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Autothermal biochar production and characterization at pilot scale

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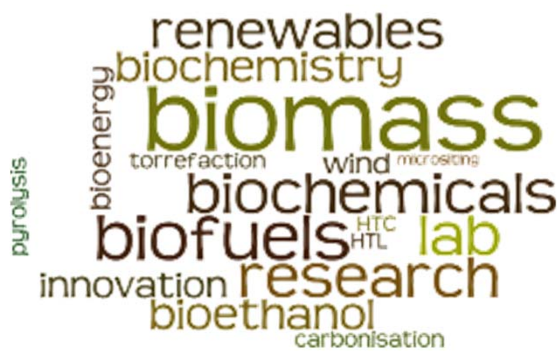

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Outline

01 Introduction & Background

02 Pilot plant layout

03 Quality of products

04 M&E Balances

05 Conclusions

01

Introduction & Background

Charcoal – estimated market size

EUROPE (EU-27)

Tot consumption: 1.3-1.4·10^6 t/y

Tot production: 0.4 ·10^6 t/y

→ IMPORT ≈1 ·10^6 t/y (500 M€/y)

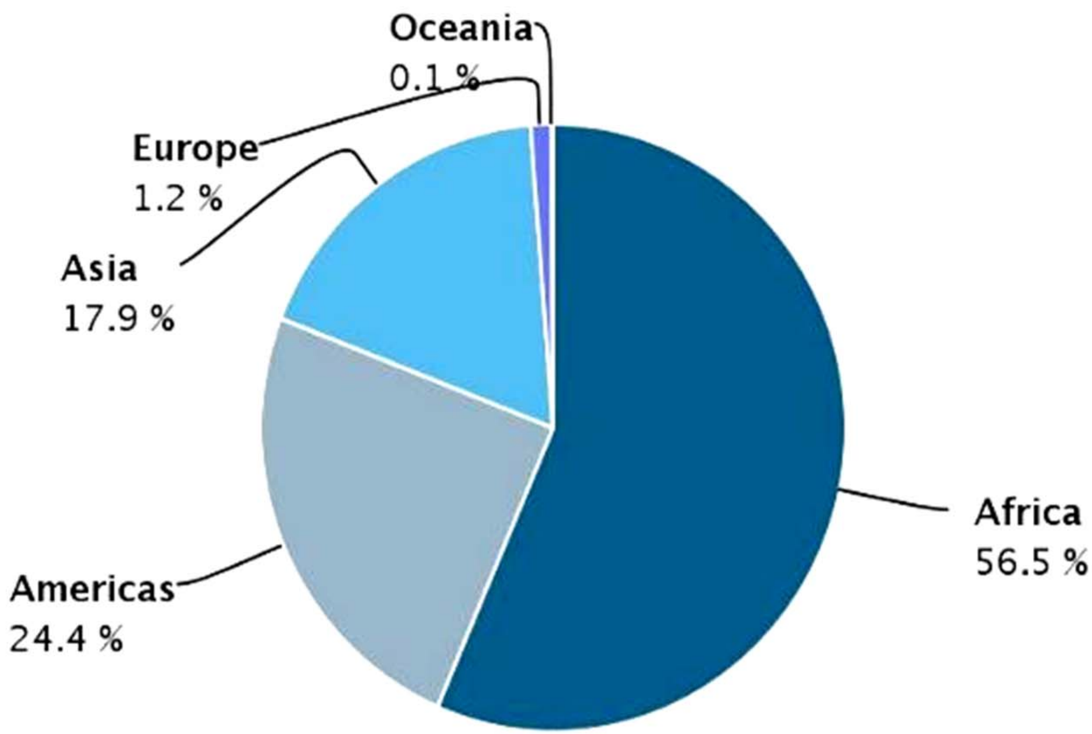
ITALY

Production: 0.016·10^6 t/y
(source: National Energy Balance – BEN)

Consumption: 0.07·10^6 t/y
(source: National Energy Balance – BEN)

World charcoal production (FAO): 51.7 Mt/y

source: FAO-FAOSTAT. "Wood Charcoal Trade Statistics." vol. 1. p. 56. 2014



Motivation

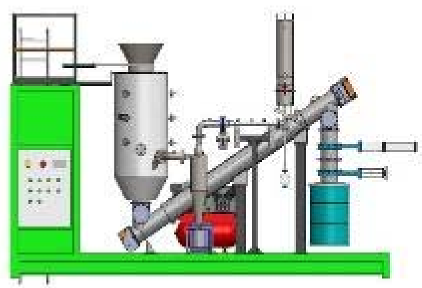
Address needs and opportunities offered by charcoal manufacturing for small-scale forestry companies and farms

RE-CORD (CarbOn)

Earth pits + kilns

- ✓Batch (RT: days)
- ✓Char yield: 8-12%
- ✓Biomass size: large
- ✓autothermal – no recovery, polluting
- ✓low CAPEX/labor-intensive
- ✓Medium/large scale

RE-CORD (CarbOn)



- ✓Continuous process (RT: 5h)
- ✓Char yield: 22-25%
- ✓Biomass size: small
- ✓Autothermal
- ✓Low CAPEX
- ✓Small scale (farm/forestry company)

Industrial systems

- ✓(Semi)Continuous operation (RT: 8h)
- ✓Char yield: 20-25 %
- ✓Biomass size: small
- ✓Gas/condensable recovery
- ✓Capital intensive
- ✓Industrial size

02

Pilot plant layout

Autothermal carbonization plant - CarbON

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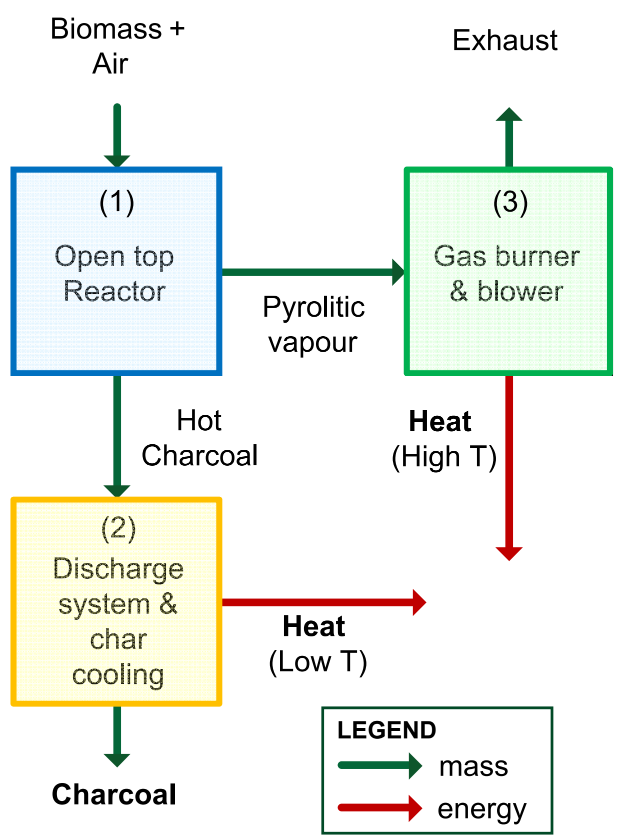
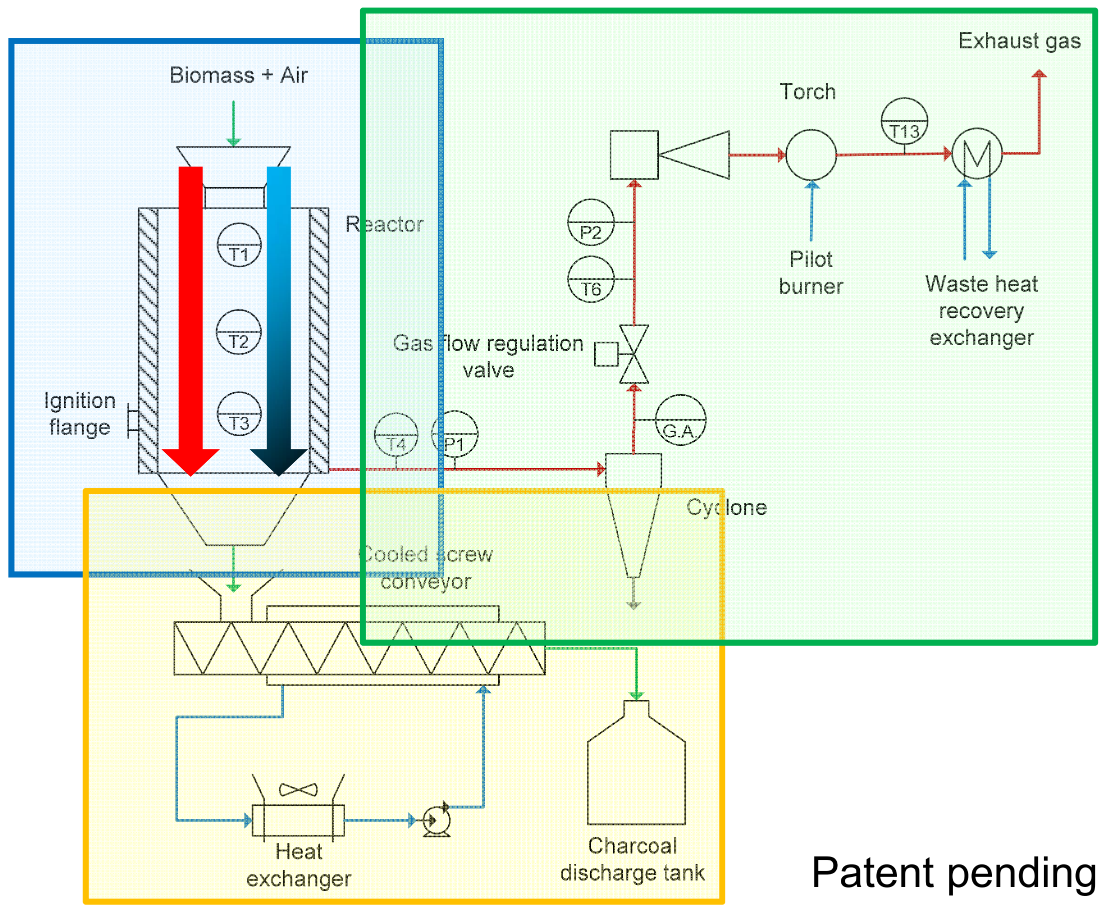
1 – Biomass loading and conversion

2 - Discharge and cooling system

3 – PG Extraction and combustion

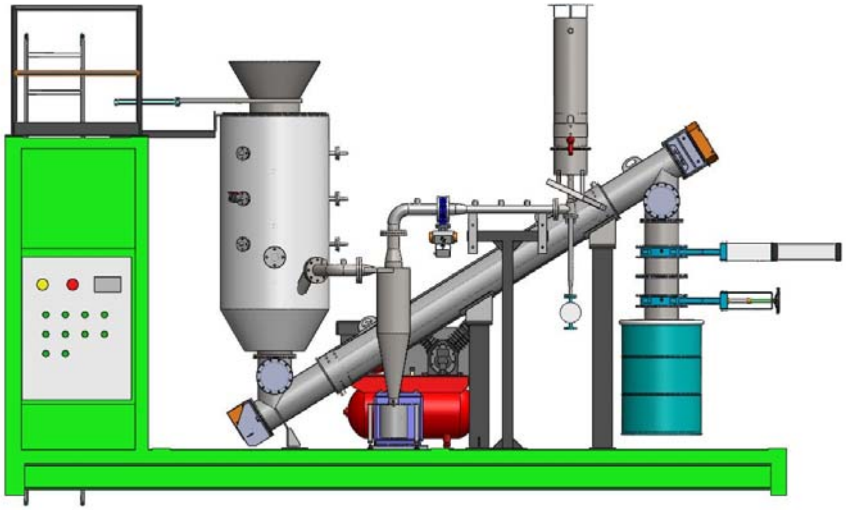




Patent pending

Autothermal carbonization plant - CarbON

- Continuous system
- Capacity 50 kg/h (woodchips or cubes)
- Oxidative process (autothermal)
- Open top, downdraft design
- Integrated charcoal cooling
- Equivalence ration (ER) 0.1÷0.2
- Hot pyrogas extraction
- High temperature heat as coproduct



03

RESULTS:
Quality of products

Feedstock properties (extract)

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TEST 11

Large woodchip

- Mean nominal size **1-2 cm**
- Rich in thin particles and dust
- Prone to **bridging**
- Hardwood (mainly chestnut)
- Drum chipper

- Mean nominal size **3-5 cm**
- Mixed acacia, alder, elm
- Limted in fines & dust
- Screw chipper (Laimet HP 21)

TEST 12

Small woodchip

Feedstock characterization	Small wood chips	Large wood chips	Reference
Type of biomass	hardwood		-
Size (*P-class*)	P 31.5	P 63	EN 14961
Bulk density (*kg m^{-3} ar*)	225	228	EN 15103
Moisture (*% w/w ar*)	18.7	11.0	EN 14774
Volatile matter (*% w/w db*)	74.1	80.8	EN 15148
Ash *(% w/w db*)	0.68	0.67	EN 14775
Fixed carbon (*% w/w db*)	25.2	18.5	-

Thermal profile (small wood chips)

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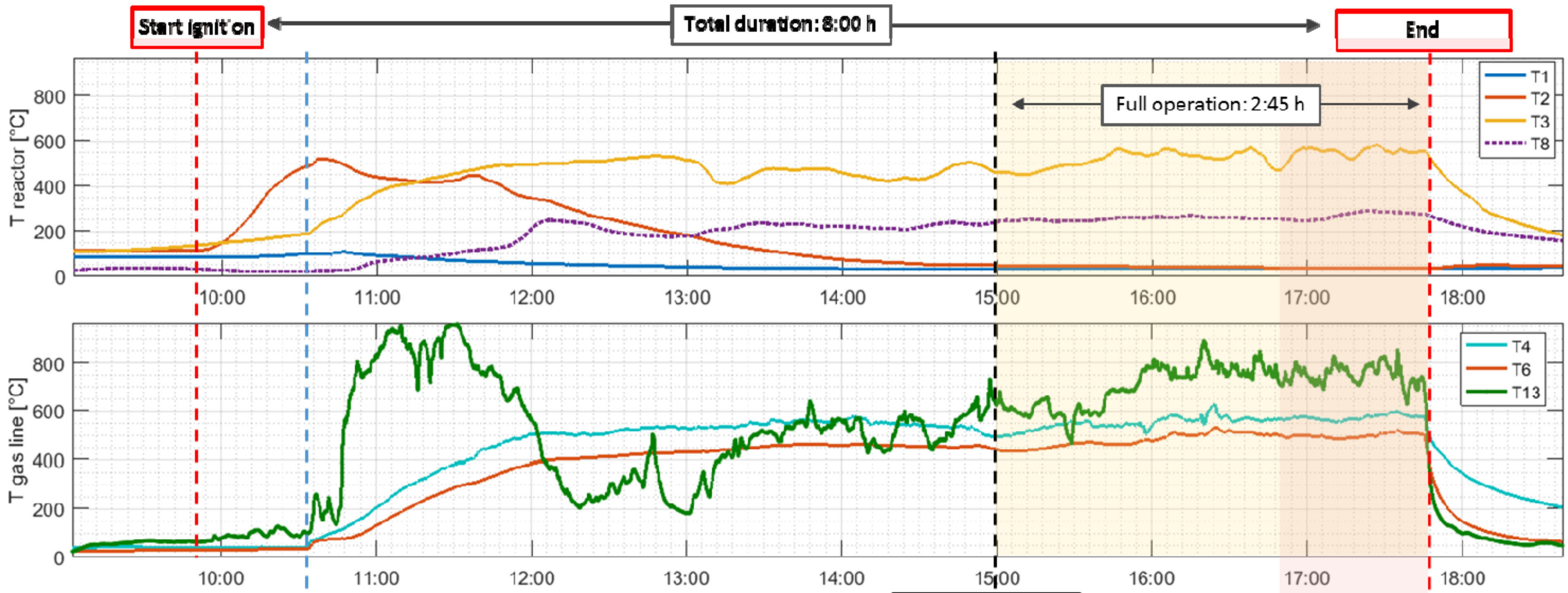
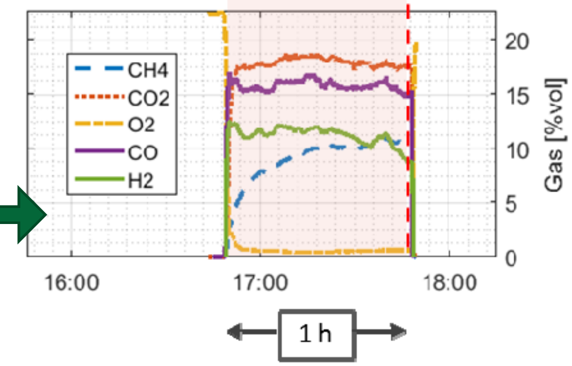


Ejector ON
Char discharge ON

End of transient time



Av. Gas flow
66,5 kg/h

Biomass input
34.5 kg/h db
(42 kg/h wb)

Gas composition during condensate sampling
$CO_2 \approx 18$ %vol.
$CO \approx 15.8$ %vol.
$H_2 \approx 11.2$ %vol.
$CH_4+ \approx 9.3$ %vol

- **Excellent stability** at nominal operation
- **Bridging** effect were **minimized**

Carbonization - Large wood chips / test 11

Charcoal **sampling** approx. every **15 min** at the discharge port

Charcoal characterization								
Sample n.	VM (%w/w db)	Ash (%w/w db)	FC (%w/w db)	LHV (MJ kg^{-1} db)	C (%w/w db)	H (%w/w db)	Surface Area (m^2 g^{-1} ar)	
	EN 15148	*EN 1860*	*EN 1860*	*EN 14918*	*EN 15104*	*EN 15104*	*granules*	*powder*
1	8.9	3.8	87.3	32.6	87.9	1.9	-	125.0
3	9.5	3.6	86.9	32.0	87.5	2.2	93.5	140.7
5	12.1	3.0	85.0	32.2	88.0	1.9	94.7	106.6
7	8.4	3.3	88.2	31.3	88.4	2.0	158.0	214.5

Sample n.7

Charcoal yield (d.b.): $Cy = \frac{M_{char}}{M_{bm}}$

Fixed carbon yield: $FCy = Cy * \frac{\%FC}{(100 - \%Ash_{bm})}$

Char carbon yield: $CCy = Cy * \frac{\%C_{char}}{(\%C_{bm})}$

Yields	Cy (%)	FCy (%)	CCy (%)
	24.1 ± 0.7	20.0 ± 2.2	42.8 ± 1.6

Carbonization - Small wood chips / test 12

Charcoal **sampling** approx. every **15 min** at the discharge port

Charcoal characterization										
Sample n.	Moisture (%w/w ar)	VM (%w/w db)	Ash (%w/w db)	FC (%w/w db)	LHV (MJ kg^{-1} db)	C (%w/w db)	H (%w/w db)	Surface Area (m^2 g^{-1} ar)	PAH *US EPA* (mg kg^{-1})	Bulk density (kg m^{-3} ar)
	EN 14774	*EN 15148*	*EN 1860*	*EN 1860*	*Calc.*	*EN 15104*	*EN 15104*	*granules*		*EN 15103*
15	3.2	8.7	2.2	89.1	31.9	90.4	1.7	196	3.69	130
16	3.3	9.1	1.8	89.1	32.1	91.1	1.7	163	nd	128
19	3.3	11.6	2.5	85.9	32	89.9	2	124	nd	130
21	3.9	19.2	1.2	79.7	30.1	85.3	2.5	98	1.14	134
23	3.2	12.7	3.9	83.4	30.8	86.8	2.1	138	nd	146

Sample n.15

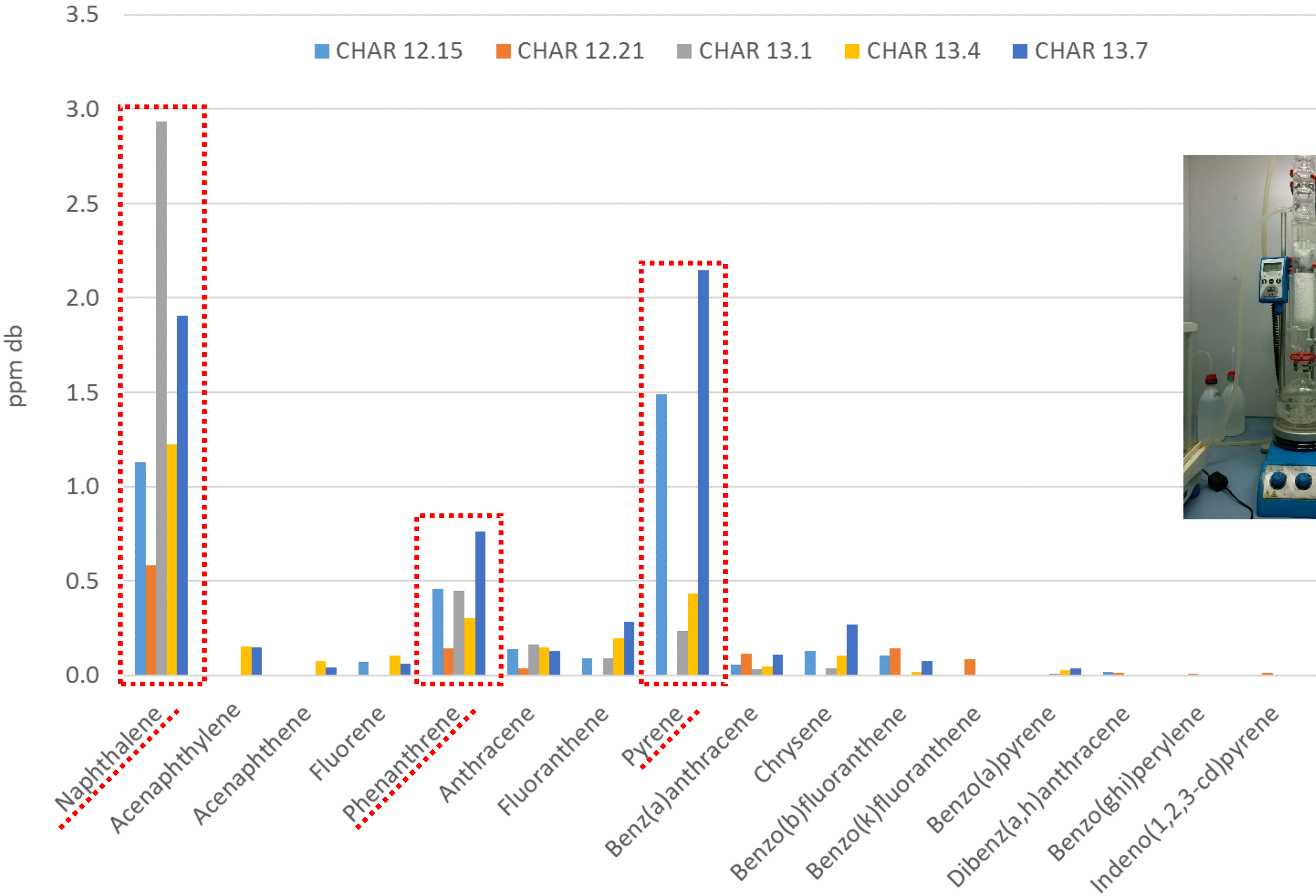
Charcoal yield (d.b.): $Cy = \frac{M_{char}}{M_{bm}}$

Fixed carbon yield: $FCy = Cy * \frac{\%FC}{(100 - \%Ash_{bm})}$

Char carbon yield: $CCy = Cy * \frac{\%C_{char}}{(\%C_{bm})}$

Yields	Cy (%)	FCy (%)	CCy (%)
	22.4	18.2	38.3

PAH (US EPA)



3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
ppm db
CHAR 12.15
CHAR 12.21
CHAR 13.1
CHAR 13.4
CHAR 13.7
Naphthalene
Acenaphthylene
Acenaphthene
Fluorene
Phenanthrene
Anthracene
Fluoranthene
Pyrene
Benz(a)anthracene
Chrysene
Benzo(b)fluoranthene
Benzo(k)fluoranthene
Benzo(a)pyrene
Dibenz(a,h)anthracene
Benzo(ghi)perylene
Indeno(1,2,3-cd)pyrene

Sampling of condensable matter

Objective:

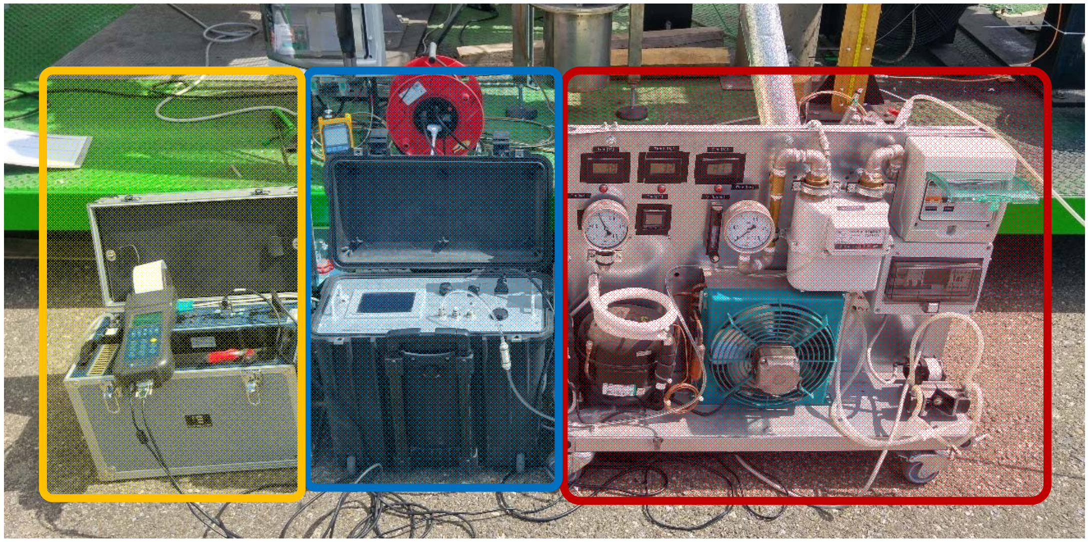
- Benchmarking the produced condensable matter with data from literature

Test setup:

1. **Tar sampling bench**
   + thermostatic line & filter
   non-isokinetic
   (UNI CEN/TS 15439:2008)

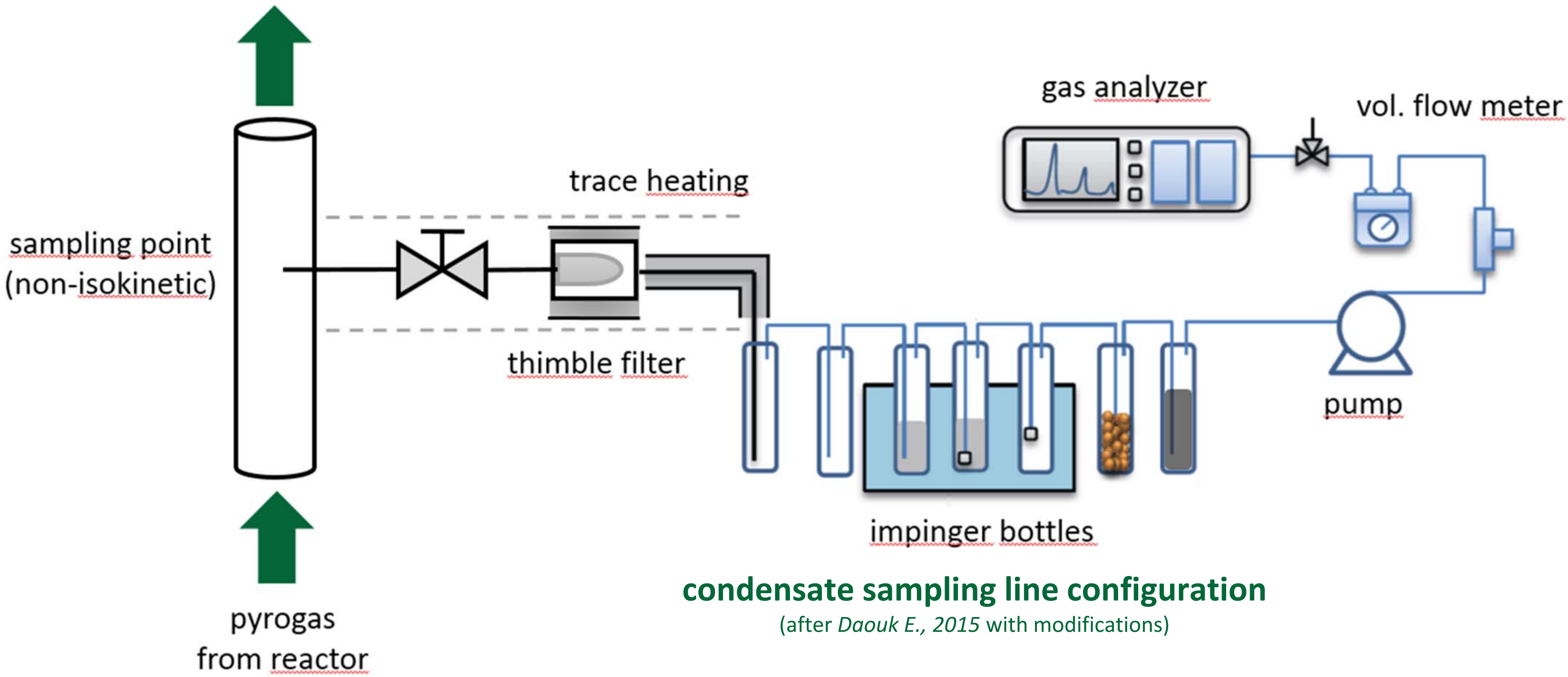
2. **NDIR**
   pyrogas: CO, CO2, O2, CH4

3. **Gas analyzer (electrochemical)**
   exhaust gas: CO, O2, NO



Characterization of condensate in PG

Filter and line T = 350°C
Sampling duration: 1h (0.270 m^3)



condensate sampling line configuration
(after *Daouk E., 2015* with modifications)

Characterization of condensate in PG

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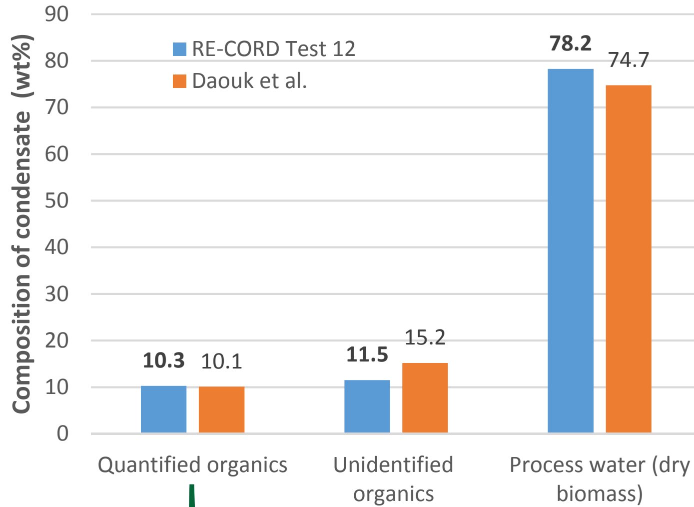
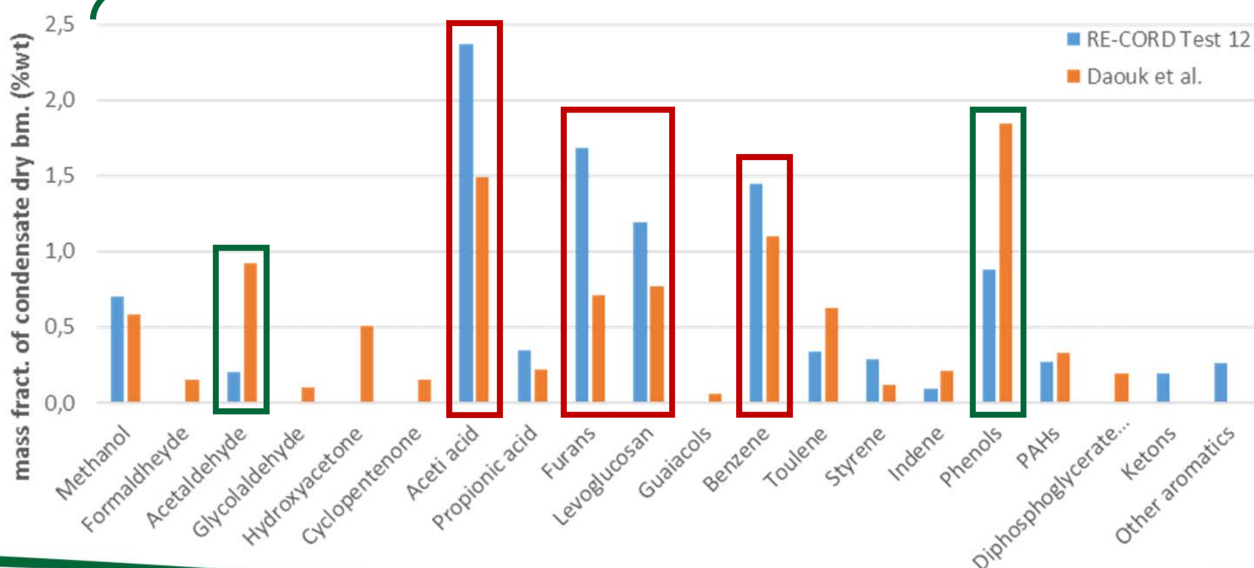
Sampling train at the end of the test

Rotavapor

Light condensate (L) and heavy bottom (R)





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Benchmark of results

	RE-CORD	*Daouk E., 2015*
Biomass capacity (kg/h db)	**34.5**	3.34
Biomass type	**Chestnut**	Maritime pine
Process Equivalence Ratio (ER)	**0.15**	0.13
Quantified organics (w/w % of total organics)	**47 %**	40 %

Daouk E, *Études Expérimentale et Numérique de la Pyrolyse Oxydante de la Biomasse en Lit Fixe*, (**2015**), PhD Thesis

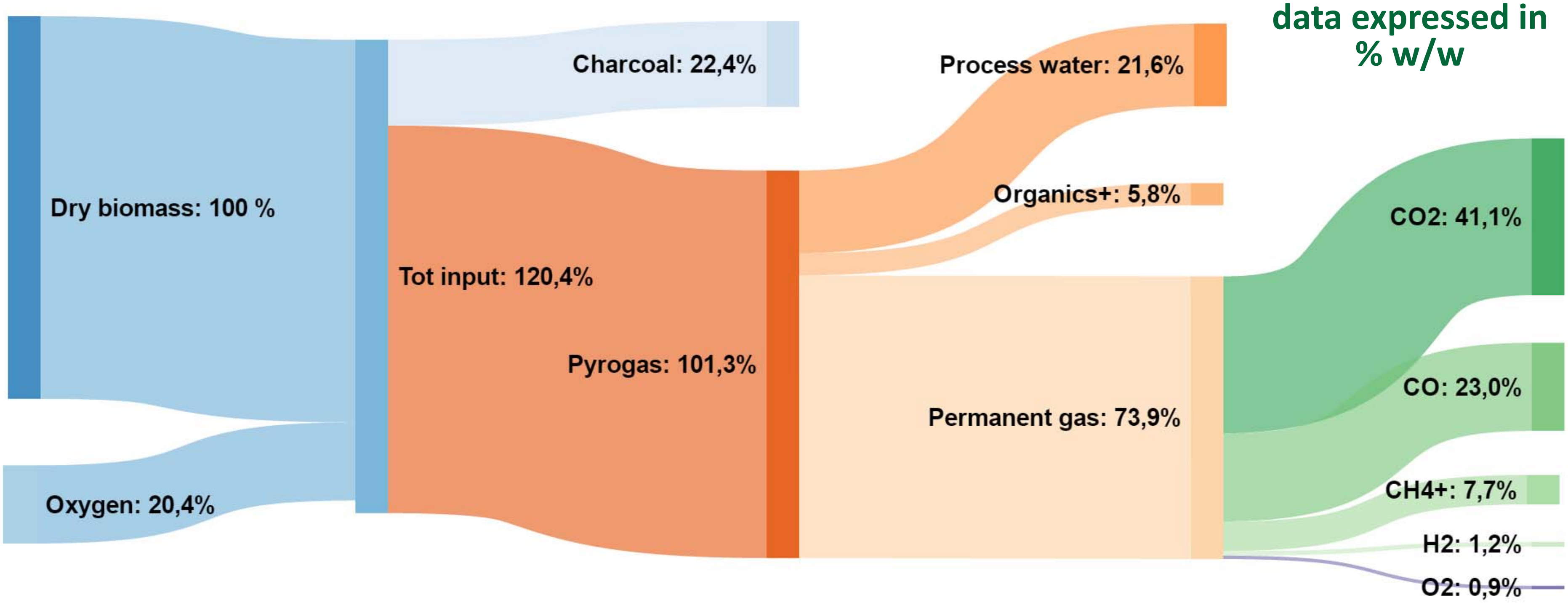
04

RESULTS:

M&E Balances

Mass balance – (small wood chips)

- **22.4 %** of dry biomass input is converted in **charcoal;**
- remaining is a **low calorific value pyrogas** composed of water, organics and permanent gases

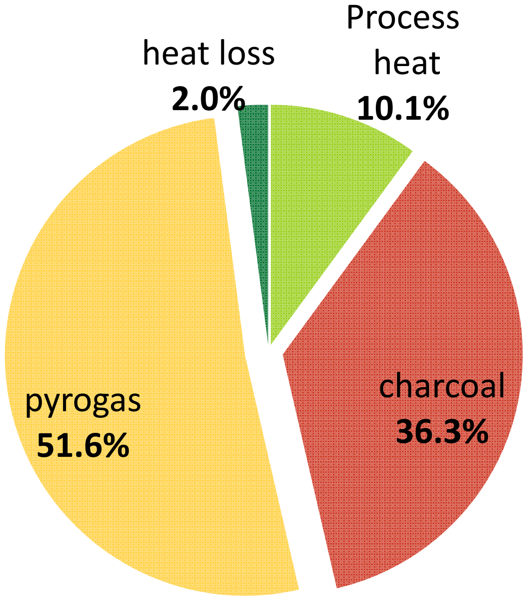


data expressed in % w/w

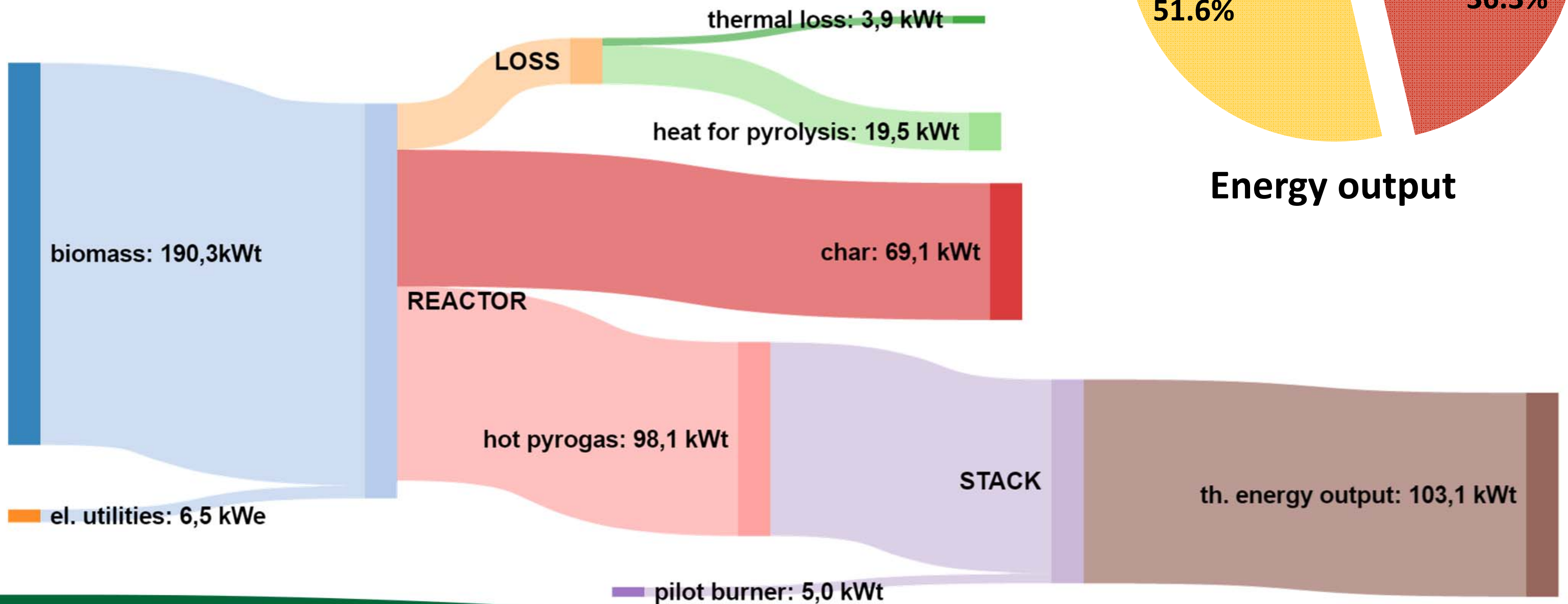
ER = 0.15

Energy balance (small wood chips)

- **>50%** energy output in pyrogas (sensible + chemical)
- **>100 kWt can be recovered as high temperature heat**



Energy output



05

Conclusions

Conclusions

- Pilot carbonization plant
  - Modular, farm-sized
  - Currently under engineering for commercialization
- Very good conversion effectiveness
  - Cy 22-25% w/w db, FCy 18-20% w/w db
  - dependent on feed size
- Excellent product quality
  - High FC, low VM, very low PAH
- High temperature heat as co-product

Acknowledgement

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Thank you for your attention

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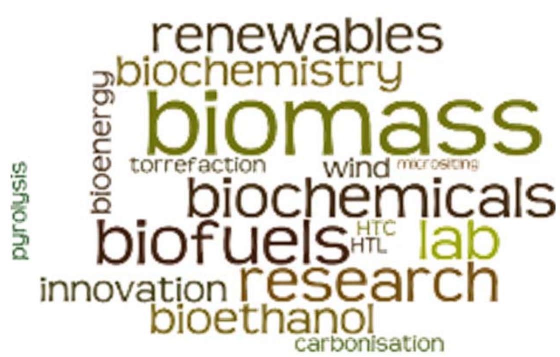

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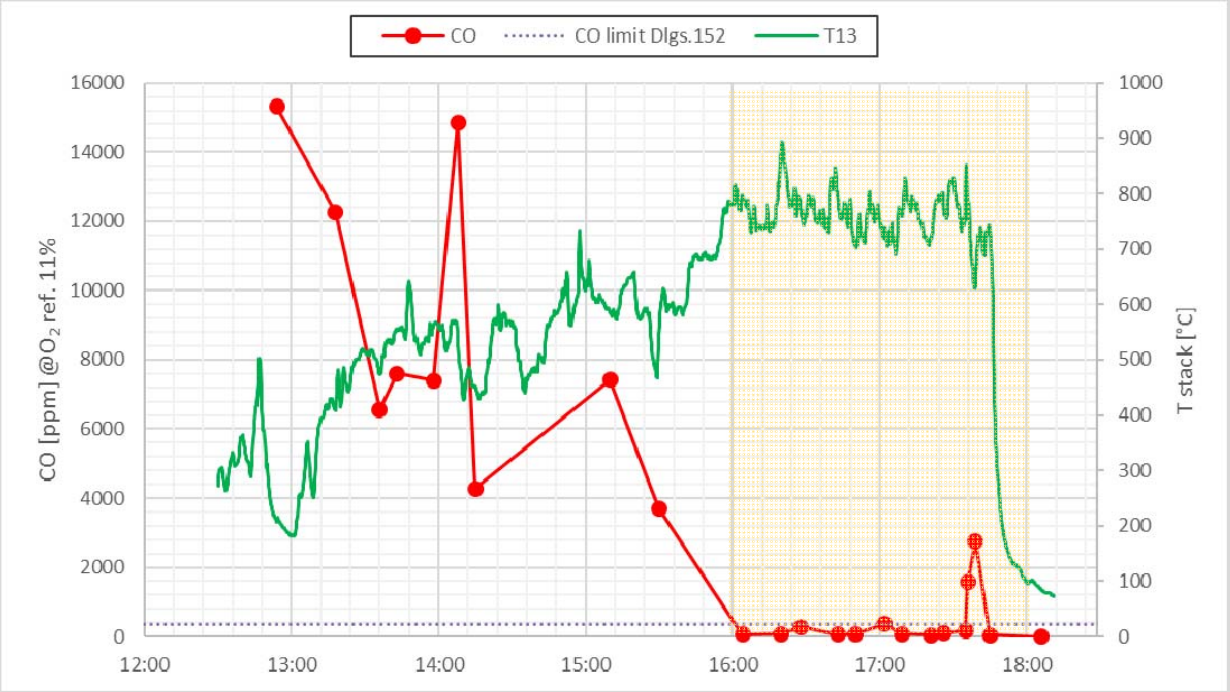
Emissions analysis

Extremely **low pollutants emissions** at full operation with stack propely working (T>700 C)

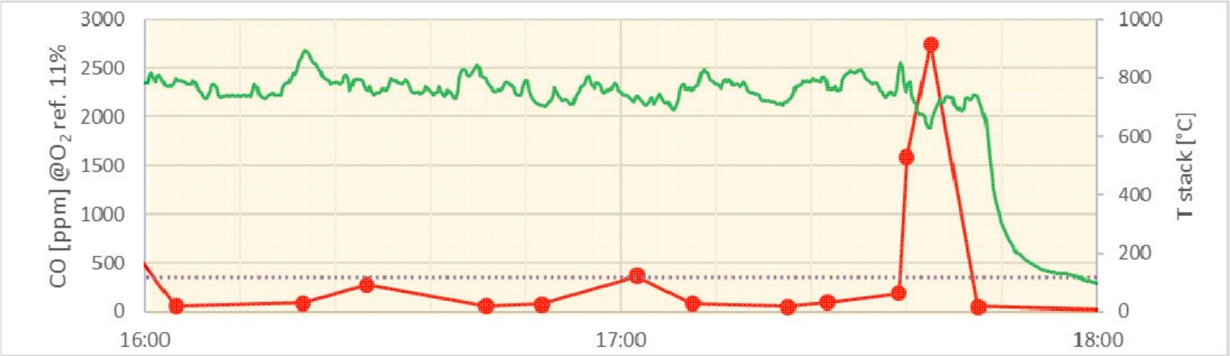


CO accuracy at FO (low conc.).:

- Rel. Error +/- 10 ppm <300 ppm

Max NO conc. measured:

- 15 ppm +/- 8 ppm



Italian emission limit (D.Lgs.152/06):

- CO max 350 ppm
- NO2 max 500 ppm

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