Freie Universität Bozen
Libera Università di Bolzano
Università Liedia de Bulsan

Biomass to Power and Heat 2018
6 -7 June 2018, IPM Hochschule Zittau/Görlitz Campus

The final results from the NEXT project: Tracking the development and assessing the performance of small-scale gasifiers in South Tyrol (Italy)

Dr. Stergios Vakalis
Freie Universität Bozen, Fakultät für Naturwissenschaften und Technik

AUTONOME PROVINZ BOZEN - SÜDTIROL PROVINCIA AUTONOMA DI BOLZANO - ALTO ADIGE

PROVINZIA AUTONOMA DE BULSAN - SÜDTIROL

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Bioenergy & Biofuels Lab

Industrial Technical Physics Group

Associate Professor (Head of the group)

Marco Baratieri

Assistant Professors

Francesco Patuzzi

Stergios Vakalis

Post-Doc fellows

Daniele Basso

Snehesh Shivananda Ail

PhD students	Year	Coop
Junaid Ahmad	(3rd year)	
Alessandro Bellini	(2nd year)	EURAC
Vittoria Benedetti	(2nd year)	
Carlo Caligiuri	(2nd year)	ING-IND/08
Simone Buffa	(2nd year)	EURAC
Daniele Antolini	(1st year)	
Eleonora Cordioli	(1st year)	
Filippo Marchelli	(1st year)	ING-IND/24
Gioacchino Morosinotto	(1st year)	EURAC

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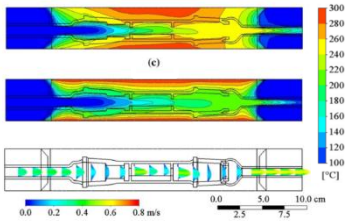
Bioenergy & Biofuels LAB

Thermochemical conversion (pyro-gasification)

+ Analytics
  . Feedstock characterization
  . Advanced thermal analysis
  . Catalyst analysis
+ Process analysis

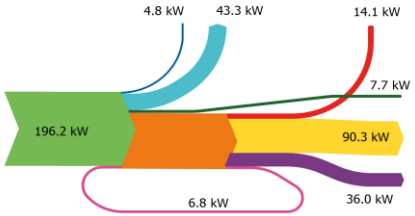
+ Thermo-fluidynamic modelling
+ Kinetic modelling

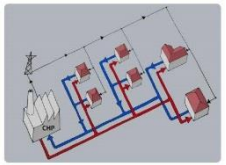


CHP systems

+ Pilot/bench scale plant design and development
+ Monitoring of real scale plants

+ Modelling of energy systems
+ Modelling of DH systems

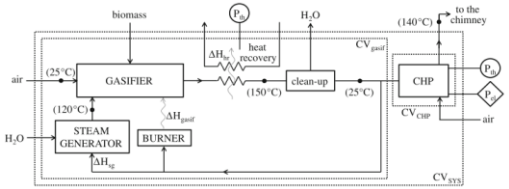




By-products management - Polygeneration

+ Char valorisation pathways
  . Activated carbon production
  . FT synthesis
  . Biodiesel production
+ Tar analysis / reduction

+ Analysis of scenarios
  . Optimization strategies
  . B.O.P.



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Projects on gasification

GAST (2013-16): "Experiences in biomass **Ga**sification in **S**outh **T**yrol: energy and environmental assessment"

NEXT GENERATION (2016-17): "**N**ovel **EXT**ension of biomass poly-**GENERATION** to small scale gasification systems in South-Tyrol

WOOD-UP (2016-2019): "Optimization of **WOOD** gasification chain in South Tyrol to prod**U**ce bio-energy and other high-value green **P**roducts to enhance soil fertility and mitigate climate change"

FlexiFuelGasControl (2017-2020): "Increased **FUEL FLEXI**bility and modulation capability of fixed-bed biomass **GAS**ifiers by means of model based **CONTROL**"

Project partners

Funding bodies

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The NEXT GENERATION project (2016-17)

"**N**ovel **EXT**ension of biomass poly-**GENERATION** to small scale gasification systems in South-Tyrol"

Project partners

Funded by:
Autonomous Province of Bolzano

AUTONOME PROVINZ BOZEN - SÜDTIROL
Abteilung 40. Bildungsförderung, Universität und Forschung

PROVINCIA AUTONOMA DI BOLZANO - ALTO ADIGE
Ripartizione 40. Diritto allo Studio, Università e Ricerca scientifica

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Transition to the NEXT project

Main scope

- Extension of the monitoring campaign
- Identification of valorization pathways for the by-products

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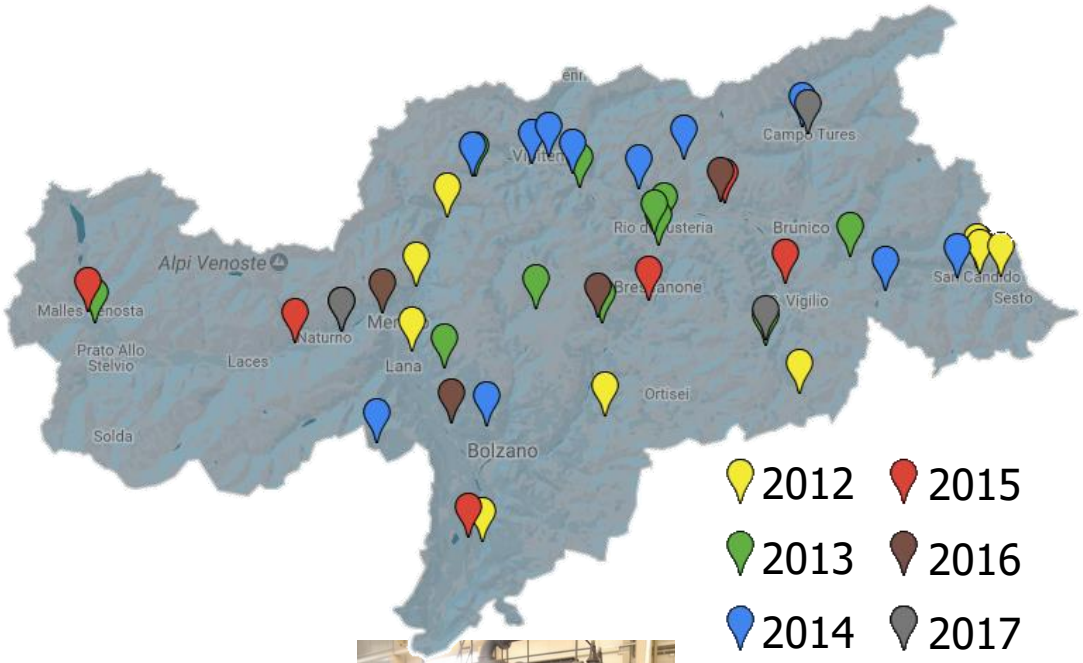
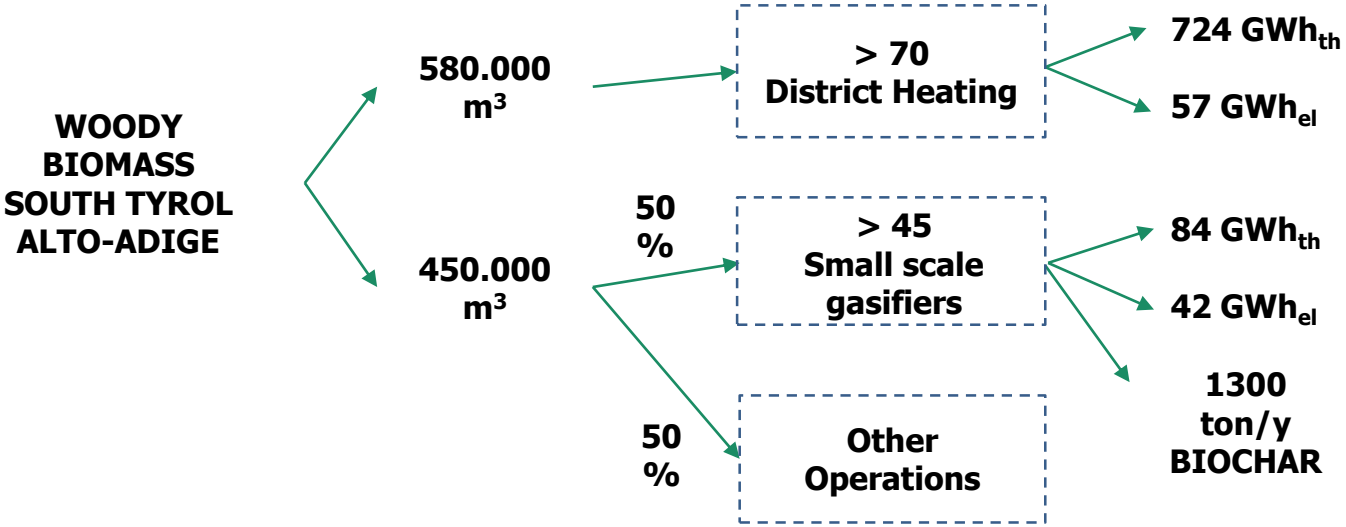
Gasification technologies in South Tyrol



Pictures by: Diego Andreasi, IDM Südtirol – Alto Adige

The case made from previous knowledge



Source: Daniele BASSO et al. (2018) Possibilità di valorizzazione dei biochar da gassificazione in applicazioni di tipo industriale. Fachtagung - Die Holzvergasung. 31. Mai 2018, NOI Techpark – Bozen (Italy)

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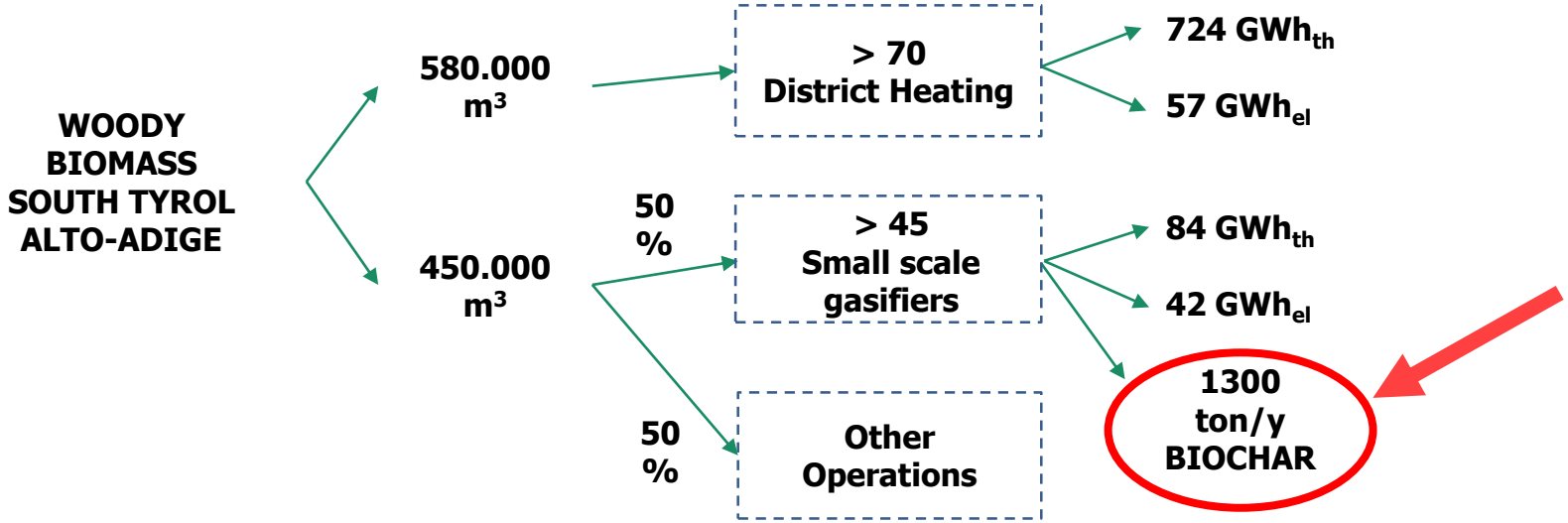

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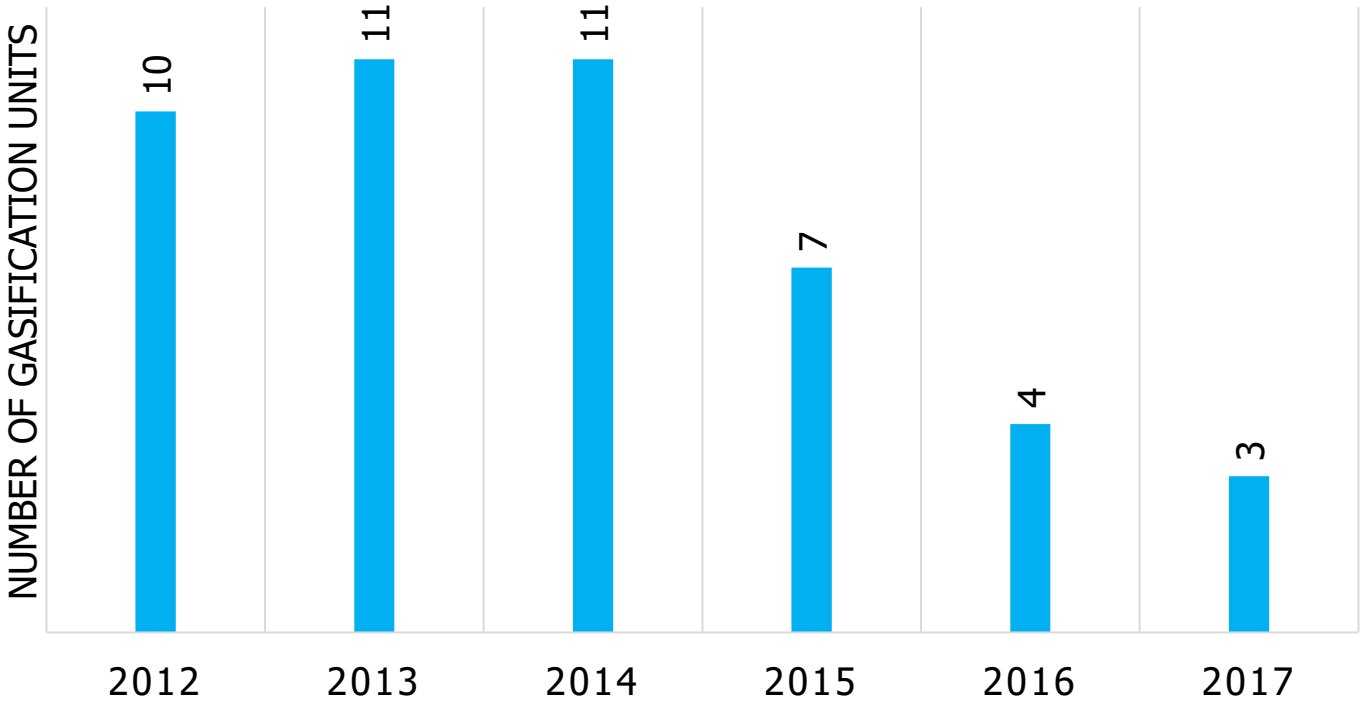
FIRST YEAR OF OPERATION



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Gasification technologies in South Tyrol

Technology	Type of fuel	Electrical Power [kW]	Thermal Power [kW]
Burkhardt GmbH	pellets & bio oil	180	270
Entrade Energiesysteme GmbH	pellets	25	60
Future Green Srl (Wubi)	wood chips	100	200
Hans Gräbner	logs or wood chips	30	60
Holzenergie Wegscheid GmbH	wood chips or briquettes	140	270
Kuntschar Energieerzeugung GmbH	wood chips	150	260
Spanner Re² GmbH	wood chips	45	105
Stadtwärke Rosenheim	wood chips	50	100
Syncraft Engineering GmbH	wood chips	250	990
Urbas Maschinenfabrik GmbH	wood chips	296	550
Xylogas & EAF	wood chips	440	880

Pictures by: Diego Andreasi, IDM Südtirol – Alto Adige

Monitoring on-site

plants: 10/46

technologies: 8

Typology of fuel:
- pellet: 1/10
- wood chips: 9/10

Type of reactors:
- Fixed bed downdraft: 7/10
- Rising co-current: 1/10 (updraft with downdraft zone separation)
- Double stage: 2/10 (1 downdraft and 1 updraft)

Common traits that were identified

- High quality biomass feedstock
- Automated systems
- Preheating of air
- Extensive drying before use
- Feeding with screws/augers (sometimes also pneumatic pumps)
- Hot gas filtering and tar condensation (with some exceptions)
- Otto engines or modified Diesel engines for increased CR

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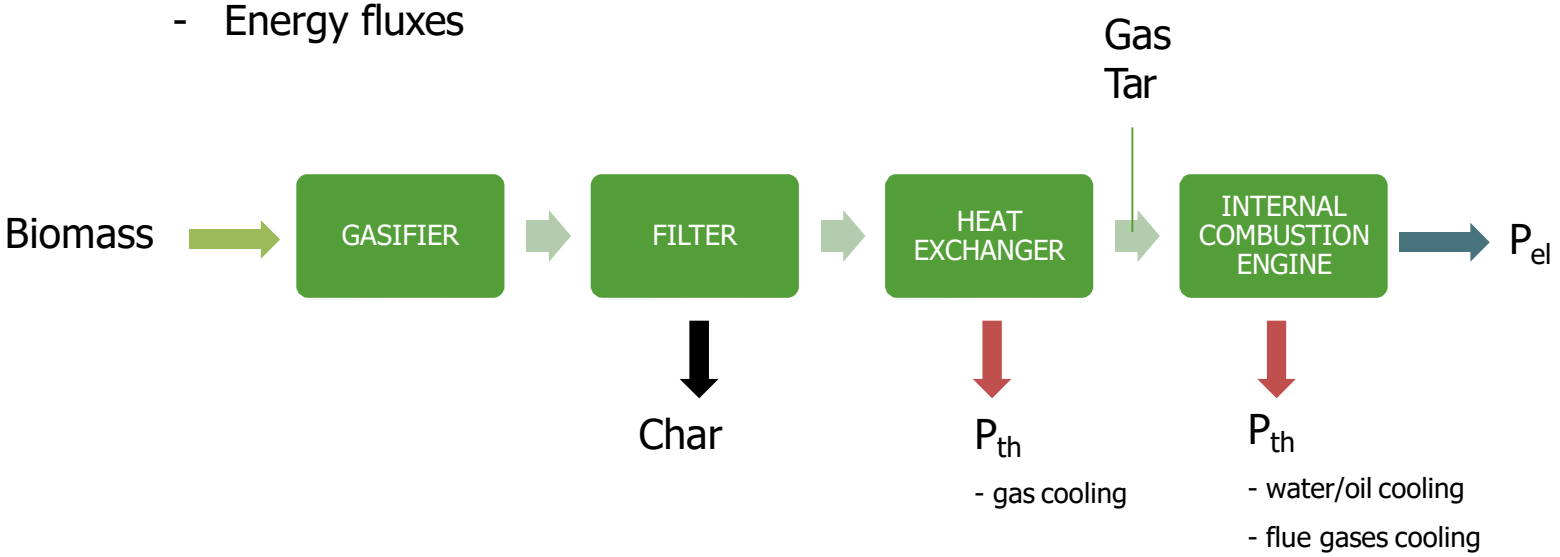
Unique characteristics that were identified

- The biomass is first dried in a separated vessel
- "Floating fixed-bed" reactor, takes advantage of the compaction forces
- Rising co-current - creates a vortex above the combustion zone
- Dual-fuel engines
- Reduction zones that allow char beds of significant height
- Recirculation of producer gas back into the combustion zone.
- Carbonization of biomass prior to the input of the gasifier
- Char recirculation in the reactor

The points of monitoring

Analyzed parameters

- Feedstock and gasification products (gas, char and tar) characteristics
- Mass fluxes
- Energy fluxes

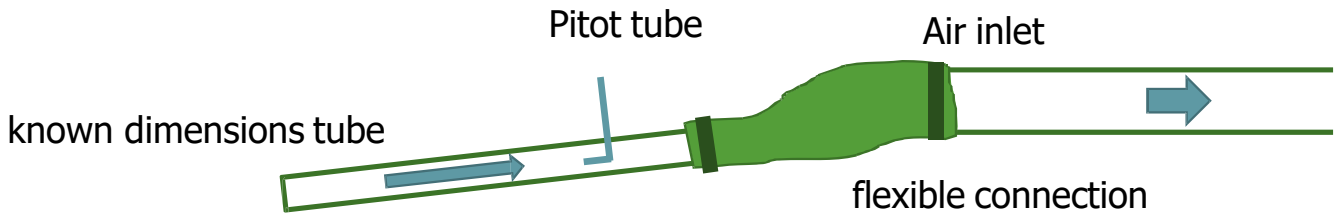


Applied methodologies

Mass fluxes

- Woody biomass flow rate
- Gasifying agent (air) flow rate
- Producer gas flow rate
- Char flow rate

Air flow: Determined by means of the **velocity in a known dimensions tube** connected to the air inlet. Velocity measured by means of a **Pitot tube**.



Applied methodologies

Energy fluxes

- Energy related to the input fuel
- Energy related to the producer gas
- Produced electrical and thermal energy

Producer gas LHV calculated on the basis of its **composition**, measured by means of a **portable gas chromatography system.**

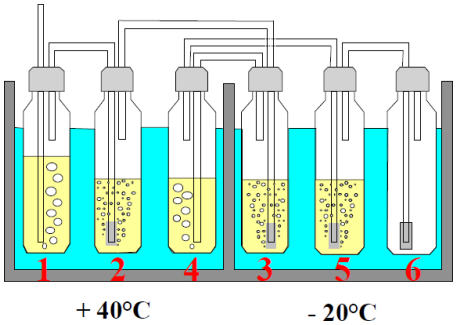
$$P_{gas} = m_{gas} \cdot LHV_{gas}$$

Applied methodologies

By-products characterization

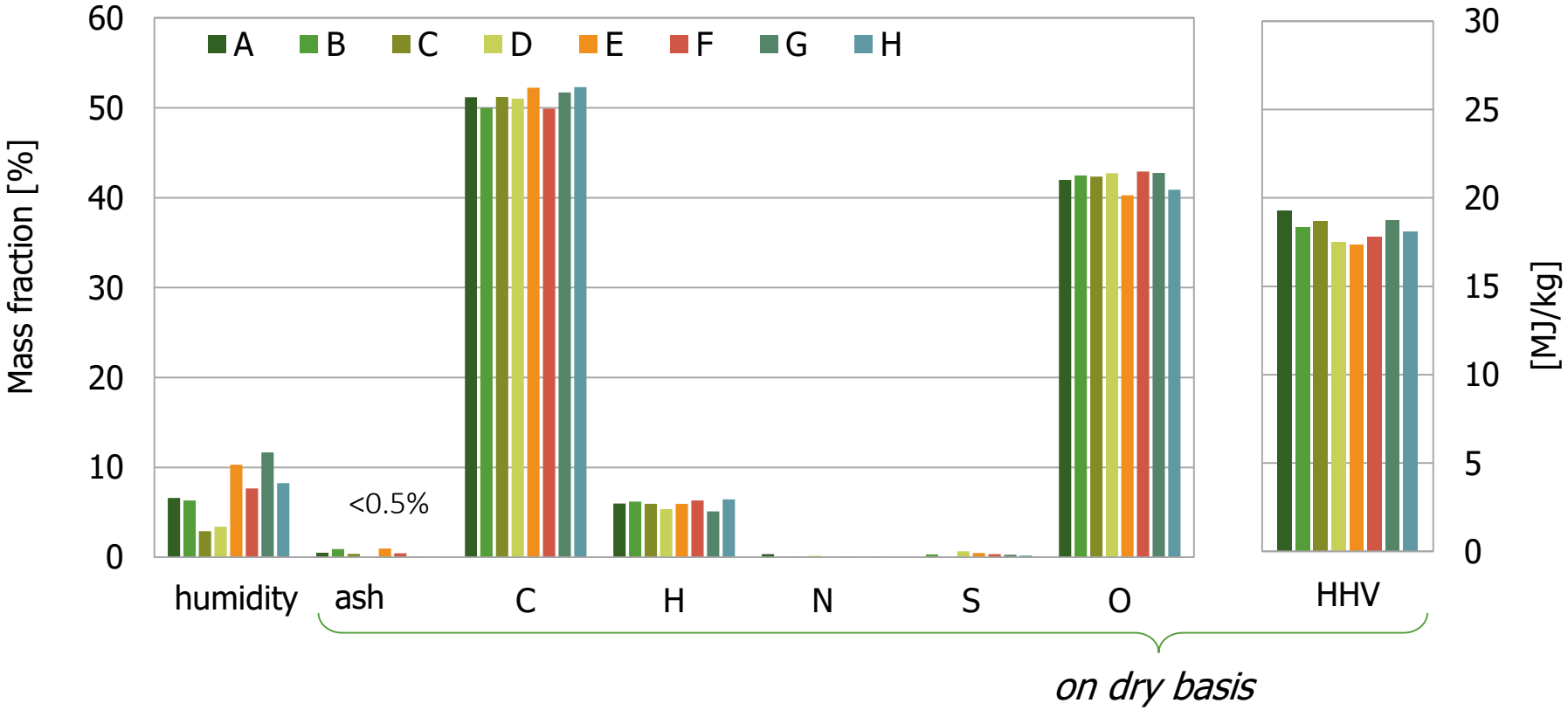
- Liquid: tar
- Solid: char

Tar in the producer gas sampled and analyzed according to **UNI CEN TS 15439** (bubbling in **isopropanol**)



See also: S. Vakalis, et al. (2014). Assessment of a test methodology suitable for small scale biomass gasifiers. 22nd European Biomass Conference and Exhibition. 23rd - 26th June 2014, Hamburg.

Characterization of input fuel



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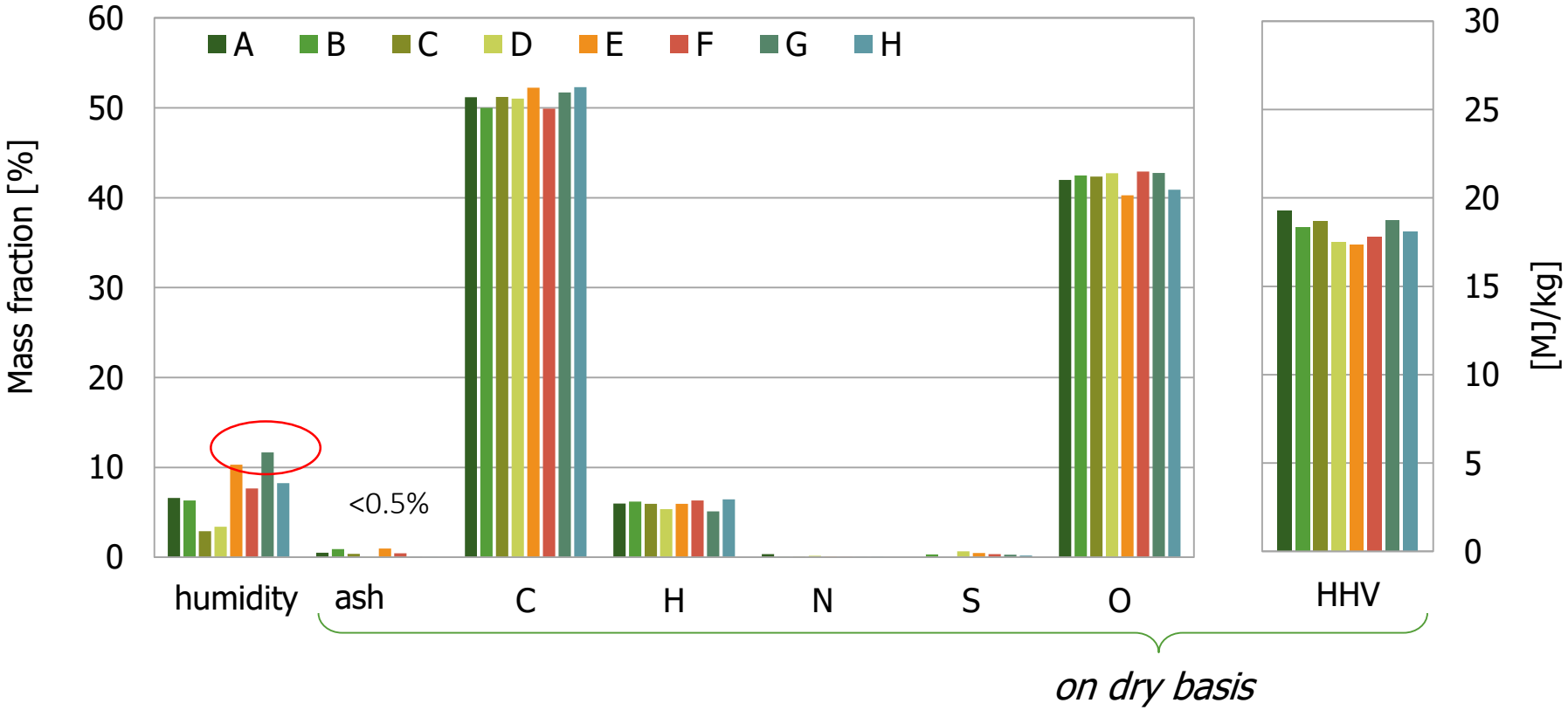

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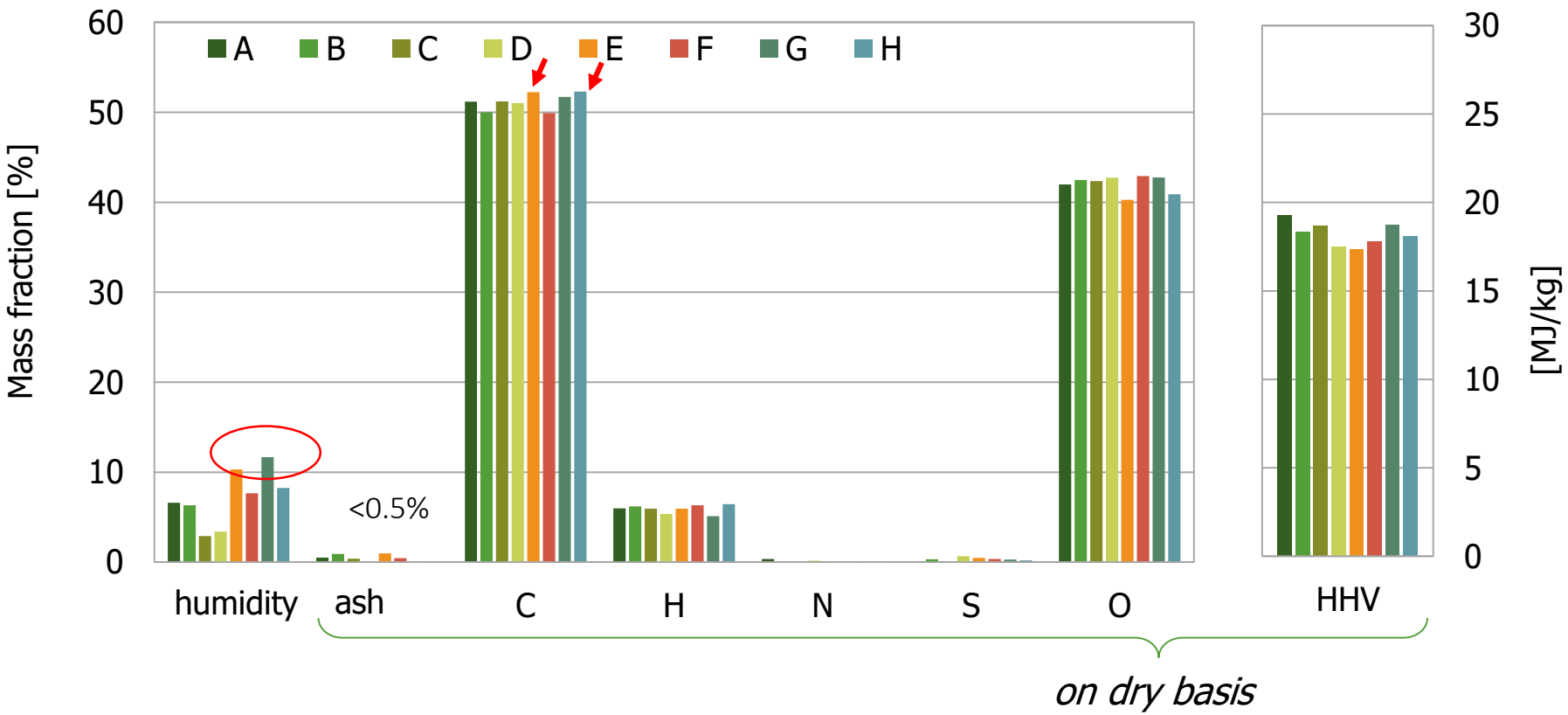
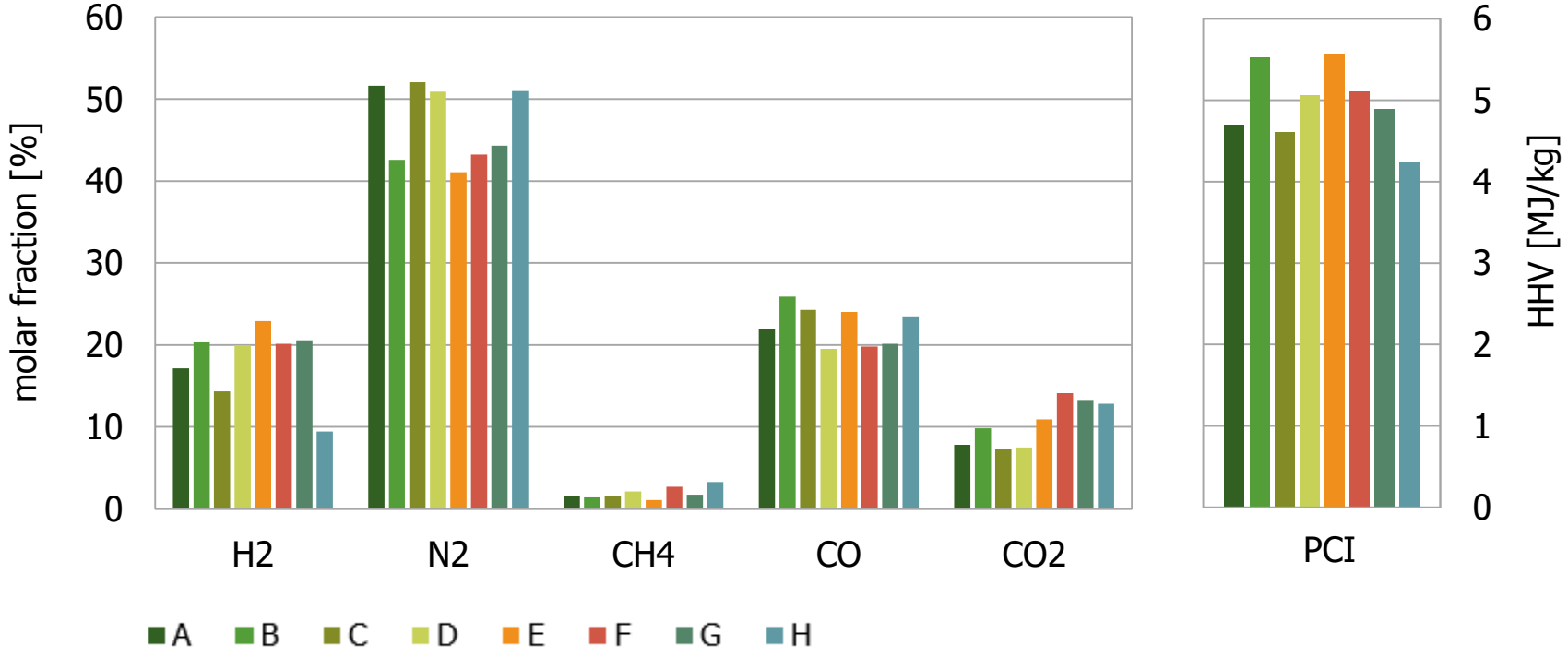


Gas composition



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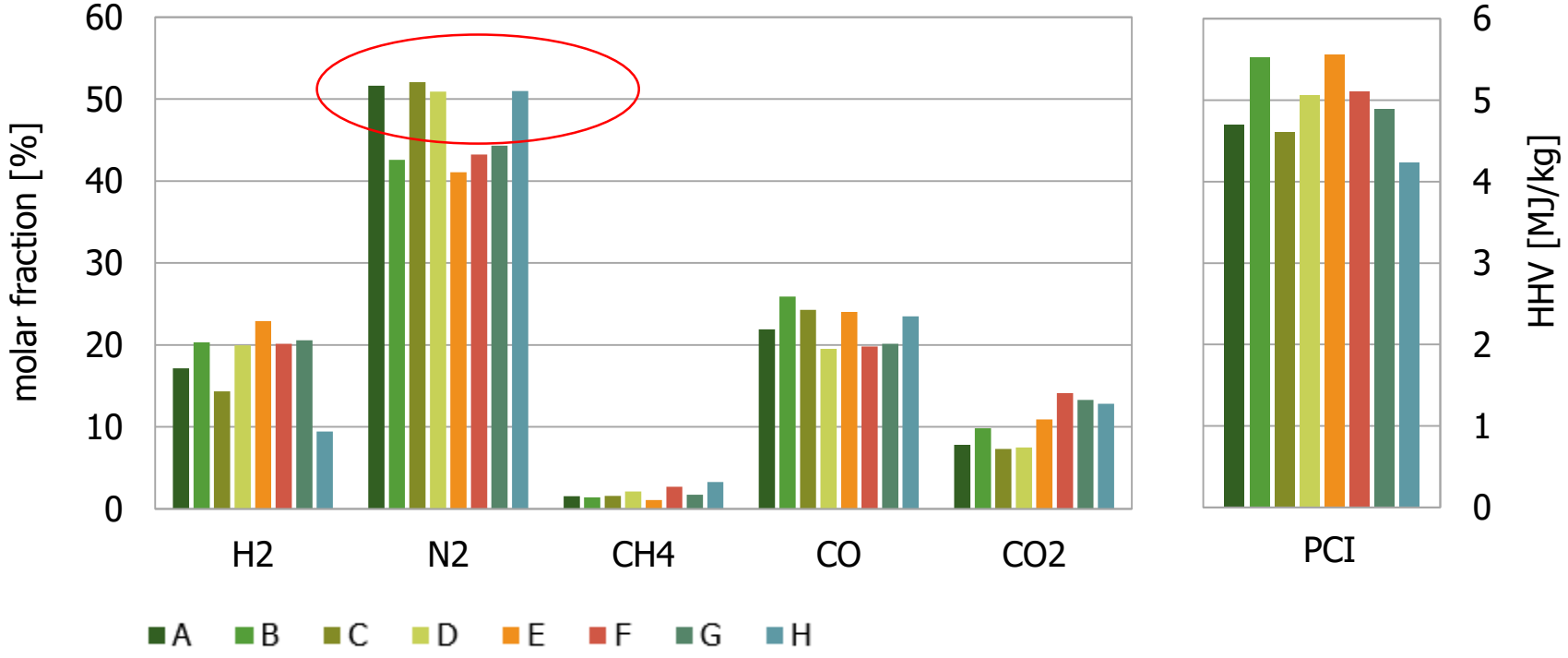

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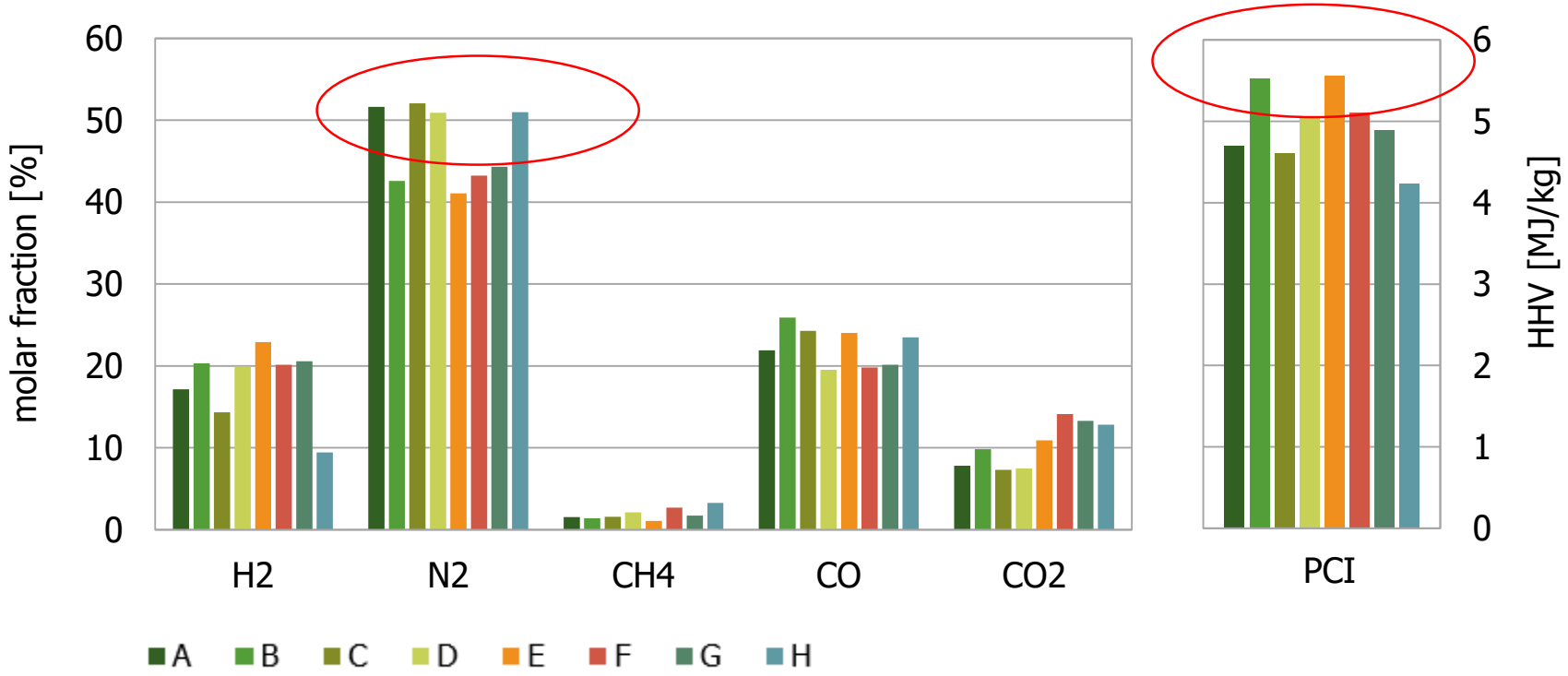

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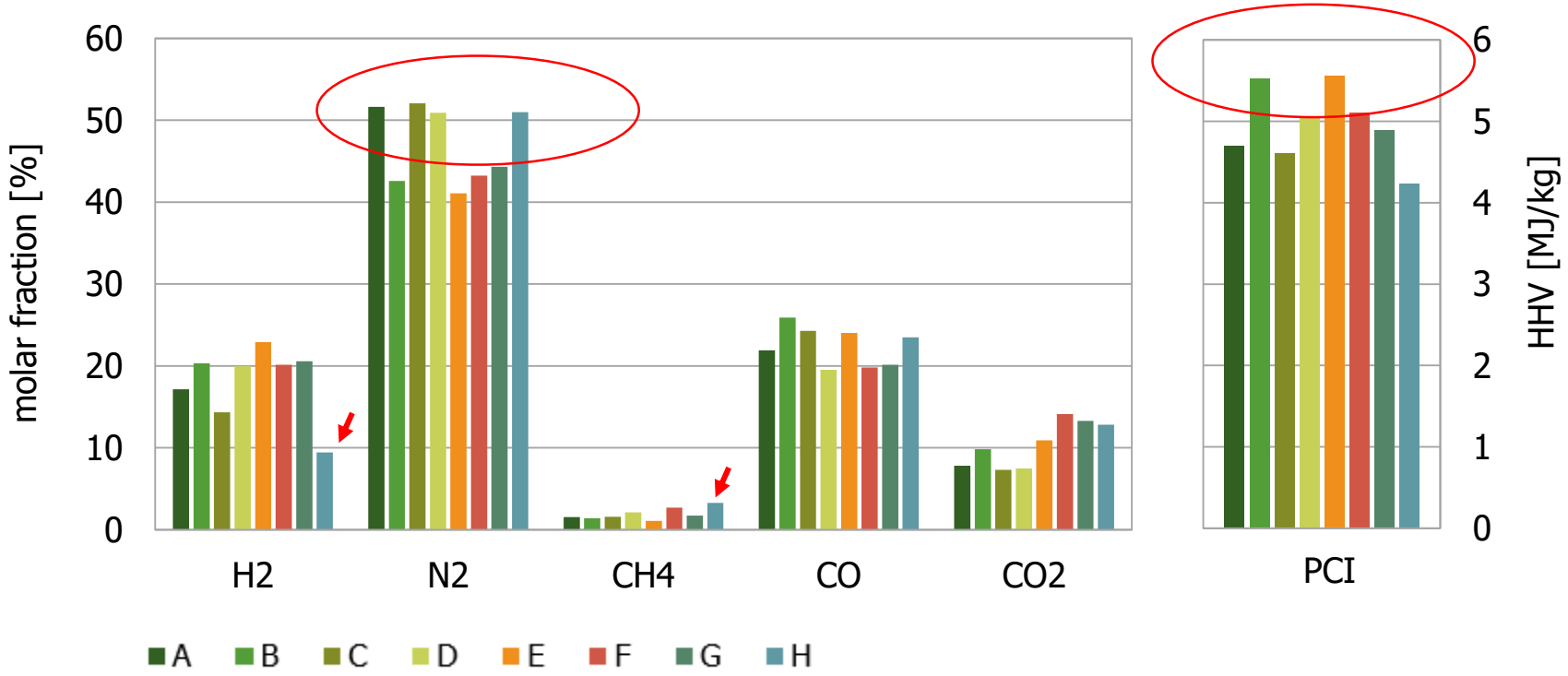
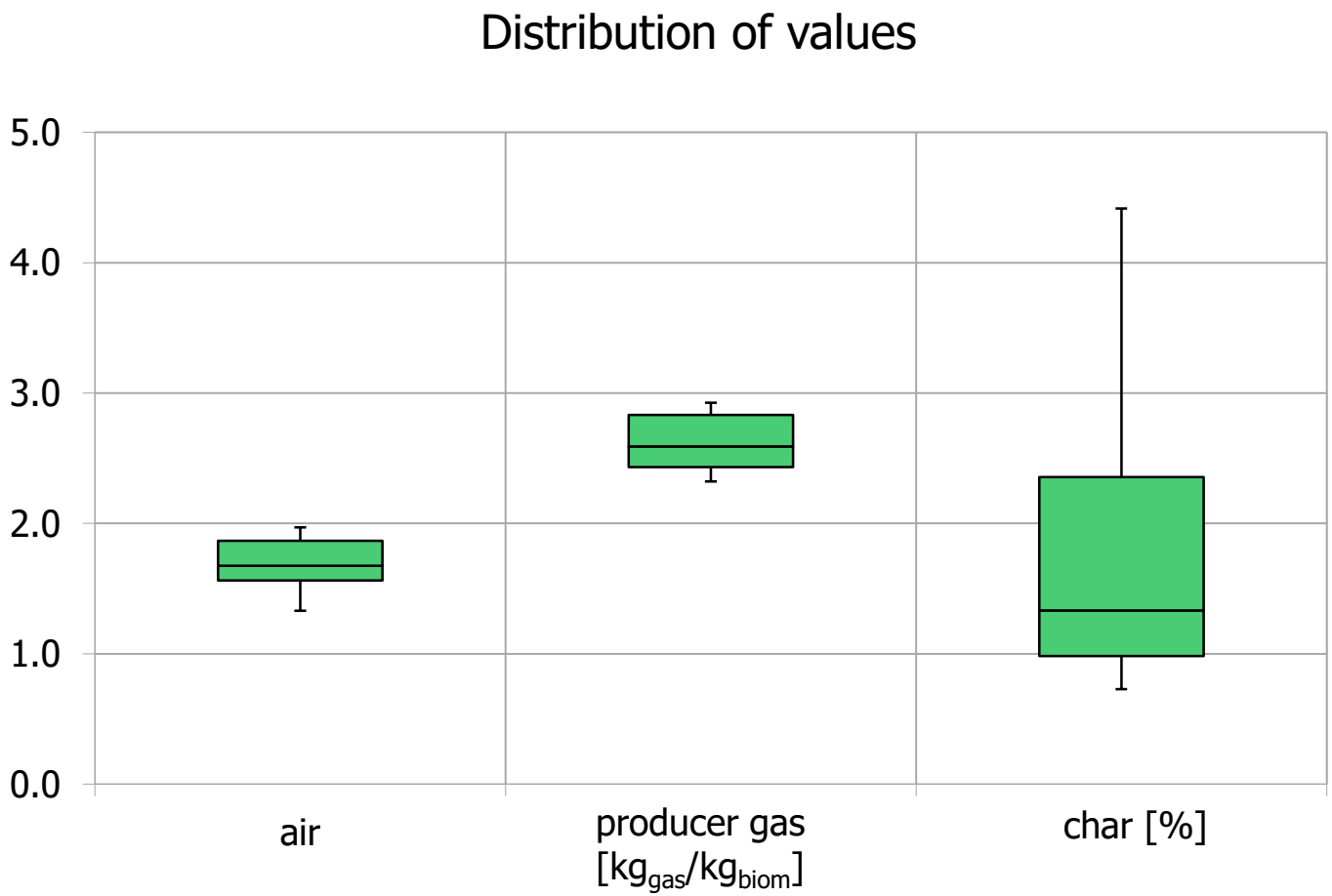
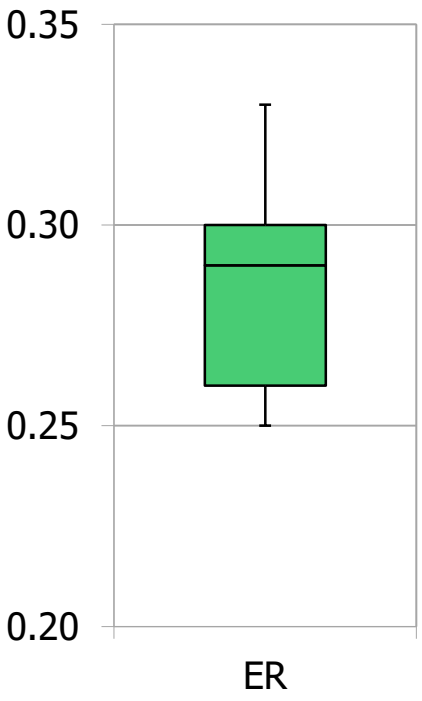
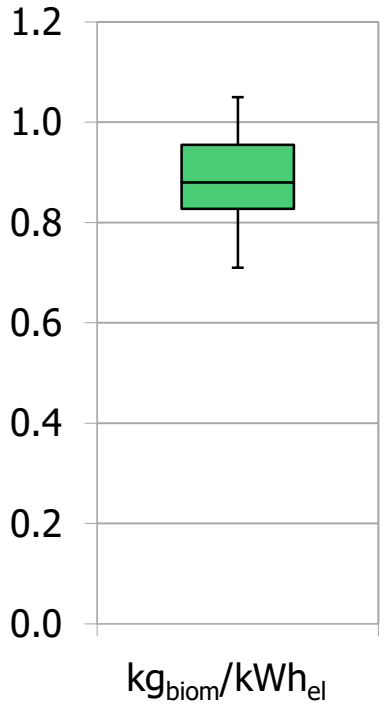


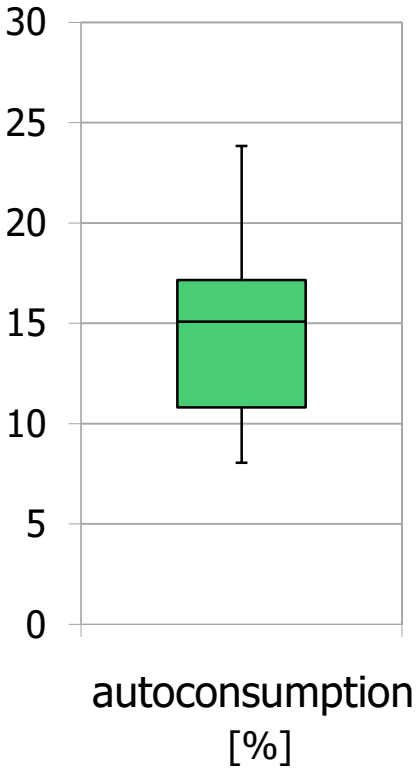
Mass balances



Parameters of operation

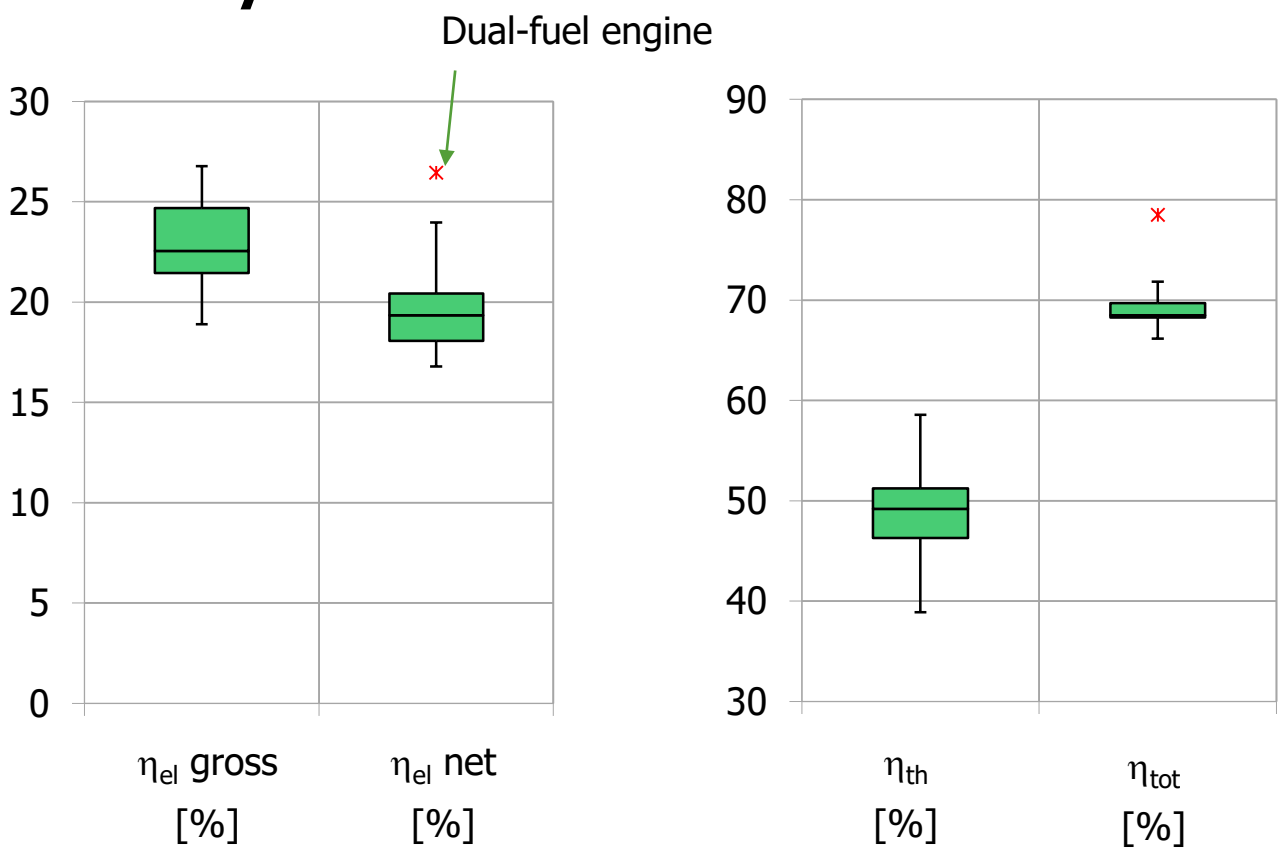






Source: Francesco PATUZZI et al. (2018) Monitoraggio on-site degli impianti di gassificazione in Alto Adige: analisi delle prestazioni energetiche. Fachtagung - Die Holzvergasung. 31. Mai 2018, NOI Techpark – Bozen (Italy)

Efficiency



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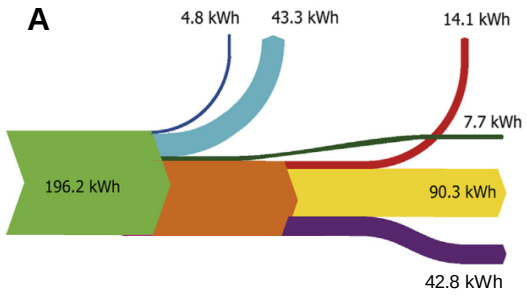
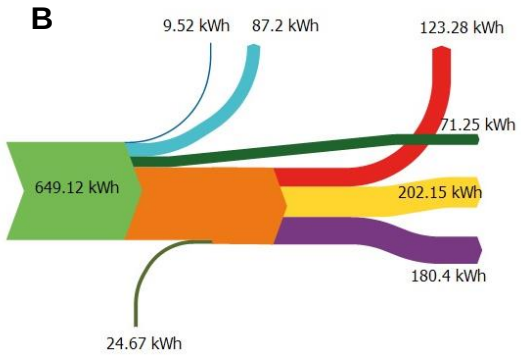
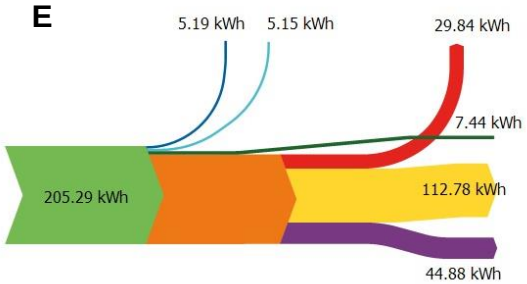
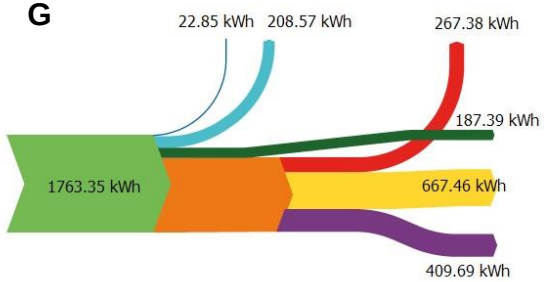
Energy Balances

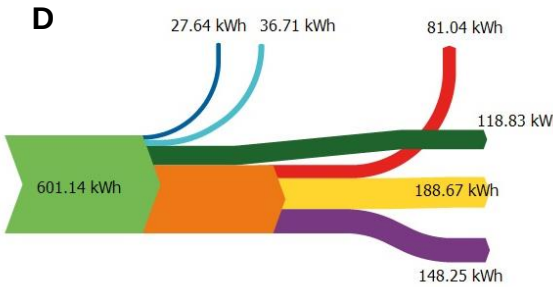
- Input biomass
- ICE thermal output
- ICE loss
- Output char
- ICE input
- ICE electric output
- Gasifier thermal loss
- Gas-cooling thermal output

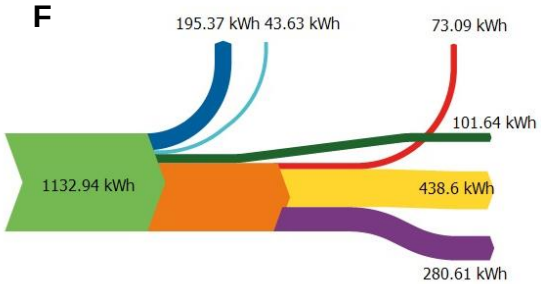


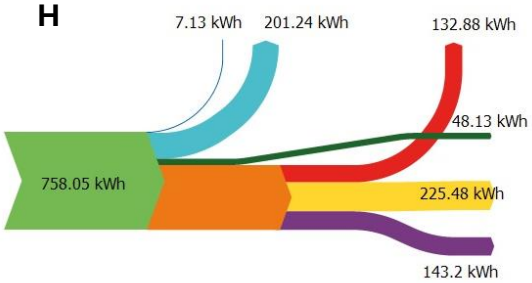












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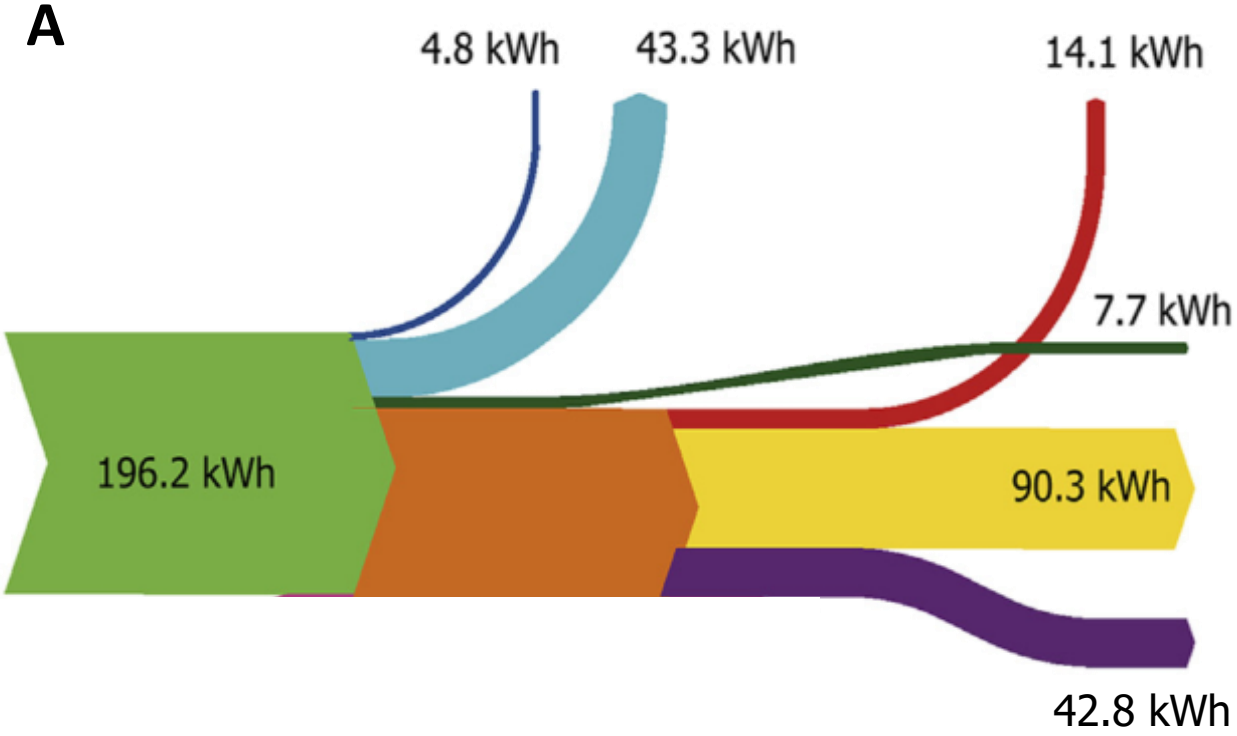
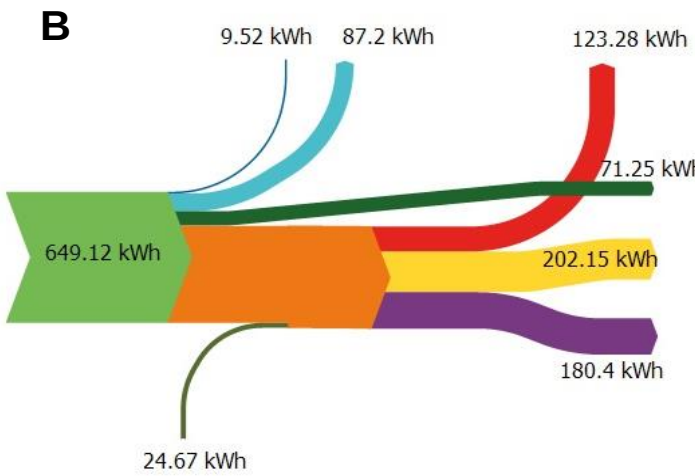
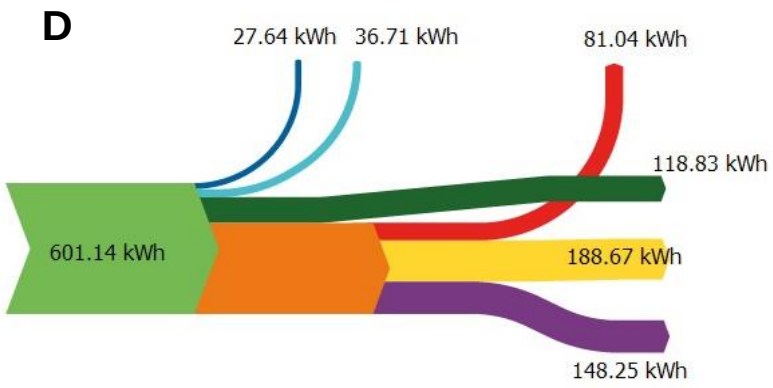



B
9.52 kWh
87.2 kWh
123.28 kWh
71.25 kWl
649.12 kWh
202.15 kWh
180.4 kWh
24.67 kWh


D
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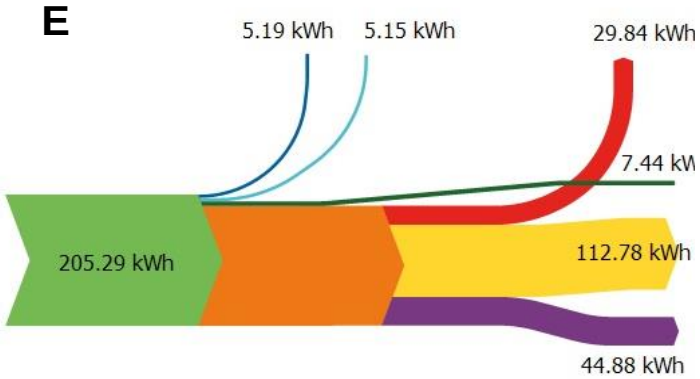
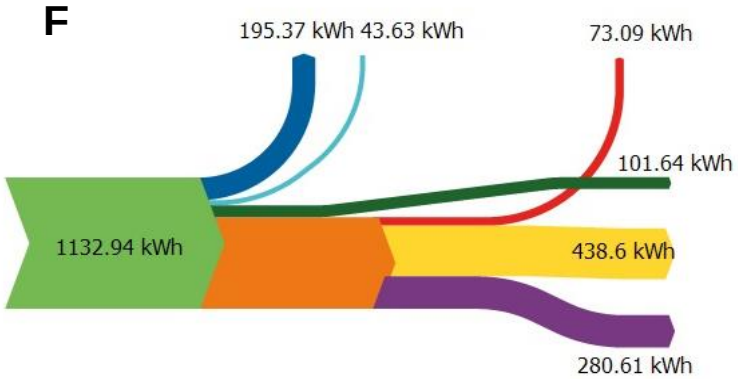
36.71 kWh
81.04 kWh
118.83 kWh
601.14 kWh
188.67 kWh
148.25 kWh


E
5.19 kWh
5.15 kWh
29.84 kWh
7.44 kW
205.29 kWh
112.78 kWh
44.88 kWh


F
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43.63 kWh
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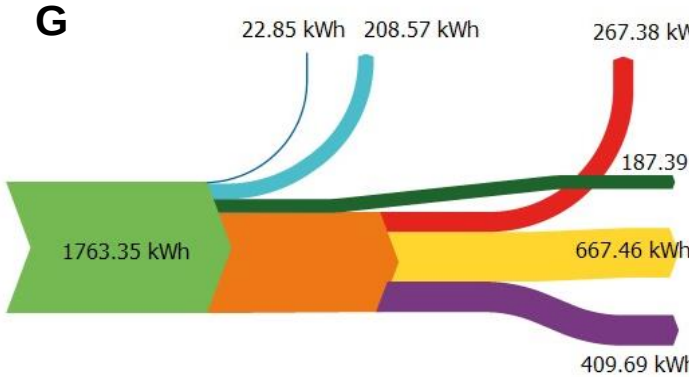
101.64 kWh
1132.94 kWh
438.6 kWh
280.61 kWh


G
22.85 kWh
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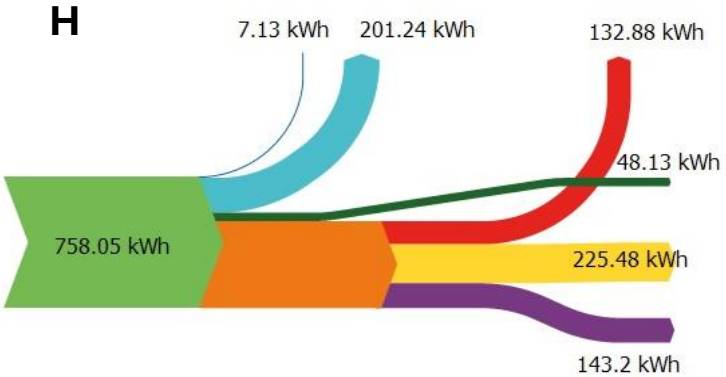
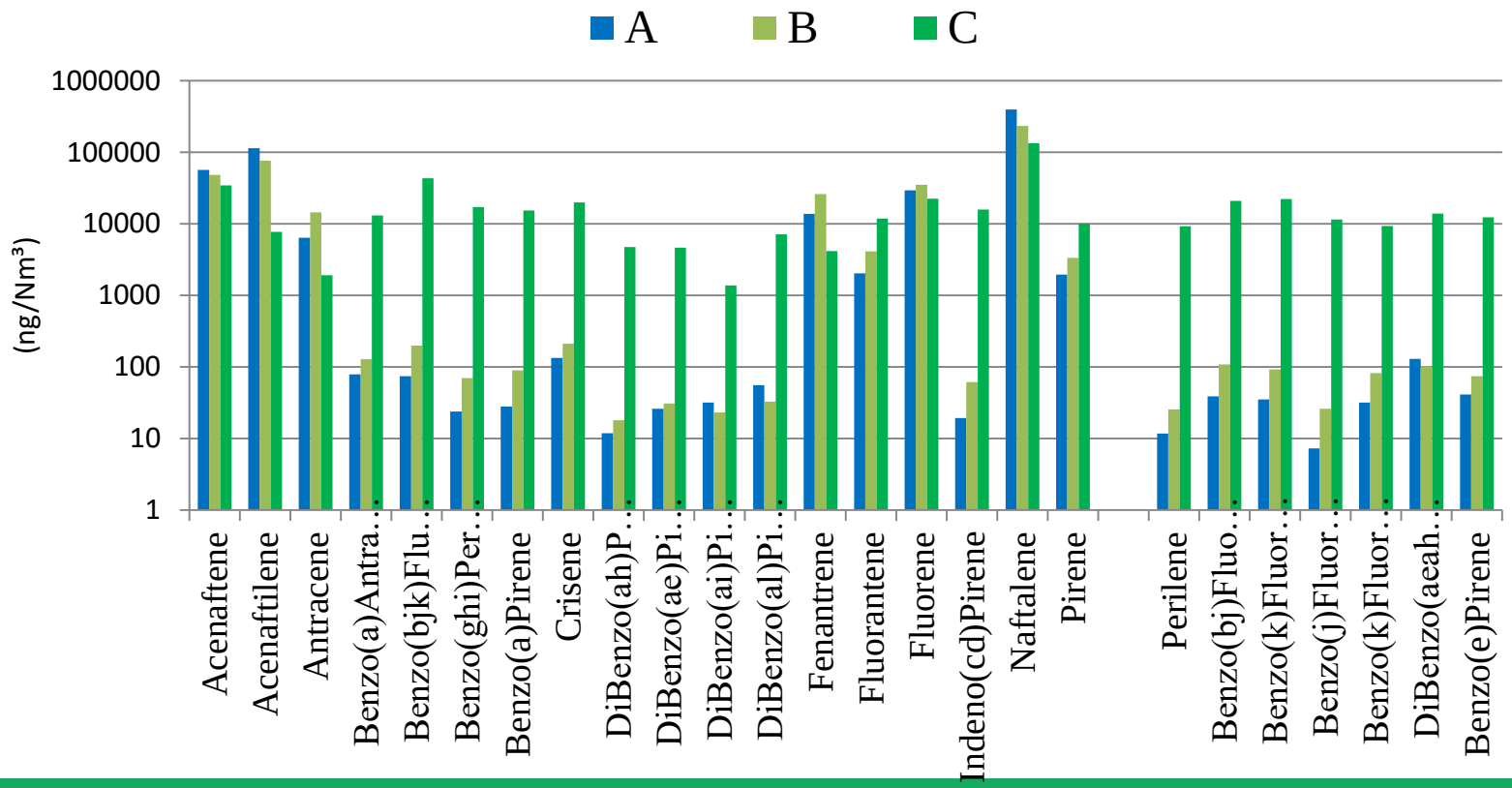
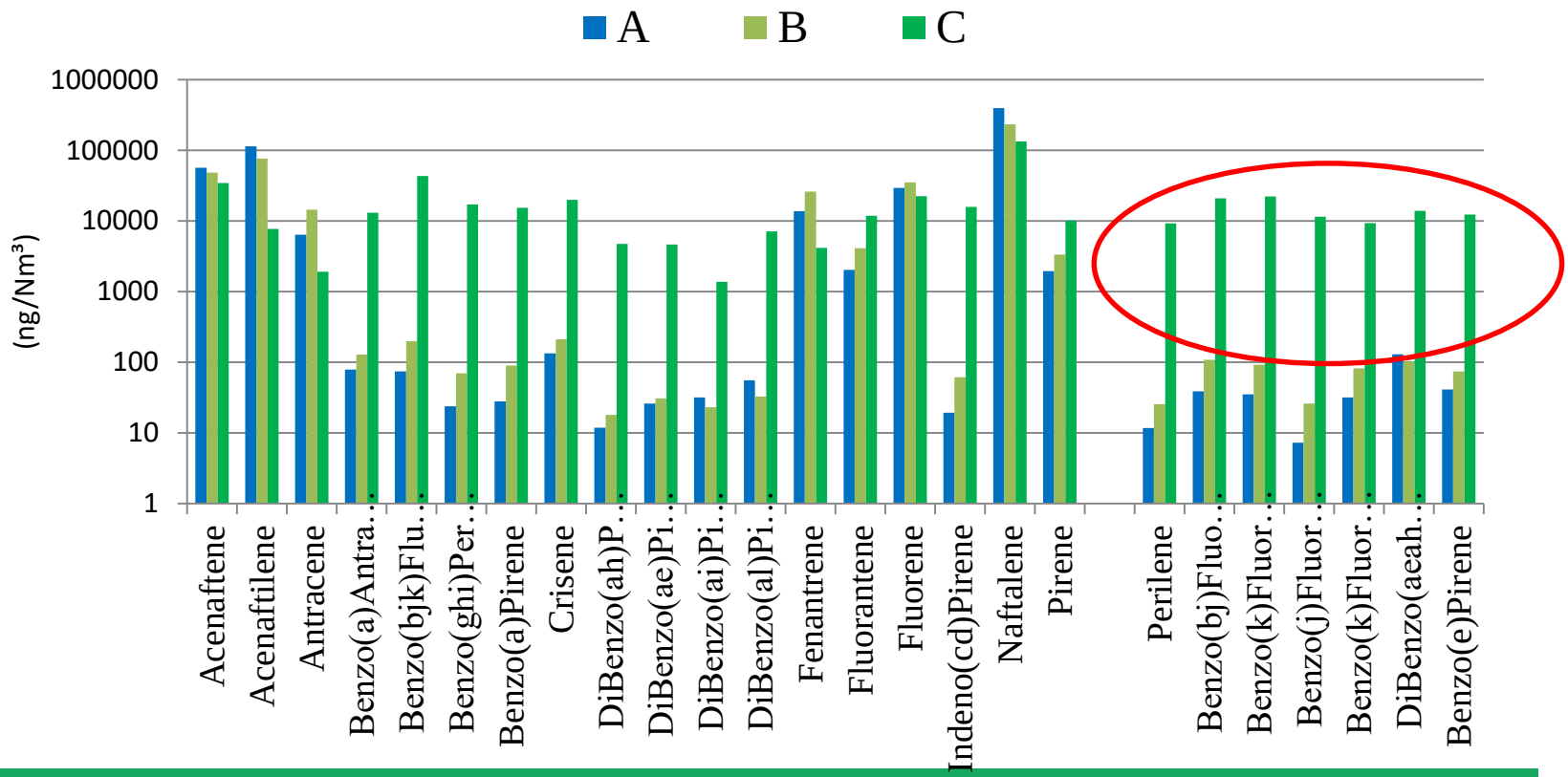
267.38 kW
187.39
1763.35 kWh
667.46 kWh
409.69 kWl


H
7.13 kWh
201.24 kWh
132.88 kWh
48.13 kWh
758.05 kWh
225.48 kWh
143.2 kWh

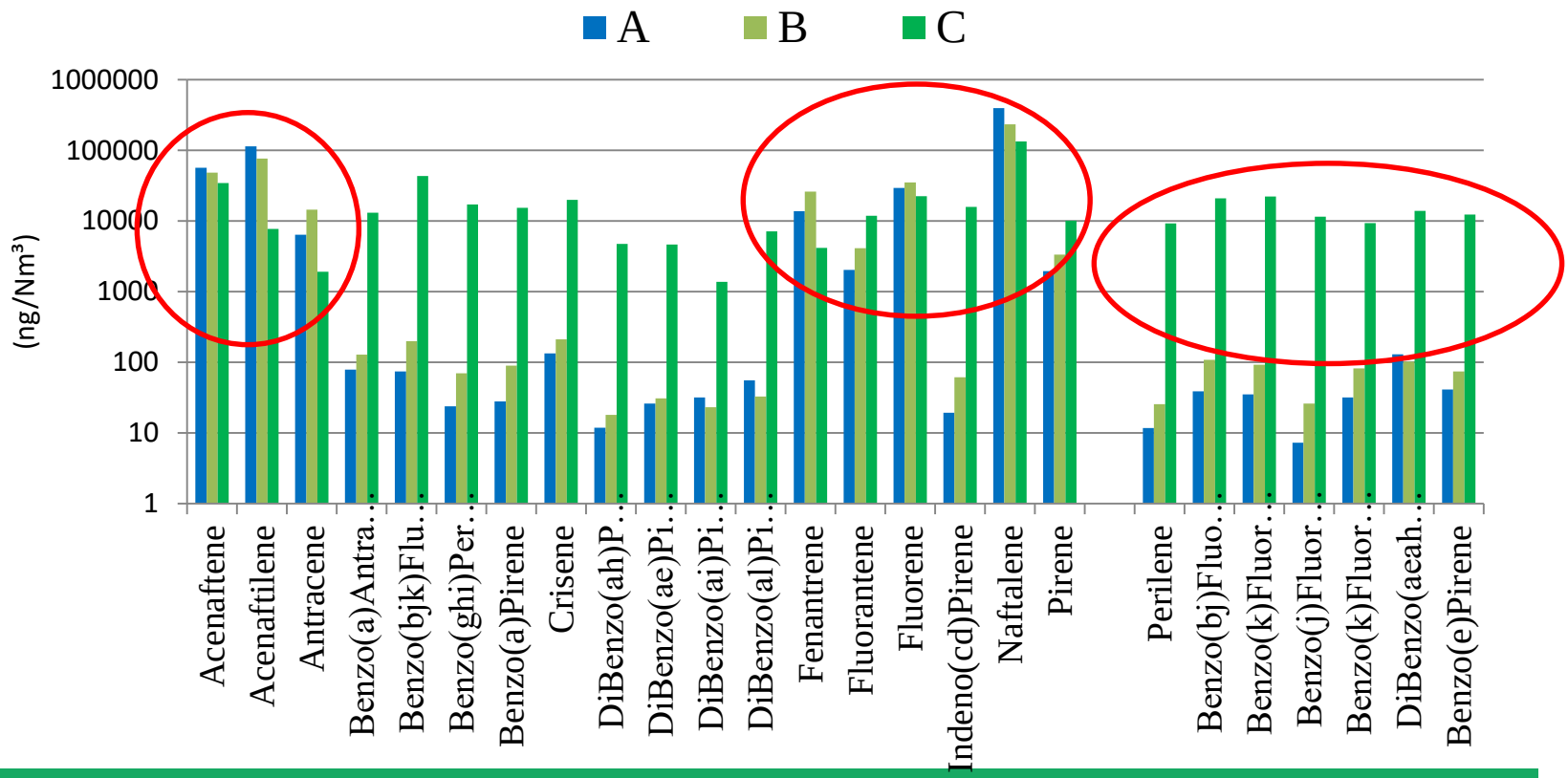
Tar in the producer gas



Tar in the producer gas



Tar in the producer gas



Tar in the producer gas

Suggested limit value for ICE: ≈ 100 mg/Nm³

Technology	A	B	C
Gravimetric tar (mg/Nm³)	650-750	200-300	150-250

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Valorization of Char

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Possible utilization pathways

→ energy production (co-firing in power plants)

→ soil improver

→ adsorbent

→ catalyst support (FT-synthesis)

→ tar cracking applications

Source: Daniele BASSO et al. (2018) Possibilità di valorizzazione dei biochar da gassificazione in applicazioni di tipo industriale. Fachtagung - Die Holzvergasung. 31. Mai 2018, NOI Techpark – Bozen (Italy)

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Adsorption

- Large surface area (200-2000 m^2/g)
- Micro- and meso-pore distribution compatible with the molecular dimensions of the adsorbates
- Surface chemistry that does not inhibit the adsorption mechanism.

Scarce data available on surface area of chars from actual gasification plants

Source: Daniele BASSO et al. (2018) Possibilità di valorizzazione dei biochar da gassificazione in applicazioni di tipo industriale. Fachtagung - Die Holzvergasung. 31. Mai 2018, NOI Techpark – Bozen (Italy)

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Char characteristics

Technology	Ash (%)	C (%)	H (%)	N (%)	S (%)	O (%)	HHV (MJ/kg)
B	5.47	80.23	0.49	0.23	0.28	13.29	26.74
F	4.63	89.33	0.54	0.21	0.28	9.59	30.92
E	13.34	78.97	0.68	0.20	0.31	6.50	25.53
G	25.15	69.05	0.15	0.12	0.28	5.24	22.87
H	16.03	69.49	0.20	0.46	0.33	13.49	24.17
D	19.40	66.96	0.18	0.16	0.63	12.67	18.11

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Carbon contents <70% indicate recirculation or post-treatment of char.

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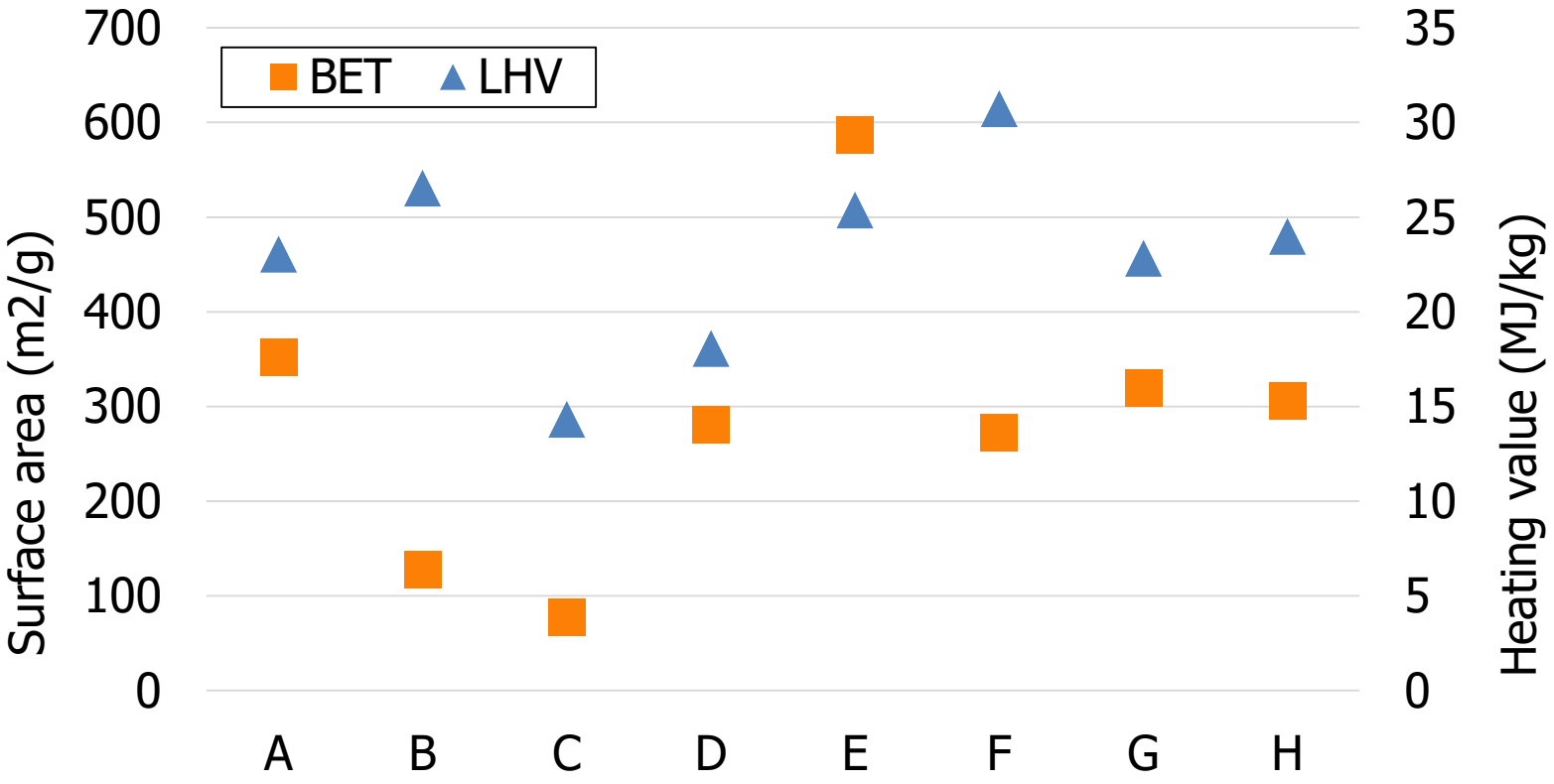
Char surface area and Heating Value



Possible utilization of char

1. Material adsorbent
   - Removal of CO_2, H_2S and tar

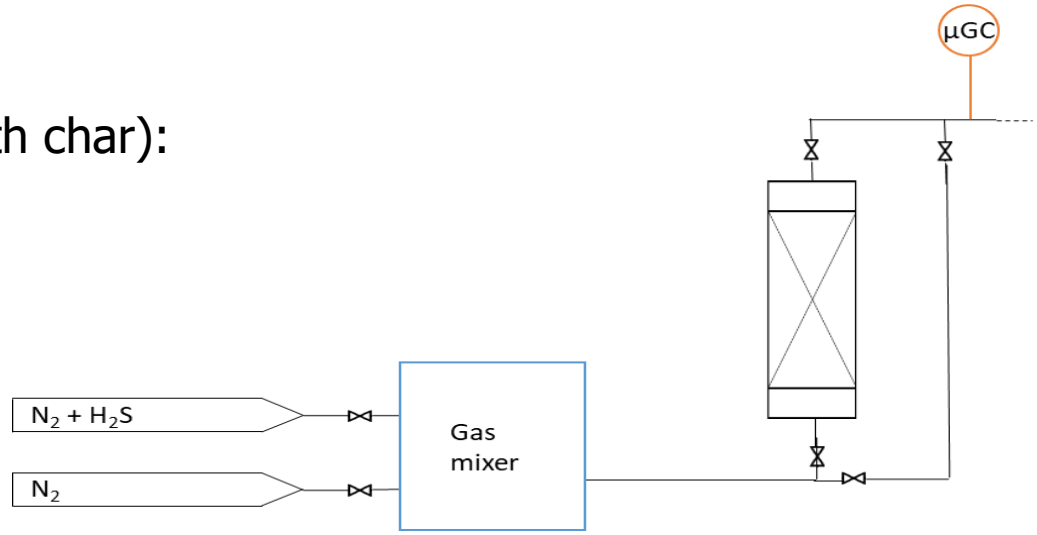
2. Support for catalysts
   - Fischer-Tropsch Synthesis (FTS)
   - Dry Reforming of Methane (DRM)

Source: Daniele BASSO et al. (2018) Possibilità di valorizzazione dei biochar da gassificazione in applicazioni di tipo industriale. Fachtagung - Die Holzvergasung. 31. Mai 2018, NOI Techpark – Bozen (Italy)

ADSORPTION OF H_2S:

Fixed bed quartz reactor (packed with char):

- Input gas: 250 ppm of H_2S in N_2
- Total flow of gas: 100 ml/min
- Height of the char bed: 2.5 cm (150-200 mg)



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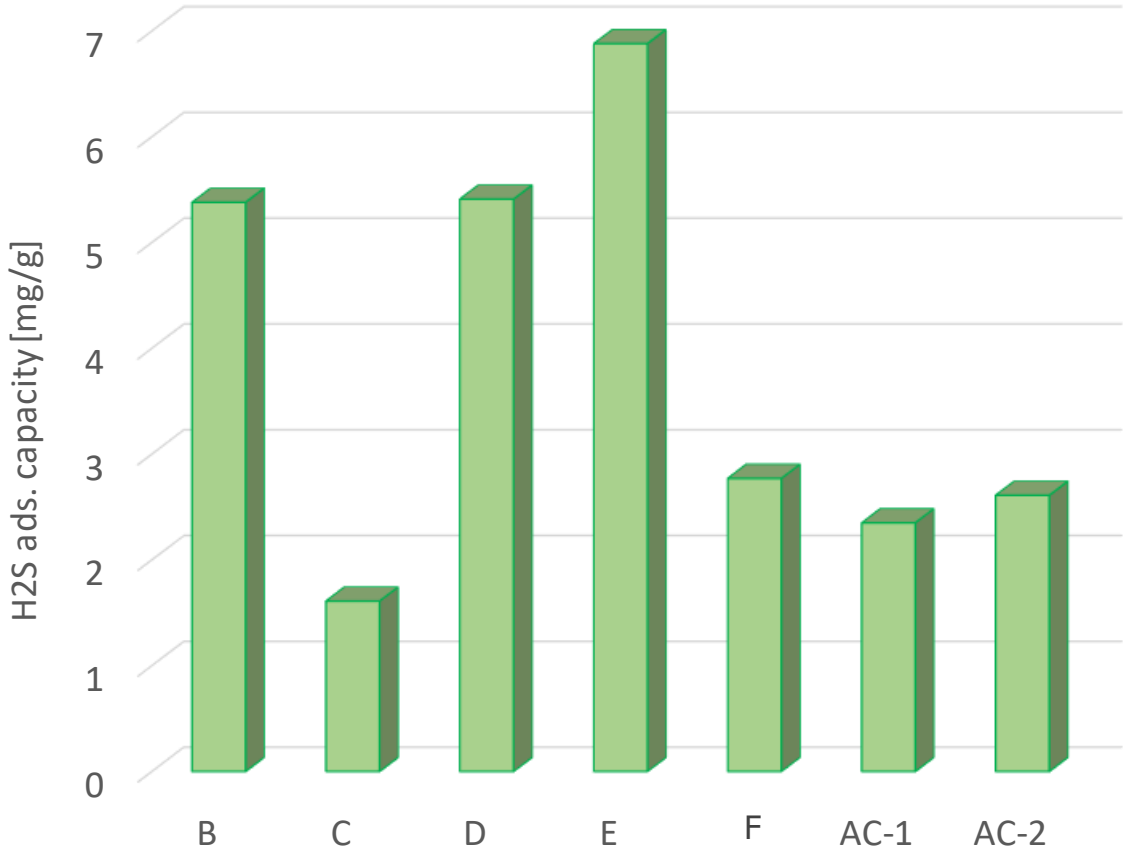

Source: Filippo MARCHELLI, Eleonora CORDIOLI et al. (2018) Adsorption of H2S on Residual Biomass Gasification Char. Conference Proceedings. EUBCE 2018 – 26th European Biomass Conference & Exhibition, 14-17 May, Copenhagen (Denmark)

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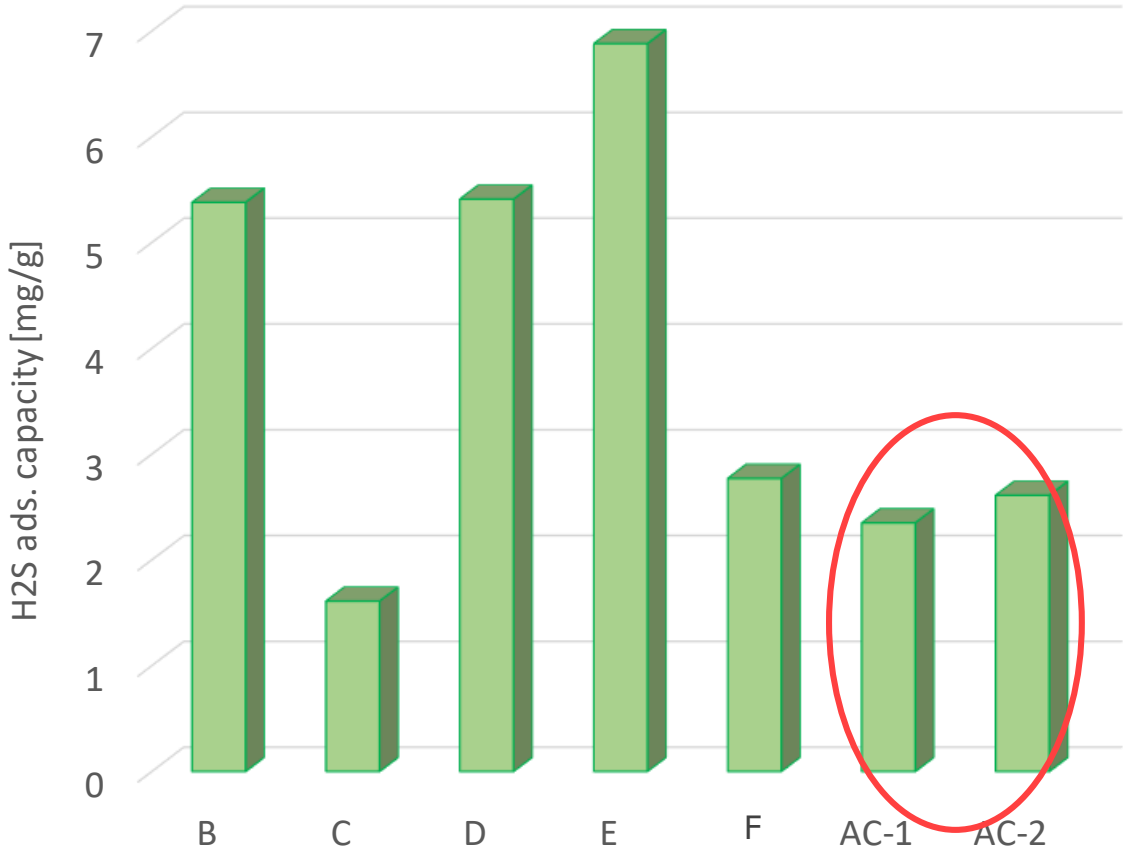

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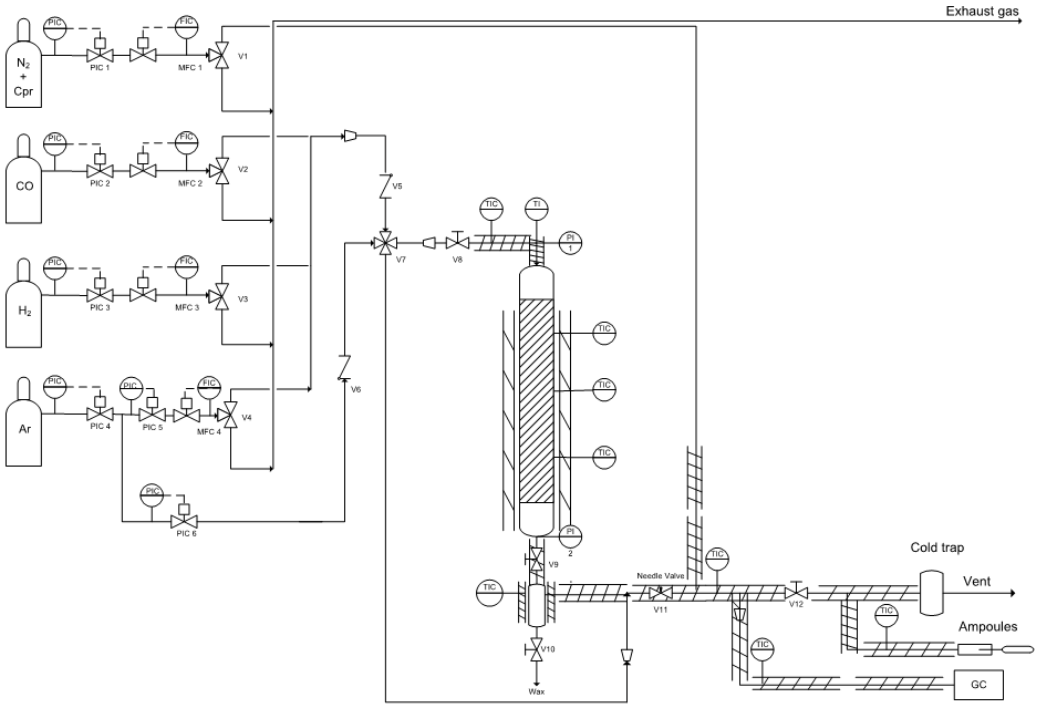
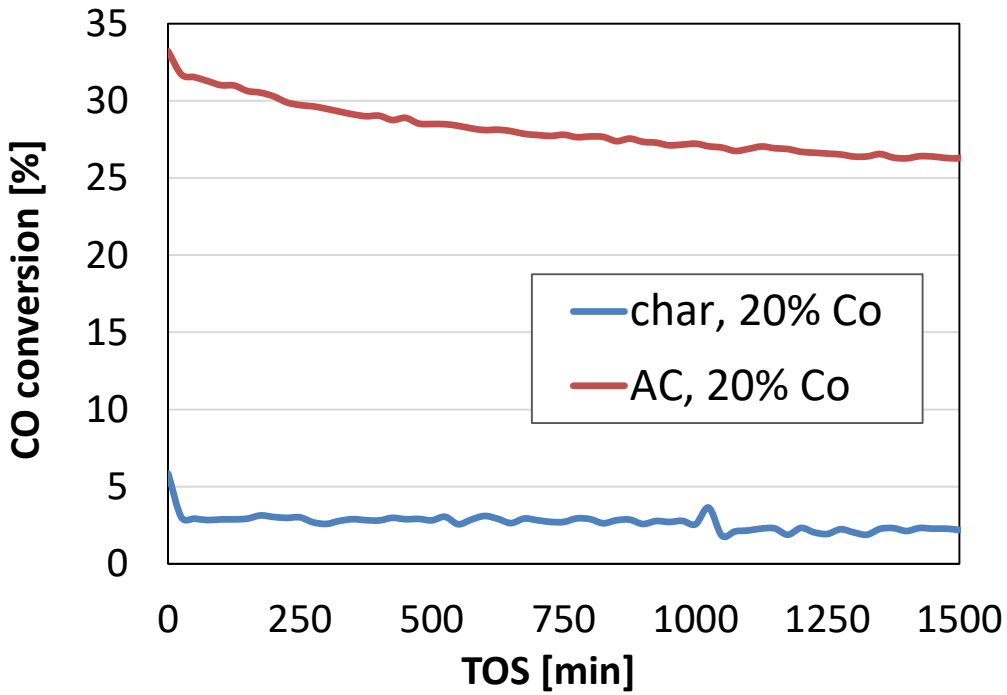
CATALYST SUPPORT (FTS)



- Fixed bed reactor
- H_2 : CO = 2 : 1
- T = 240 °C
- P = 16 bar
- Char = 2 g
- Flow = 50 ml/min

CATALYST SUPPORT (FTS)



	CO conv., %
Biochar, 20% Co	2.6
AC, 20% Co	27.7
Literature	15 – 80
Biochar, 10% Fe	26

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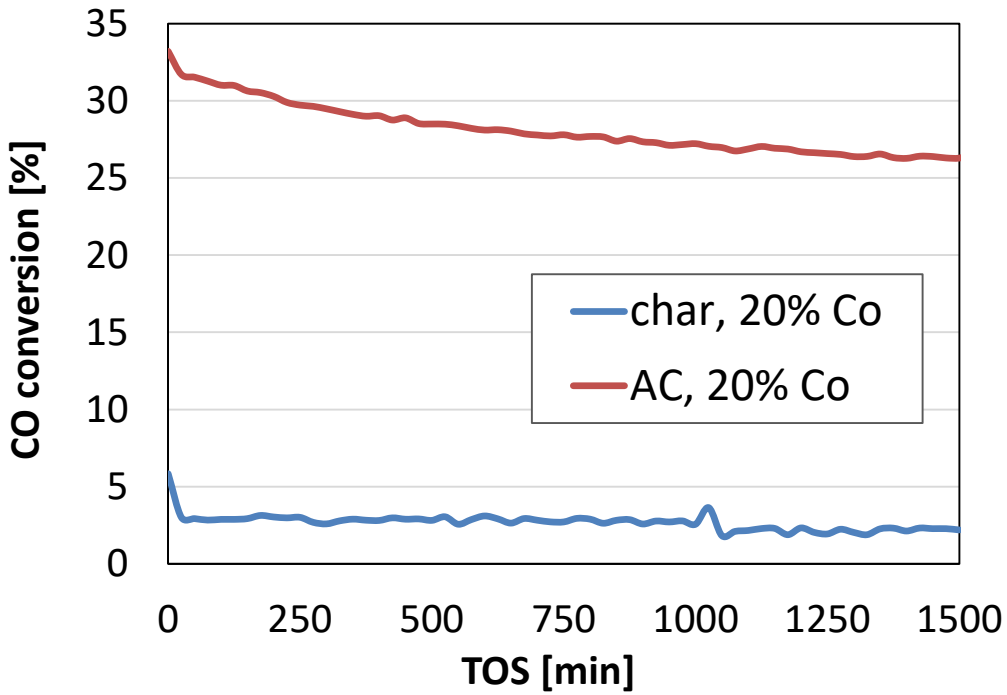

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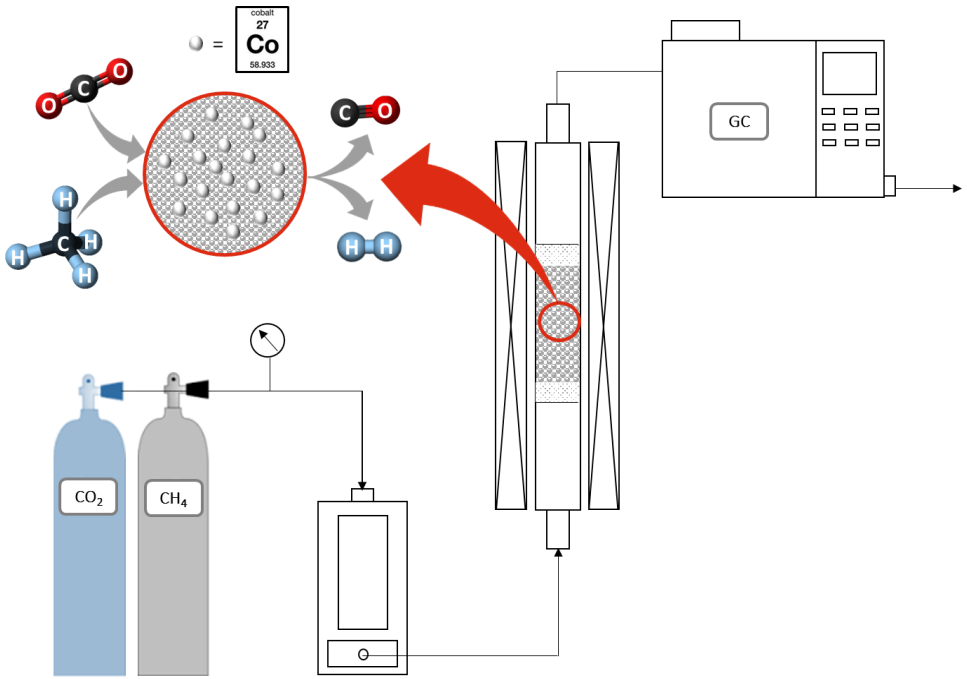
CATALYTIC DRM



$$CO_2 + CH_4 \rightarrow 2CO + 2H_2$$

Parameters:

- $CH_4 : CO_2 = 1 : 1$
- T = 850 °C
- P = 1 bar
- t = 4-5 h

CATALYTIC DRM

%	Biochar	Biochar impregnation			
		10% Co	15% Co	20% Co	HNO_3, 10% Co
CO_2 activity	17.73	22.52	12.06	11.72	29.04
CH_4 activity	12.41	17.14	7.56	5.76	18.97
H_2 yield	1.74	1.33	0.76	0.63	2.87
CO yield	10.95	14.44	7.84	7.12	17.54

Source: Vittoria BENEDETTI et al. (2018) Char Supported Catalysts for Dry Reforming of CH4 - Preliminary Investigations for Valorization of Biomass-Derived Char. Conference Proceedings. EUBCE 2018 – 26th European Biomass Conference & Exhibition, 14-17 May, Copenhagen (Denmark)

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Conclusions

Main results

- Quite **reliable operation** of commercial small scale CHPs (< 200 kW_{el})
  - the plants ensure 7000 h/year of operation
  - similar overall efficiencies for the compared technologies (≈ 70%)
  - high electrical efficiency (20-30 %)
  - Interesting char valorization possibilities

  but…

  - high quality feedstock (agricultural waste are a challenge)
  - **tar** content higher than the limit suggested in the scientific literature (frequent engine **maintenance** required)
  - **char** (for the moment) has to be disposed off and this is a **cost**

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The Path Forward

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The Bioenergy & Biofuels Lab is now operating from our new facilities at the

NOI Technology Park

- Within the next 1-2 years, the scope of the group is the operation of a commercial scale gasification plan at the NOI Technology Park.

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One last thing!

A Special Thank You!

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Ripartizione 40. Diritto allo Studio, Università e Ricerca scientifica

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THANK YOU FOR YOUR ATTENTION!

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