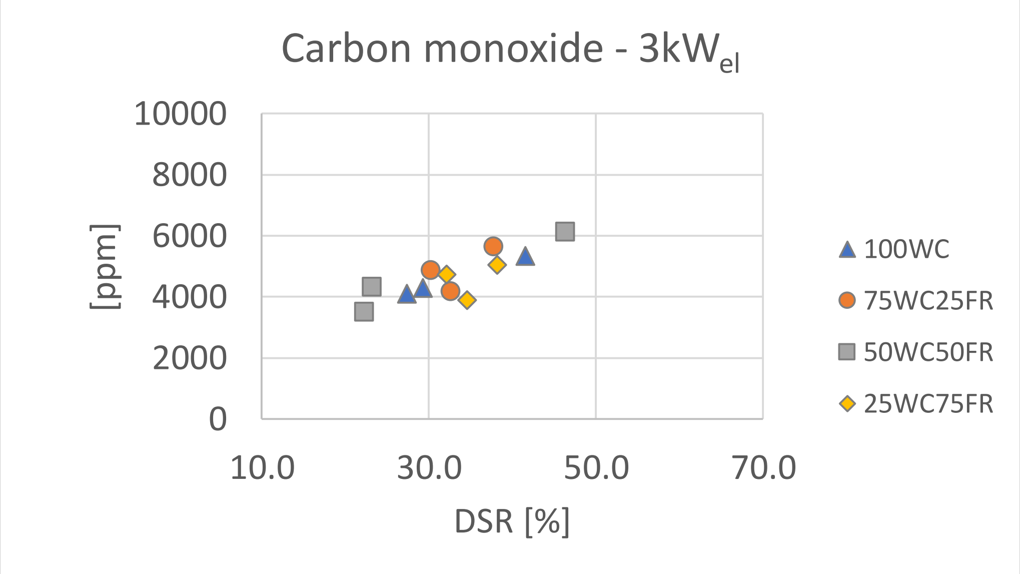
$$DSR = \frac{\dot{m}_D - \dot{m}_d}{\dot{m}_D}$$

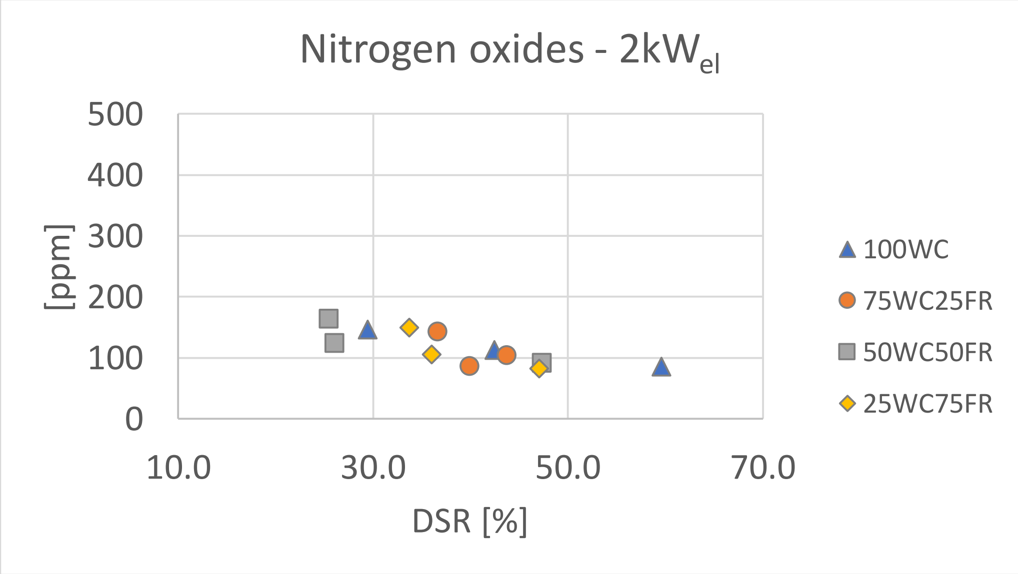
$\dot{m}_D = \dot{m}_{diesel}$ (only diesel)

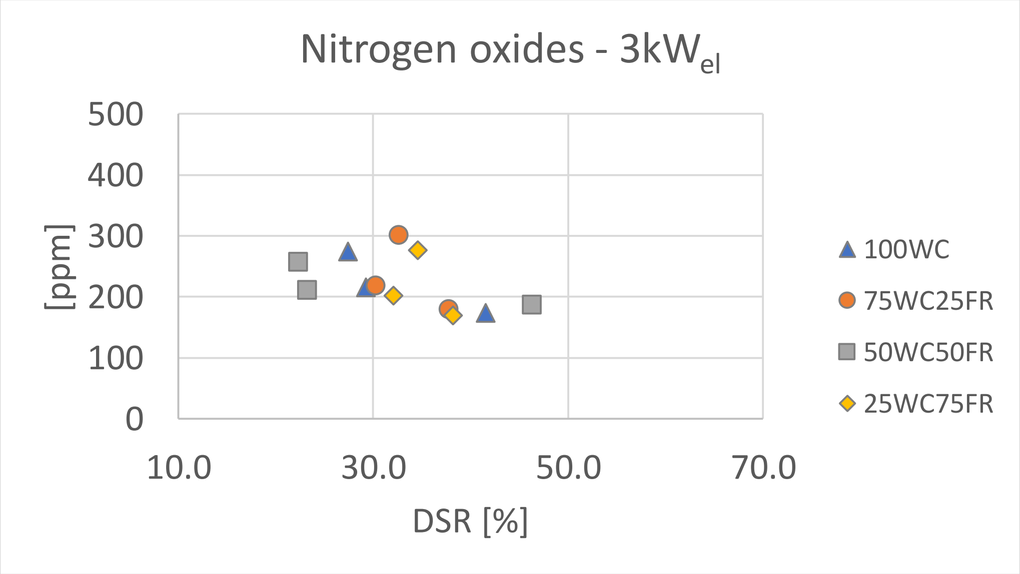
$\dot{m}_d = \dot{m}_{diesel}$ (in dual fuel mode)

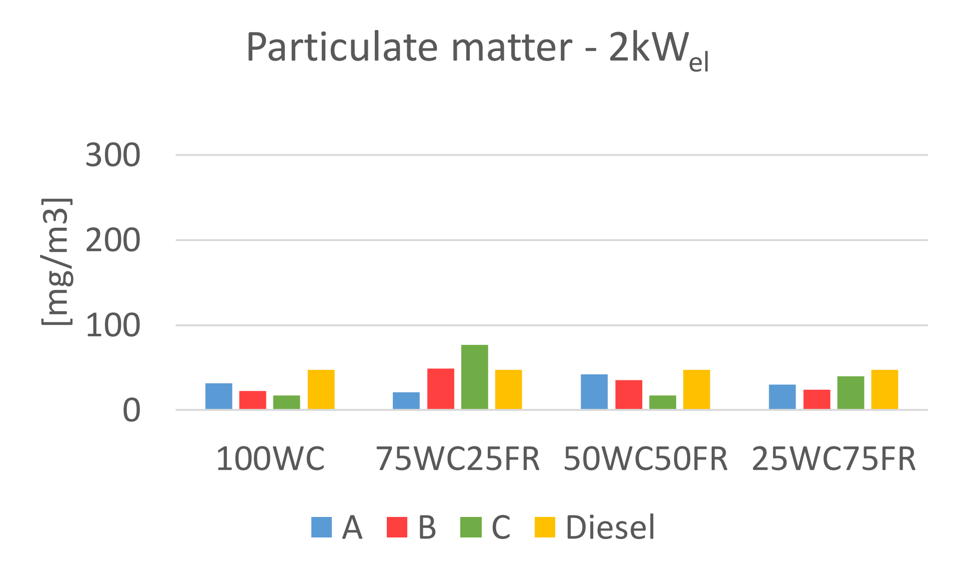

Carbon monoxide - 2kW$_{el}$
[ppm]
10000
8000
6000
4000
2000
0
100WC
75WC25FR
50WC50FR
25WC75FR
A B C Diesel
Carbon monoxide - 3kW$_{el}$
[ppm]
10000
8000
6000
4000
2000
0
100WC
75WC25FR
50WC50FR
25WC75FR
A B C Diesel
Nitrogen oxides - 2kW$_{el}$
[ppm]
600
400
200
0
100WC
75WC25FR
50WC50FR
25WC75FR
A B C Diesel
Nitrogen oxides - 3kW$_{el}$
[ppm]
600
400
200
0
100WC
75WC25FR
50WC50FR
25WC75FR
A B C Diesel

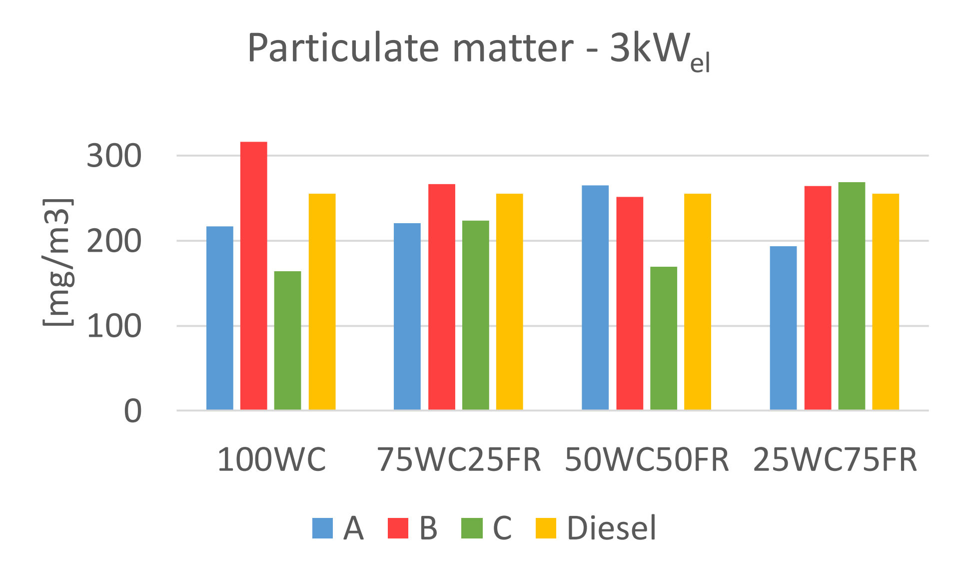

Carbon monoxide - 2kWel
[ppm]
10000
8000
6000
4000
2000
0
10.0
30.0
50.0
70.0
DSR [%]
100WC
75WC25FR
50WC50FR
25WC75FR

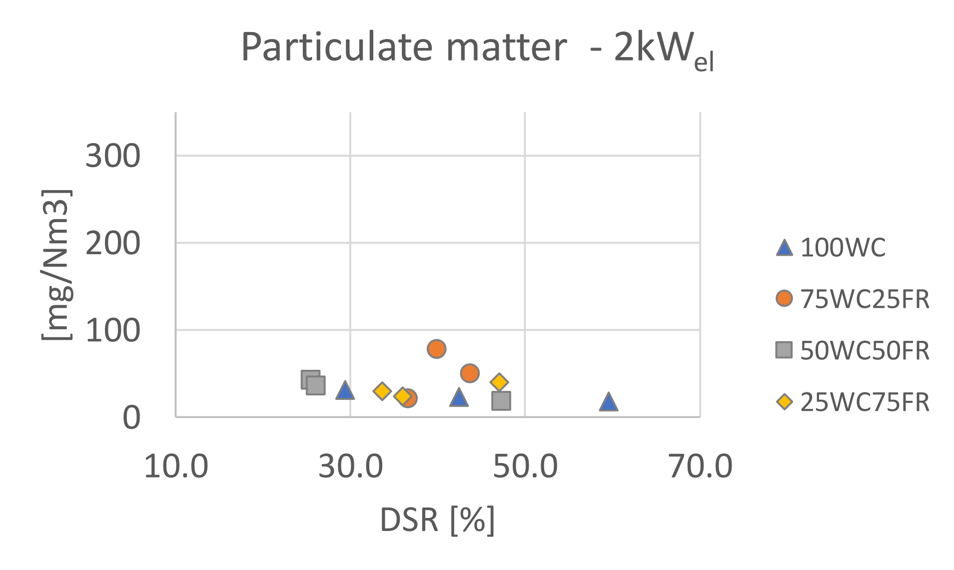

Carbon monoxide - 3kWel
[ppm]
10000
8000
6000
4000
2000
0
10.0
30.0
50.0
70.0
DSR [%]
100WC
75WC25FR
50WC50FR
25WC75FR

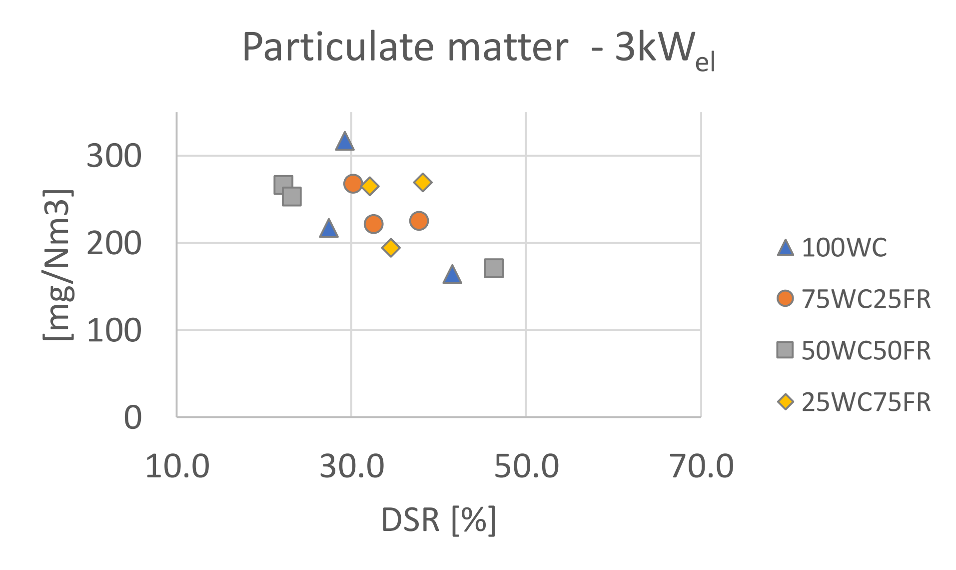

Nitrogen oxides - 2kWel
[ppm]
500
400
300
200
100
0
10.0
30.0
50.0
70.0
DSR [%]
100WC
75WC25FR
50WC50FR
25WC75FR

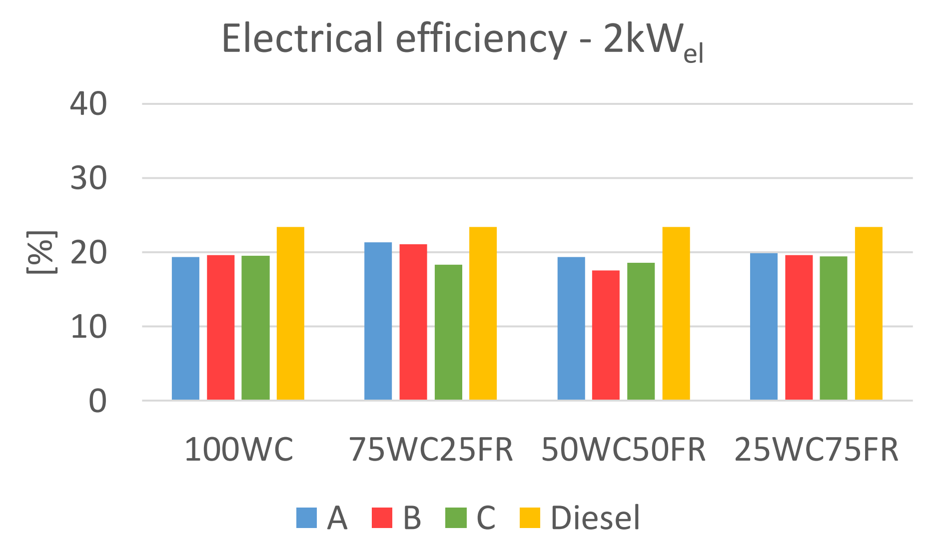

Nitrogen oxides - 3kWel
[ppm]
500
400
300
200
100
0
10.0
30.0
50.0
70.0
DSR [%]
100WC
75WC25FR
50WC50FR
25WC75FR

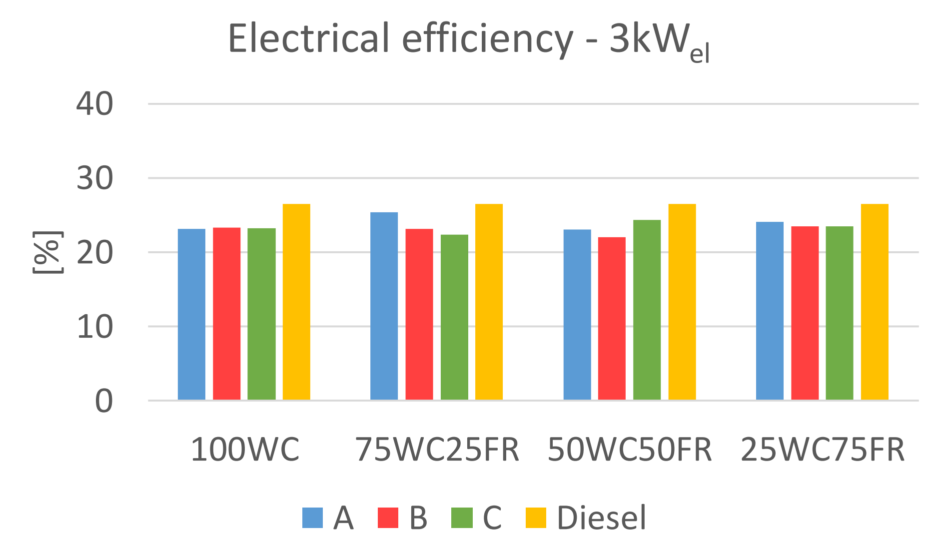

Particulate matter - 2kWel
300
200
100
0
[mg/m3]
100WC
75WC25FR
50WC50FR
25WC75FR
A B C Diesel

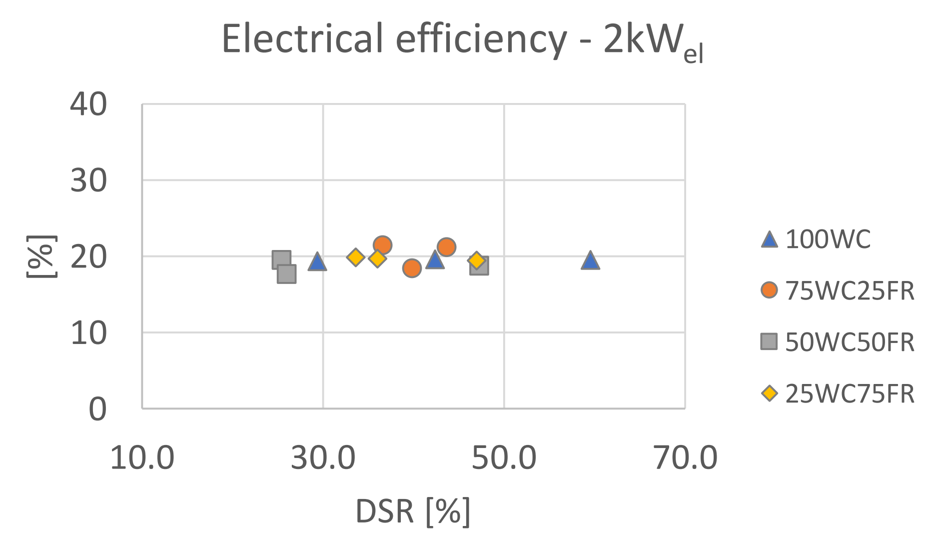

Particulate matter - 3kWel
300
200
100
0
[mg/m3]
100WC
75WC25FR
50WC50FR
25WC75FR
A B C Diesel

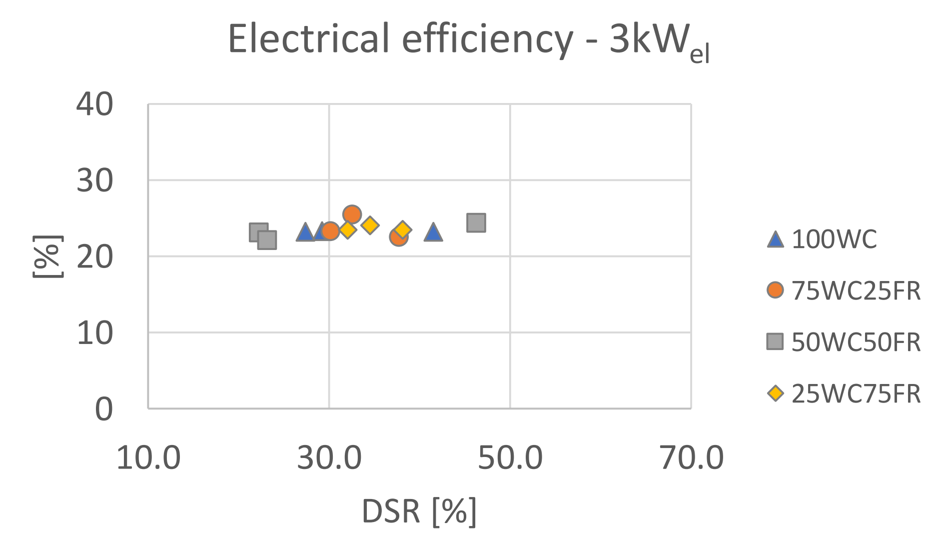

Particulate matter - 2kWel
300
200
100
0
[mg/Nm3]
10.0
30.0
50.0
70.0
DSR [%]
100WC
75WC25FR
50WC50FR
25WC75FR

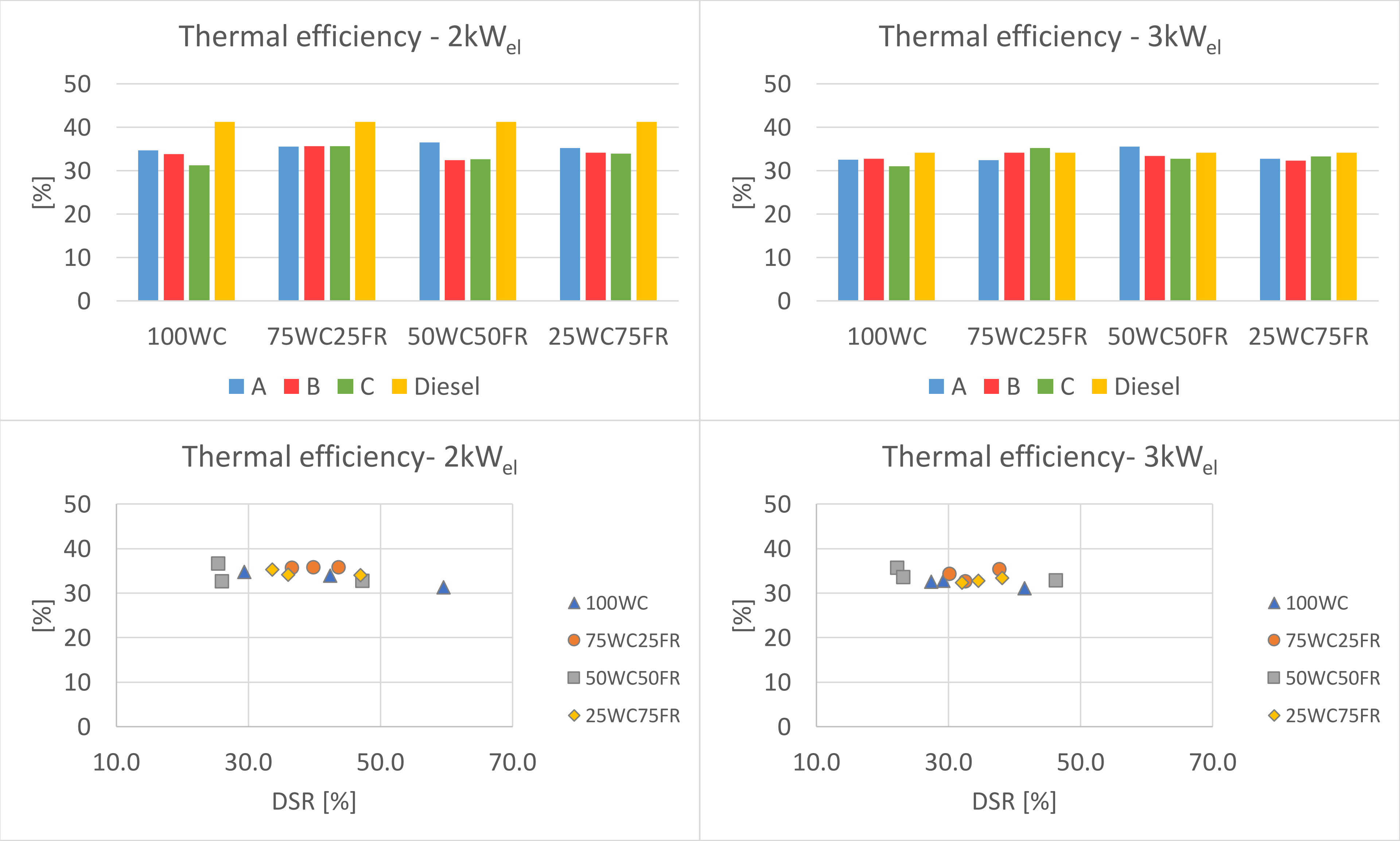

Particulate matter - 3kWel
300
200
100
0
[mg/Nm3]
10.0
30.0
50.0
70.0
DSR [%]
100WC
75WC25FR
50WC50FR
25WC75FR


Electrical efficiency - 2kWel
40
30
20
10
0
[%]
100WC
75WC25FR
50WC50FR
25WC75FR
A
B
C
Diesel


Electrical efficiency - 3kWel
40
30
20
10
0
[%]
100WC
75WC25FR
50WC50FR
25WC75FR
A
B
C
Diesel


Electrical efficiency - 2kWel
40
30
20
10
0
[%]
10.0
30.0
50.0
70.0
DSR [%]
100WC
75WC25FR
50WC50FR
25WC75FR


Electrical efficiency - 3kWel
40
30
20
10
0
[%]
10.0
30.0
50.0
70.0
DSR [%]
100WC
75WC25FR
50WC50FR
25WC75FR


Thermal efficiency - 2kW$_{el}$
[%]
100WC
75WC25FR
50WC50FR
25WC75FR
A
B
C
Diesel
Thermal efficiency - 3kW$_{el}$
Thermal efficiency- 2kW$_{el}$
DSR [%]
Thermal efficiency- 3kW$_{el}$

Conclusions

- A **small-scale open-top gasifier coupled with an engine-generator set** was operated with various mixtures of **forest residues (FR)** and standard **wood chips (WC).**
- **Different plant operation conditions** were observed for different FR fractions. Lager ER deviations were observed with increasing fraction of FR in the feedstock mixture (75% of FR).
- The variation of ER involved **some differences in performance indicators such as LHV of PG, Ychar, SGE, CGE**, etc.
- This variability was also evident in the engine output. However, some trends were observed: **an increase in terms of CO emission and a decrease for NOx and PM in relation to the growth of DSR.**
- In conclusion, biomass residues from forests could be valorized by using them as **inexpensive feedstock** in CHP processes, thereby reducing plants' operational costs.
- However, due to the inherent variability in their physical and chemical composition predictability and reproducibility of results might be a challenge.

Acknowledgments

This work has been supported by the project BIO-CHEAPER (BIOmasses Circular Holistic Economy APproach to EneRgy equipments) funded by the Ministero dell'Università e della Ricerca (MIUR) in the framework of Progetti di Ricerca di Rilevante Interesse Nazionale (PRIN) Bando 2017, nr. 20175TXJER.
The infrastructure has been provided by the Free University of Bozen-Bolzano, Italy.

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Thank you for your attention

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