SmartCHP final conference
Cogenerating a renewable future
The role of small-scale bio-CHP in Europe's Energy mix

BLAZE & SO-FREE projects

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University Guglielmo Marconi (USGM)

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The JU receives support from the European Union's Horizon 2020 research and innovation programme
and Italy, Austria, Finland, Germany, Poland, Netherlands, United Kingdom

CHP IN EU-28 (Eurostat)

- 120 GWe (ST 50%, CC 25%, ICE 13%, GT 10%): 362 TWh -> ≈3000 AEh (≈ 11% of electricity demand).
- 300 GW_{th}: 775 TWh -> ≈ 2500 AEh
- space heating ≈ 50% process heating (Germany, Italy, Poland and the Netherlands largest capacity)
- Natural gas ≈ 50%, solid fossil fuels and peat ≈ 20% , oil and oil products 5%, biomass (timber by-products, black liquor, wood, straw, animal waste, OFMSW) attained 20% but there is difficulty in converting different biomass feedstocks in a Reliable and Economic (Efficient and Clean) way
- Zero Energy Buildings (ZEB&ZED) from 31st December 2020 (public buildings from 31st December 2018)

CHP SoA & BLAZE foreseen goals

Below 1 MWe systems mainly applied :

1. Biomass combustor coupled to organic rankine cycle (ORC)
2. Biomass fixed bed gasifier coupled to internal combustion engine (ICE)

BLAZE 100 (100 kWth biomass DBFBG integrated with 50 kWe SOFC) is compared to a 100 kWth biomass combustor coupled to a 15 kWe ORC and a 100 kWth biomass fixed bed gasifier coupled to a 25 kWe ICE

Cost of a gas boiler with burner, flue tubes and accessories is added to the CHP plants cost. To this item, heating civil works, piping, pump, expansion vessel and regulation system have been added.

Buildings heat price: 0.06 €/kWht (AEh: 3000 electrical and 2500 thermal) Industrial heat price: 0.04 €/kWht (AEH: 7500 electrical and thermal).

Biomass price: 60 €/ton (similar to the price of high humidity wood chips for BLAZE) 100 €/ton (similar to the price of low humidity wood chips for ORC and ICE systems).

BLAZE: overall 90% (versus 65%, target SET-PLAN 75%) , electrical 50% (versus 25%, target SET-PLAN >30%) , near-zero gaseous and PM emissions , CAPEX below 4,000 €/kWe (actual 10,000 €/kWe), OPEX of ≈ 0.05 €/kWhe (actual 0.10 €/kWhe), electricity production cost 0.10 €/kWh (actual 0.22 €/kWh, SET-PLAN target of 20% cost reduction by 2020, and 50% by 2030).

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BLAZE OBJECTIVES & SCHEME

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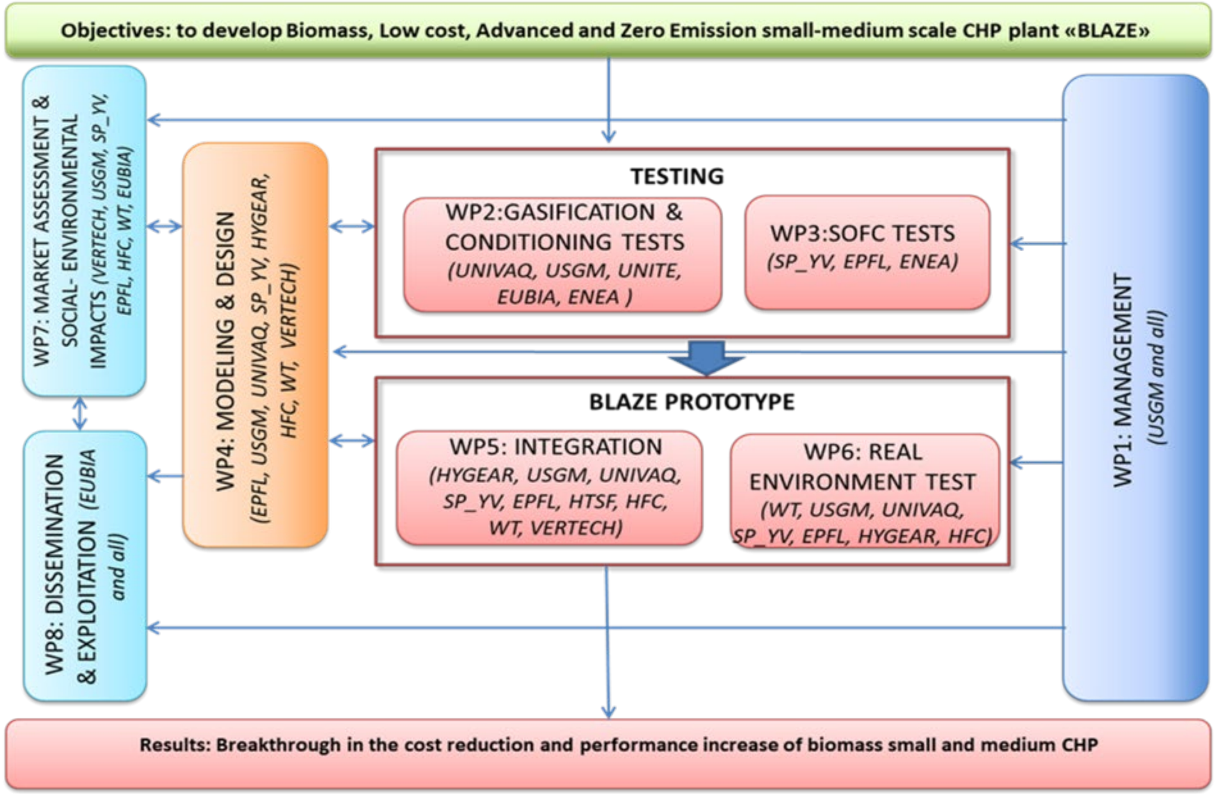

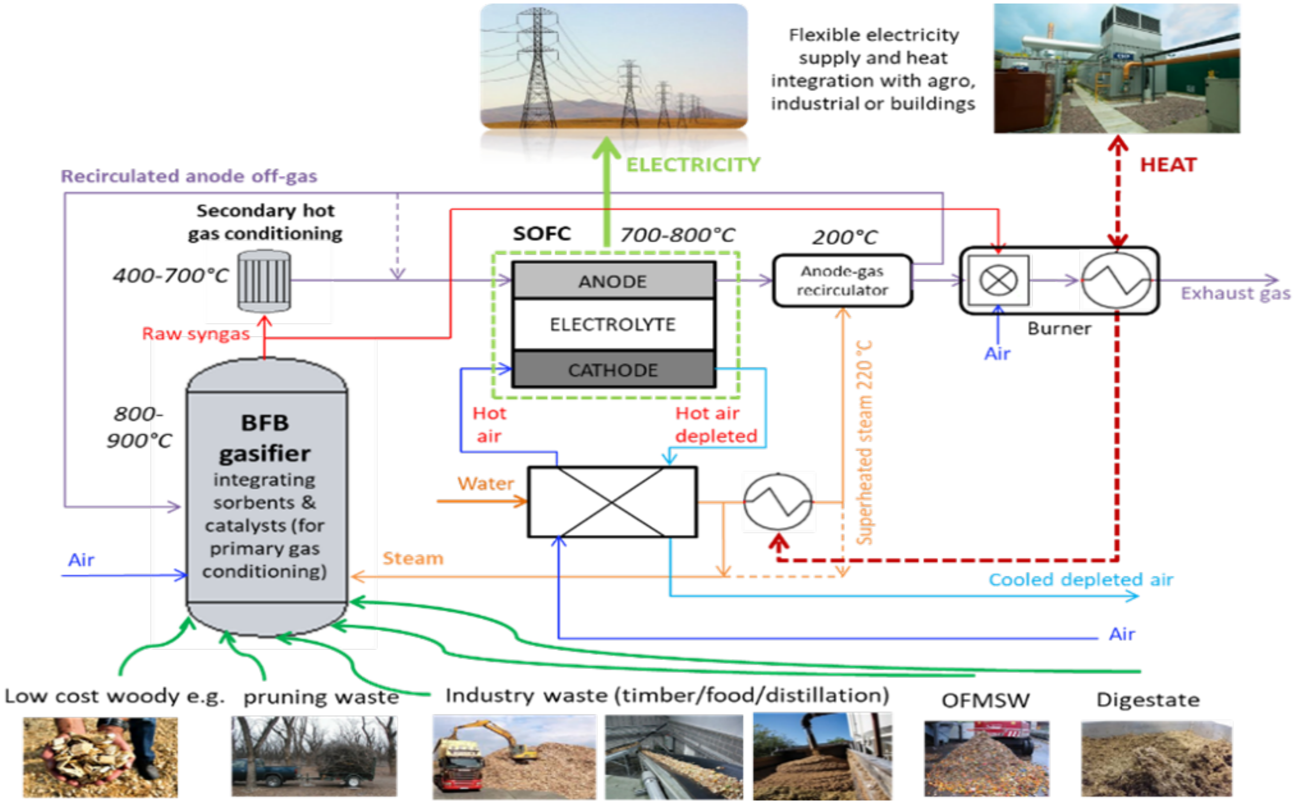

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WP2: BIOMASS ASSESSMENT, GASIFICATION AND CONDITIONING

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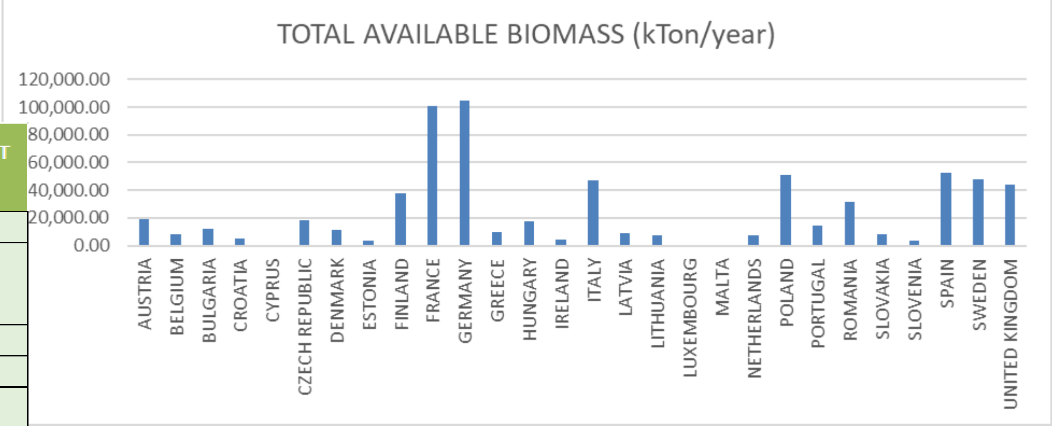

Feedstock	CATEGORY	Humidity (%-wt, as received)	LHV MJ/kg	Ash %wt, dry basis	S %wt, dry basis	Cl %wt, dry basis	Ash melting T (DT) (°C)
Subcoal	Municipal waste	3,20	21,68	15,60	0,10	1,00	1250,00
Olive pomace pitted	Secondary residues of industry utilising agricultural products	36,30	19,79	5,95	0,06	0,08	1290,00
Sawmill waste	Primary residues from forest	11,20	18,89	0,41	<0.01	<0.01	1300,00
Multi-essence wood chips	Waste from wood	24,50	17,88	1,45	0,02	<0,01	1370,00
Olive Prunings	Secondary residues from wood industries	14,90	17,76	1,55	<0.01	<0.01	1380,00
Almond shells	Secondary residues of industry utilising agricultural products	10,00	17,68	1,31	<0.01	<0.01	1000,00
Swarf and sawdust	Secondary residues from wood industries	6,60	17,14	0,43	<0.01	<0.01	>1385
Wood chips	Primary residues from forest	8,90	16,74	0,54	<0.01	<0.01	>1385
Corn cobs	Agricultural residues	9,00	16,62	3,04	0,03	0,44	645,00
Arundo Donax	Agricultural residues	10,10	16,25	3,43	0,11	0,29	1185,00
1- Wheat Straw (pellets 10 mm)	Agricultural residues	7,60	15,98	9,22	0,05	0,12	1065,00
2- Wheat Straw (pellets 6 mm)	Agricultural residues	7,60	15,40	13,29	0,08	0,21	1135,00
Rice husks	Secondary residues of industry utilising agricultural products	5,20	15,19	14,70	0,02	0,03	990,00
Digestate	Digestate from biogas production	71,20	12,69	25,81	0,97	0,10	1245,00
Black Liquor	Secondary residues from wood industries	20,60	11,20	48,28	0,74	0,12	680,00
Municipal solid waste	Municipal waste	23,00	10,22	47,01	0,20	0,40	1220,00

CATEGORY	potential (Kton dry mass/y)
Agricultural residues	264986,32
Primary residues from forest	167641,91
Municipal waste	89763,53
Secondary residues from wood industries	87906,47
Secondary residues of industry utilising agricultural products	29527,11
Waste from wood	26418,22
Digestate from biogas production	12634,60

CATEGORY	cost €/ton
Waste from wood	15
Agricultural residues	28
Primary residues from forest	35
Secondary residues from wood industries	35
Secondary residues of industry utilising agricultural products	55
Municipal waste	60
Digestate from biogas production	661

WP2: BIOMASS ASSESSMENT, GASIFICATION AND CONDITIONING

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Olive pomace

Almond shells

Feedstock	%-wt, dry basis					
	C	H	N	S	Cl	O
OP	51.8	7.1	2.8	0.06	0.08	32.1
AS	48.8	6.1	0.5	< 0.01	< 0.01	43.2

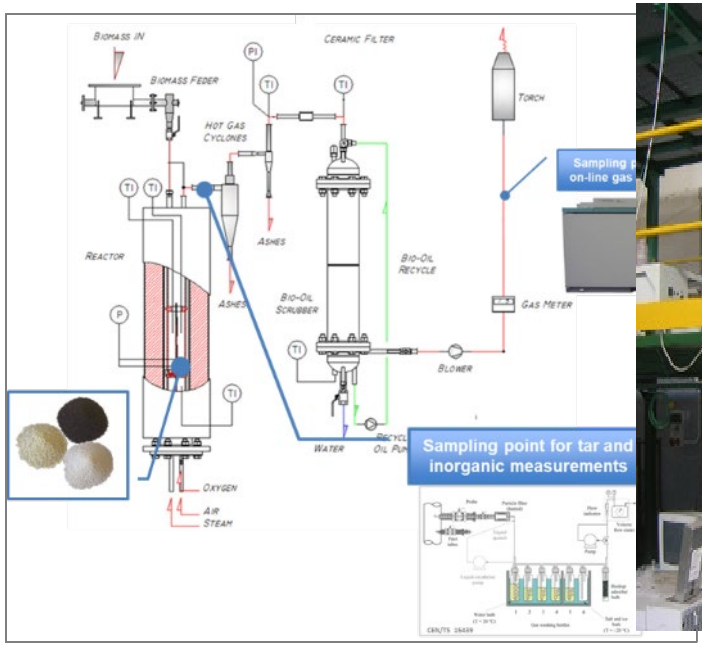
Calcin. Dolomite

Na_2CO_3

K_2CO_3

- Bed material (i.e. olivine, calcined dolomite)
- In-bed sorbents (i.e. calcined dolomite, Na2CO3, K2CO3)

In-bed implementation	Observed Effect	
	Olive Pomace	Almond shells
Primary additives		
Na_2CO_3, K_2CO_3: x 100 stoich.	1- Reduction of HCl content around ≈ 10-100 mg/Nm^3_{dry} vs 510 mg/Nm^3_{dry} (theoretical value).	1- Reduction of HCl content < 20 mg/Nm^3_{dry} vs 55 mg/Nm^3_{dry} (theoretical value)
c-Dolomite (0-45 %-wt)	1- Appreciable effect on gas composition (H2 enrichment, from 25 %-v up to 35 %-v, N2-free); 2- Important effect on Tar content reduction (%-eff: > 45%-wt on Tot GCMS: 25 g/Nm^3_{dry} vs 13.7 g/Nm^3_{dry}; Benzene, Toluene, Naphthalene ≈ 1000s mg/Nm^3_{dry}); 3- H_2S content reduced to tens/few mg/Nm^3_{dry} (vs 320 mg/Nm^3_{dry} (theoretical value);	1- No appreciable effect on gas composition (H2 content ~ 35 %-v, N2-free); 2- Important effect on Tar content reduction (%-eff: > 50%-wt on Tot GCMS: 28 g/Nm^3_{dry} vs 10 g/Nm^3_{dry}; Benzene, Toluene, Naphthalene ≈ 1000s mg/Nm^3_{dry}) 3- H_2S content reduced to tens/few mg/Nm^3_{dry} vs 27 mg/Nm^3_{dry} (theoretical value);
Steam/Biomass (OLV)		
0.5 vs 1.0	1- H_2 enrichment (H_2: 25 → 35 %-v, N2-free basis); 2- limited reduction on light hydroc. content (i.e. $CH_4 + C_2H_x$); 3- lower effect on the reduction of tar content 25 g/Nm^3_{dry} (~ 30% based on Tot GCMS);	1- H_2 enrichment (H_2: 35 → 45 %, N2-free basis); 2- No effect evidence on light hydroc. content (i.e. $CH_4 + C_2H_x$); 3- lower effect on the reduction of tar content 28 g/Nm^3_{dry} vs 19 g/Nm^3_{dry} (~ 30% based on Tot GCMS);
Equivalence Ratio		
0.25 vs 0.30	1- Minimal effect on gas composition (CO2 %-v increase); 2- Limited effect in the tar content (~ 15-20%-wt on Tot GCMS);	1- Minimal effect on gas composition (CO2 %-v increase); 2- Limited effect in the tar content (~ 15%-wt on Tot GCMS);



WP2: BIOMASS ASSESSMENT, GASIFICATION AND CONDITIONING

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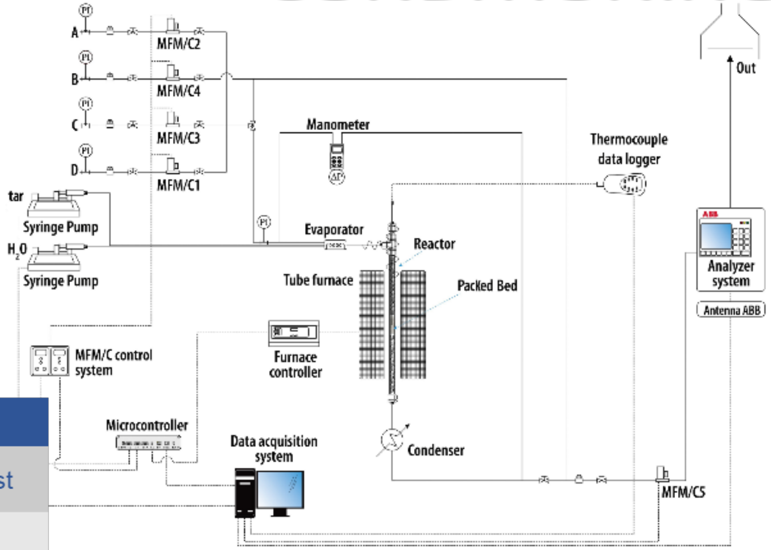
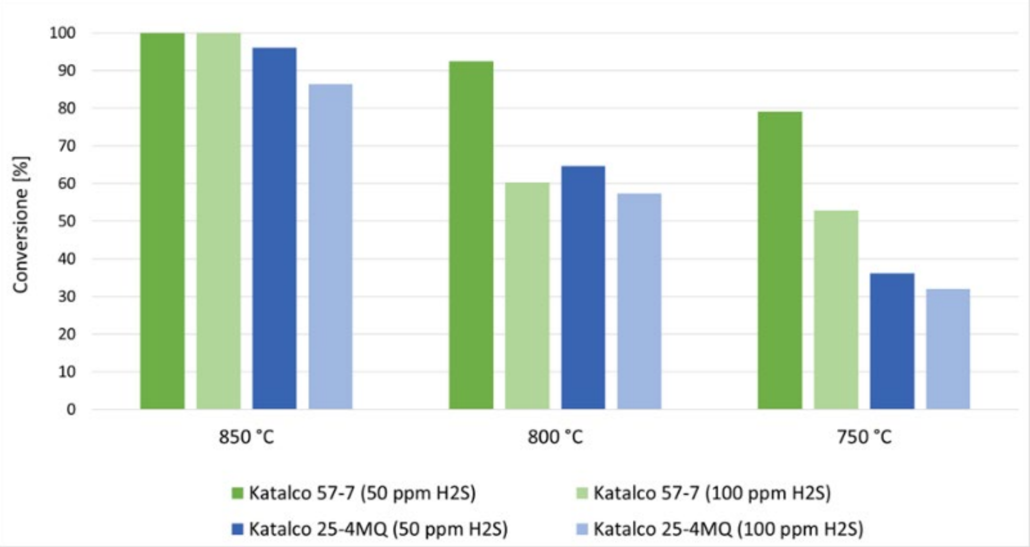
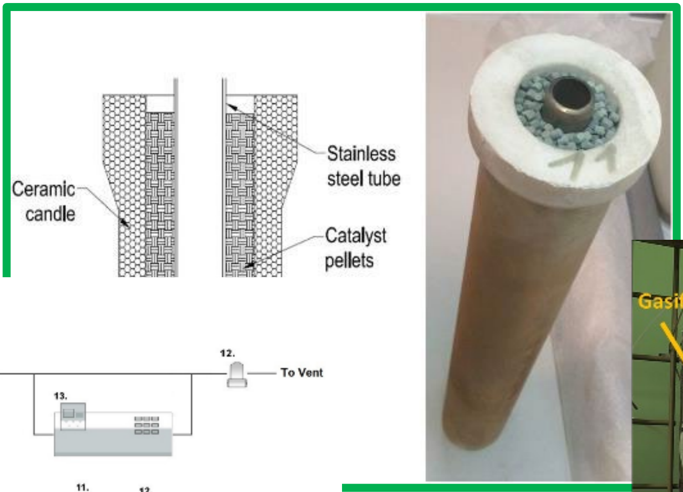
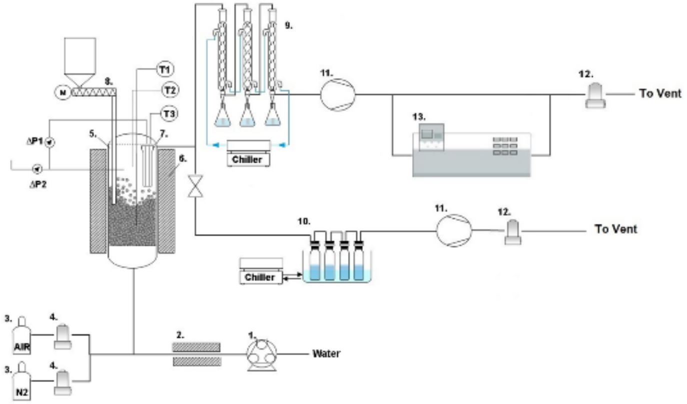
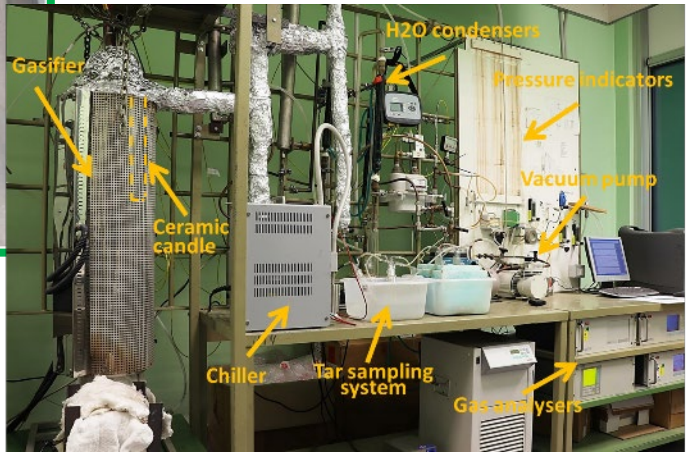




Test	#8	#10	#11
Ceramic candle	Partially filled catalyst B		2x Catalyst
Bed material	Olivine	Olivine + dolomite	
Avg Temperature (°C)	848	844	844
Steam/Biomass	0.52	0.50	0.58
GHSV (h^{-1})	4492	4227	2324
Gas yield (Nm^3 dryN_2free/kg_{bio})	**1.84**	**1.87**	**1.89**
H_2O conversion (%)	56.24	54.84	58.24
H_2 (%vol dryN_2free)	**55.69**	**55.06**	**53.31**
CO (%vol dryN_2free)	**31.59**	**31.39**	**34.73**
CO_2 (%vol dryN_2free)	**11.05**	**12.12**	**11.34**
CH_4 (%vol dryN_2free)	**1.67**	**1.44**	**0.61**
LHV (MJ/Nm^3)	9.04	8.85	8.75
H_2 (Nl/min)	10.10	10.17	10.24
Toluene/1-ring (mg/Nm^3 dryN_2free)	73/46	N.D./389	N.D./208
Naphthalene/2-ring (mg/Nm^3 dryN_2free)	162	85	N.D.
Total Tar (w/o benz) (mg/Nm^3 dryN_2free)	**342**	**474**	**208**







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WP2: BIOMASS ASSESSMENT, GASIFICATION AND CONDITIONING

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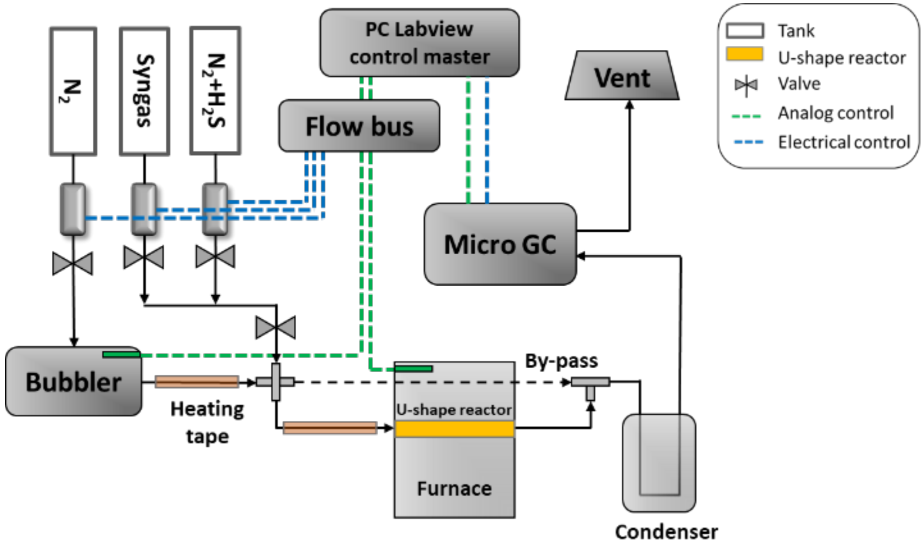
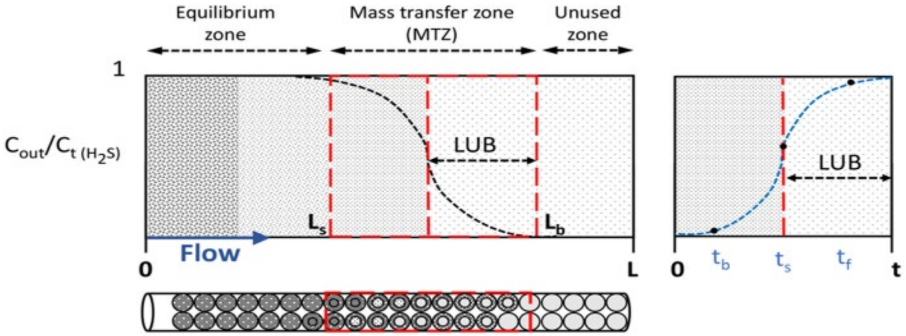
Experimental Conditions	I	II
Gas flow	Syngas*	
Sorbent (g)	0.5–0.25	
T (°C)	450–600	
P (bar)	0.95–1.05	
GHSV (10^3 h^{-1})	25–50	
C_{H_2S} (ppmv)	400	260
BL (cm)	0.8–1.5	
Bed L/D index	1–1.9	
Particle size (mm)	1.5–3.0	
Total flow (NmL min^{-1})	305 ± 1	

Paper published in

Energies journal : E. Ciro, A. Dell'Era, A. Hatunoglu, L. Del Zotto, E. Bocci

Kinetic and Thermodynamic Study of the Wet Desulfurization Reaction of ZnO Sorbents at High Temperatures





- ZnO sorbents showed the best performances of absorption capacity of the at 550 °C, achieving a sorption capacity of 5.4 g per 100 g of sorbent and a breakthrough time of 2.7 h.
- These materials also have been shown acceptable results up to 600 °C.
- A water-gas shift (WGS) and a catalytic reactions was observed on the ZnO performance.
- From thermodynamic analysis, the endothermic features for the deactivation reaction was observed and thermodynamic calculations for enthalpy, entropy, activation energy and diffusion coefficient were calculated.
- The modelling of the bed fixed reactor and subsequent estimations of bed reactor were carried out to sizing the dimensions of a fixed bed reactor.

WP3: SOLID OXIDE FUEL CELLS (SOFC) TESTS

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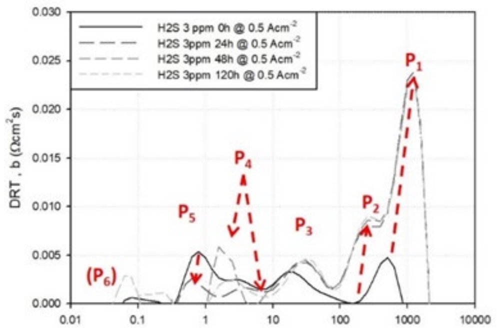
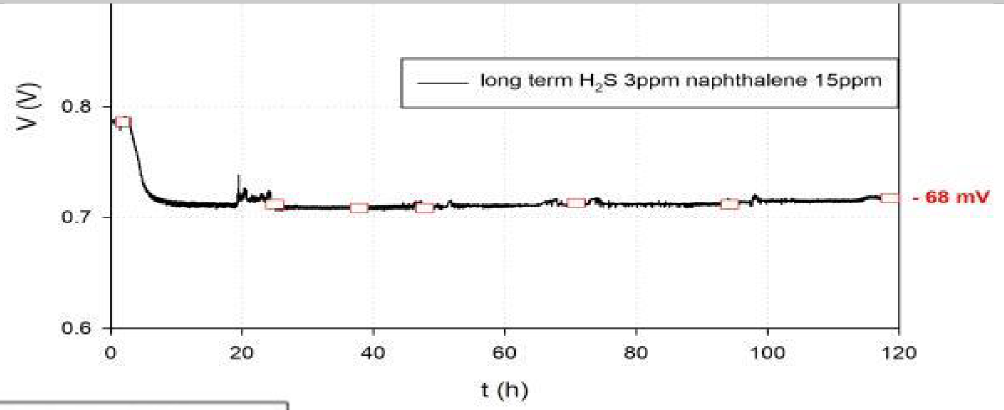
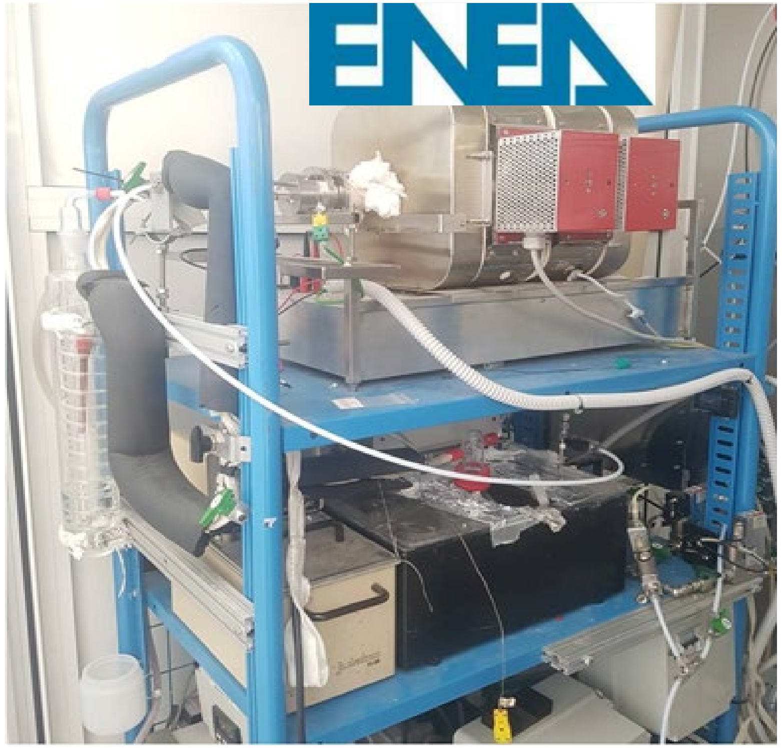
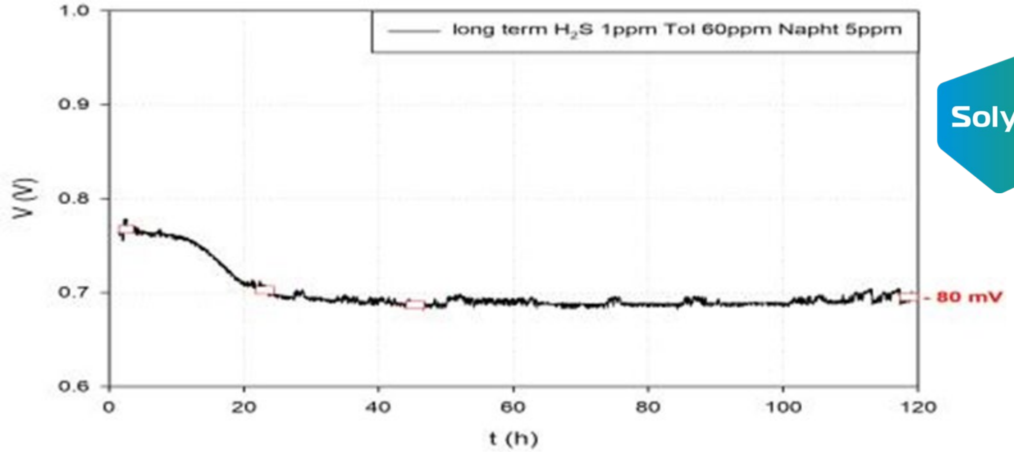
Contaminant thresholds	H_2S		1-ring tar Toluene		2-ring tar Napthalene	
	Low	High	Low	High	Low	High
ppm(v)	1	3	60	180	5	15
mg/Nm3 (dry)	-	-	250	750	25	85









SolydEra

- Several tests were performed to analyse single and multi-contaminant impact on syngas-fed SOFC
- The multi-contaminant tests generally confirm the results obtained from the single-contaminant (H2S mainly affecting charge transfer; tars affecting R0 and diffusion but also charge transfer)
- R0 mobility was observed for the tar-laden syngas compositions, possibly due to C-dep which induces a dynamic effect on R0
- Tar presence (in smaller concentrations and with cells with higher initial voltage) seem to mitigate the H2S poisoning (possibly due to a concomitant activity of Ni for tar reforming). This is however not observed for all samples, being related to H2S/Tar ratio and Tar typology

WP3: SOLID OXIDE FUEL CELLS (SOFC) TESTS

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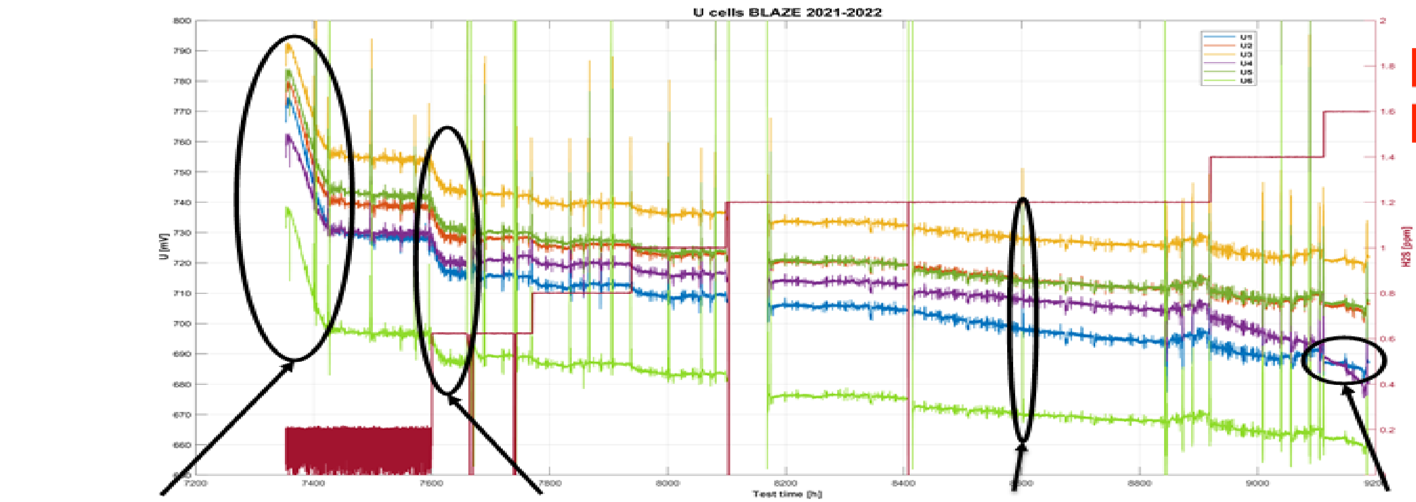
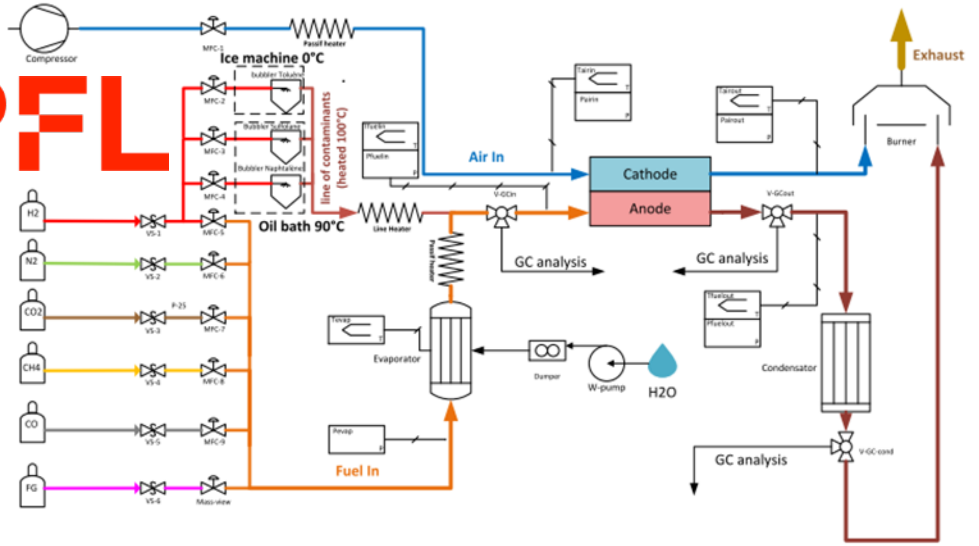


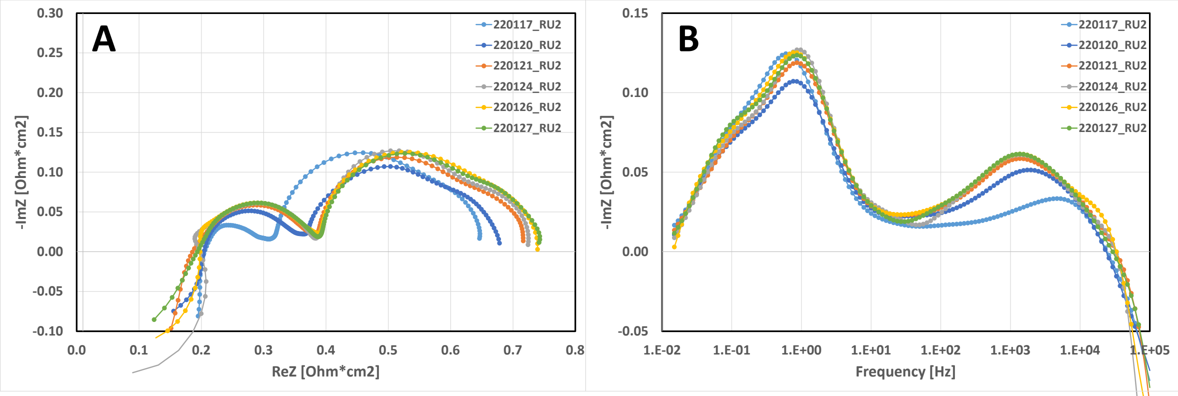
Initial drop, under 2ppm H_2S

Second drop, under 0.625ppm H_2S

EIS measurement

Cell failure





- 3 short stacks tested 22’500h in total
- 3700h of impurities exposure Sulfur (DMS): 0.2 → 4ppm Light tar (Toluene): 20 → 400ppm Halogen (HCl): 5 → 50ppm
- EIS under nominal polarization DRT analysis
- stable operation in clean syngas (9000h) -3.4 μV/h (-0.4%/kh)
- S deactivates Ni starting from 0.2ppm (30ppb) Affects CT and RWGS 9% voltage drop at 4ppm Co-feed of toluene mitigates S-contamination Partial recovery (logarithmic) 50% in 33h 80% in 250h
- HCl leads to irreversible degradation (-60 μV/h) for 5-50ppm

WP4: MODELING AND PILOT DESIGN

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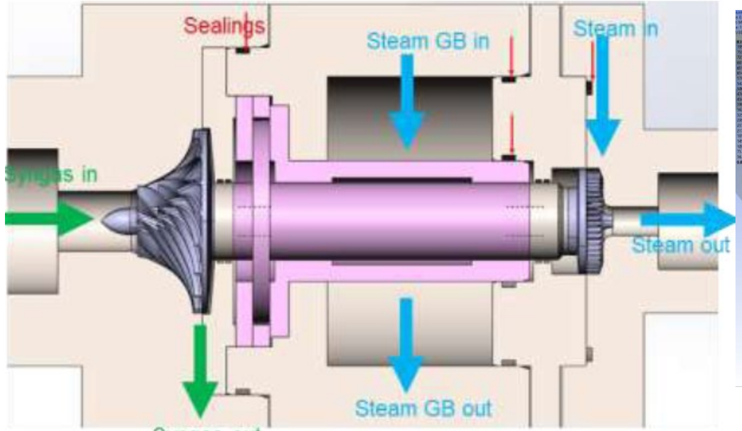
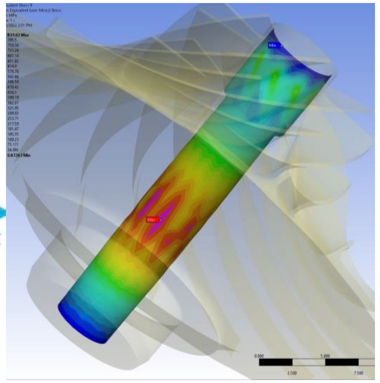
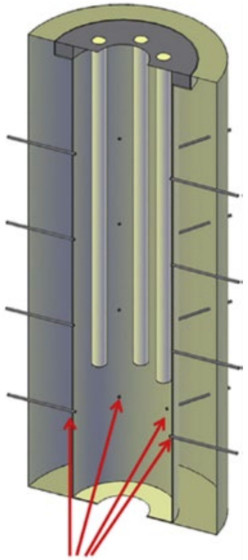
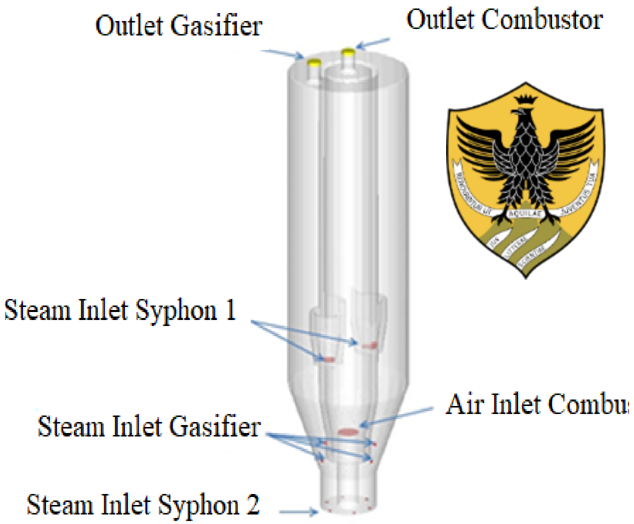
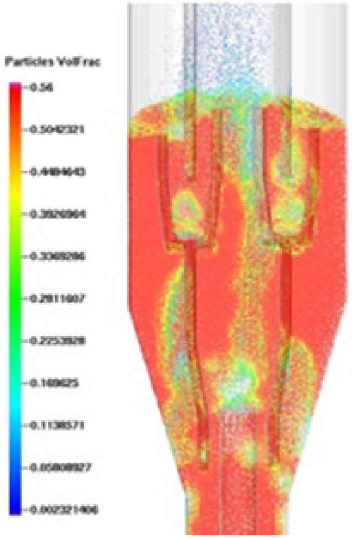






Peripheral Oxygen Injections





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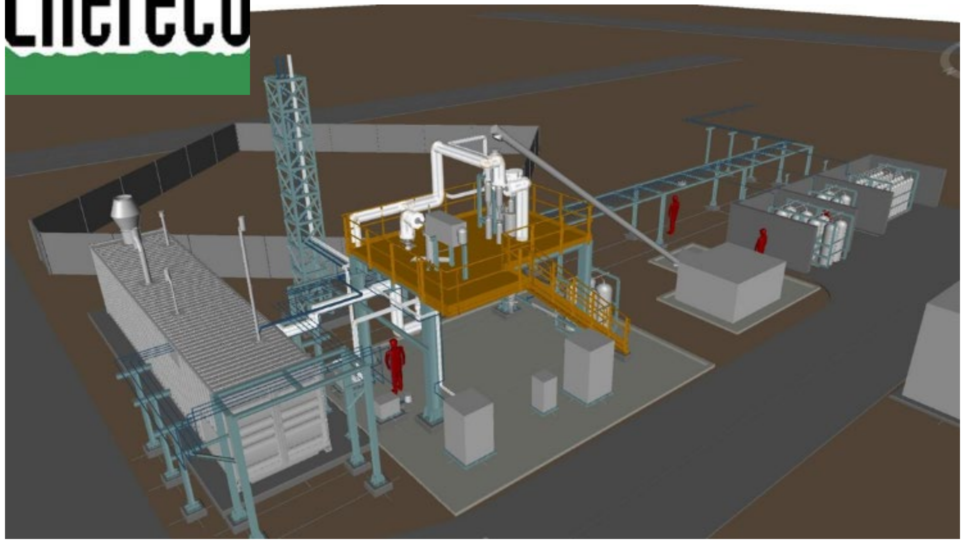

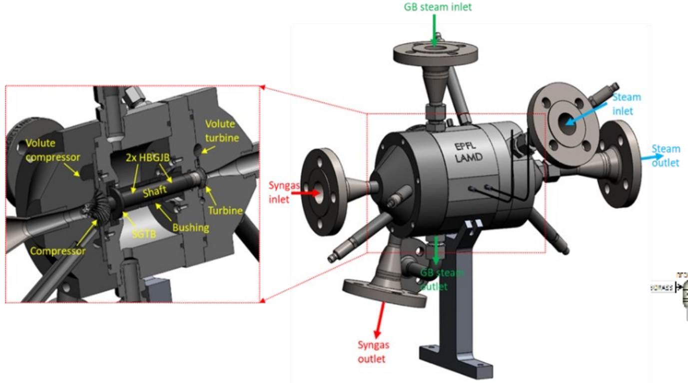

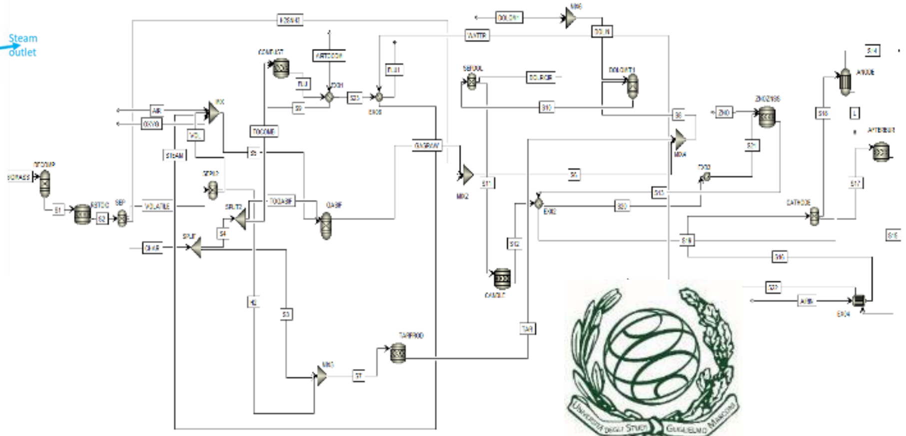

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WP4: MODELING AND PILOT DESIGN

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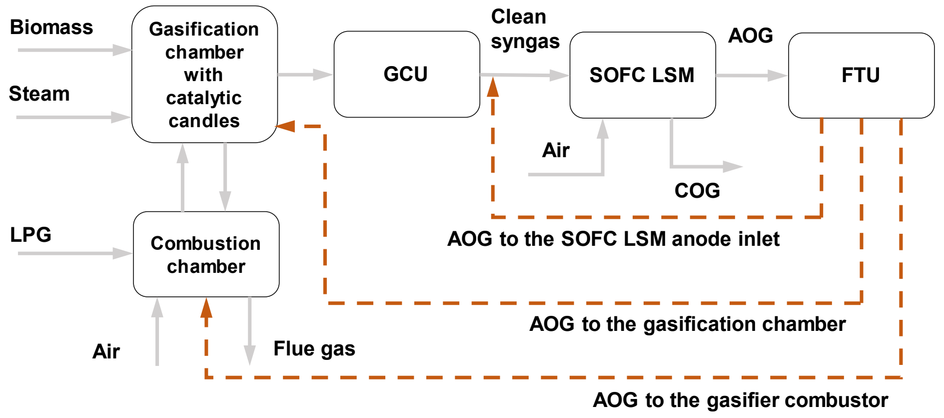
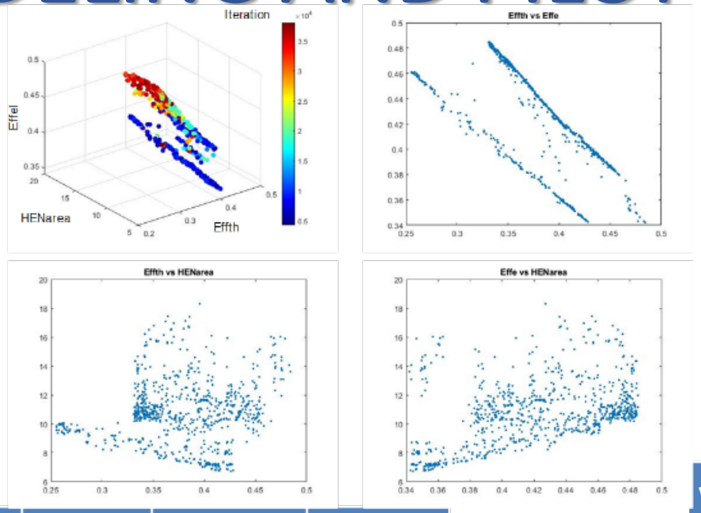




Name	Description
Case 1	Base case; BLAZE plant without AOG use.
Case 2	AOG recirculation to the gasification chamber.
Case 3	AOG recirculation to the SOFC LSM anode inlet.
Case 4	AOG recirculation to the gasifier combustor without FTU.
Case 5	AOG recirculation to the gasifier combustor with FTU.
Case 6	AOG used in a GT.

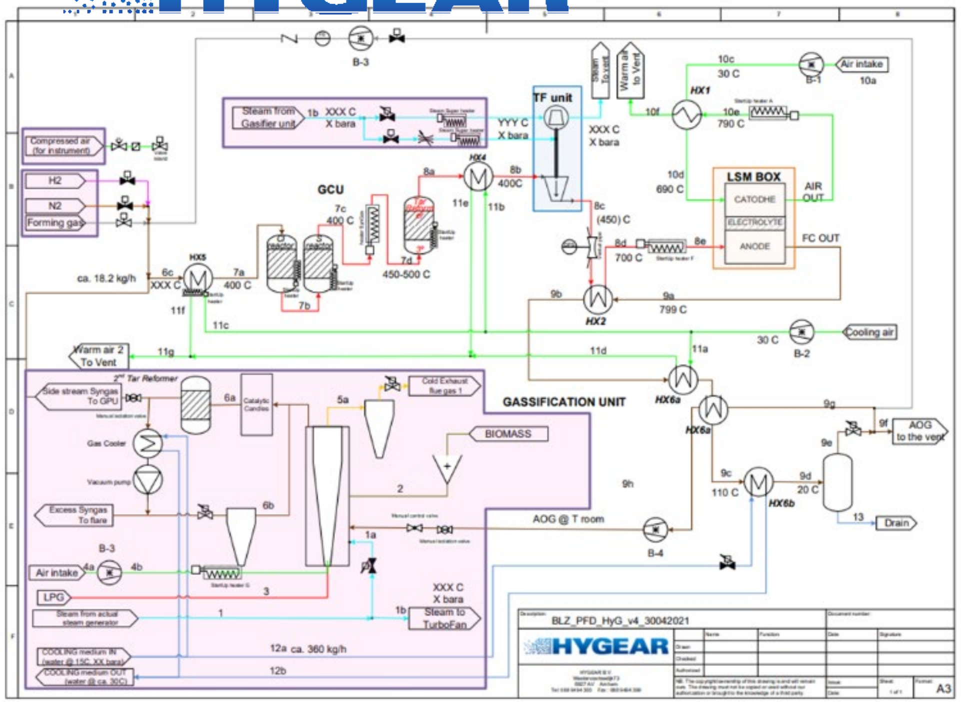
	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Gross power SOFC (kW)	25	25	25	25	25	25
Gross power turbine (kW)						8.973
Air compressor (gasifier) (kW)	0.291	0.363	0.316	0.327	0.226	0.292
Air compressor (SOFC) (kW)	0.663	0.746	0.611	0.663	0.663	0.663
AOG compressor (kW)	0	0.098	0.123	0.129	0	1.361[1]
Pumps (kW)[2]	6.00E-05	3.24E-03	6.12E-04	6.00E-05	6.00E-05	1.00E-03
Net power (kW)	24.046	23.788	23.947	23.877	24.106	31.656
CGE	0.73	0.75	0.68	0.68	0.75	0.73
SOFC efficiency	0.50	0.47	0.50	0.50	0.50	0.50
Eff_{el}	0.34	0.37	0.39	0.38	0.44	0.45
Cooling water produced (kg/h)	189.68	213.61	174.52	189.68	189.68	189.68
Cooling water produced (kW)	9.51	10.72	8.75	9.51	9.51	9.51
Cold utility (kW)	6.23	8.06	18.75	18.35	4.72	17.41
Eff_{th}	0.22	0.28	0.45	0.45	0.25	0.38
Total efficiency (Eff_{el} + Eff_{th})	0.57	0.65	0.83	0.83	0.69	0.84
FTU						
ΔP (mbar)		250	60		270	
Steam needed (kg/h)		19.85	3.75		10.19/16.50	
Inlet fan T (°C)		200	200		20/200	
Total power needed from turbine (kW)		0.315	0.060		0.162/0.209	

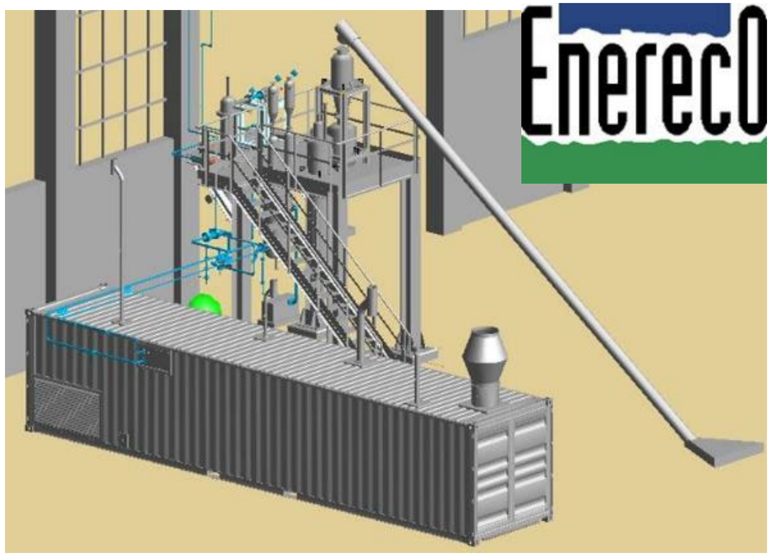
Variable / criterion	Distance utopian	Eff_{el}	Eff_{th}	HEN area
FU	0.780	0.800	0.715	0.746
STB	0.333	0.330	0.967	0.330
Tgasif (°C)	782.475	751.173	837.502	839.452
TinSOFC (°C)	690.000	690.391	697.473	690.022
TC2 (°C)	28.705	25.873	26.207	186.869
TH1 (°C)	550.054	745.798	132.408	101.537
TH6S (°C)	321.274	398.596	356.899	221.770
TC1 (°C)	279.412	200.000	236.054	428.615
TH2 (°C)	642.955	550.967	634.334	626.737
TH3 (°C)	508.714	756.581	245.333	263.241
Eff_{el}	0.4547	0.4873	0.3443	0.3493
Eff_{th}*	0.3558	0.3052	0.4736	0.4093
Eff_{tot}	0.8105	0.7925	0.8179	0.7587
Area (m^2)	9.980	11.543	13.614	6.727
Steam generated (kg/h)	14.606	10.027	29.977	26.360
Cooling water produced (kg/h)	155.826	153.954	190.537	161.233
Steam to gasifier (kg/h)	3.261	3.158	10.696	3.371
LPG (kg/h)	0.173	0.000	0.902	1.196
Recirculation compressor (kW) @ TC2	0.122	0.115	0.153	0.360
Steam needed in the FTU (kg/h) @ TC2	9.63	9.13	12.10	28.05
Steam needed in the FTU (kg/h) @ 200 °C	15.11	14.35	19.05	[1]

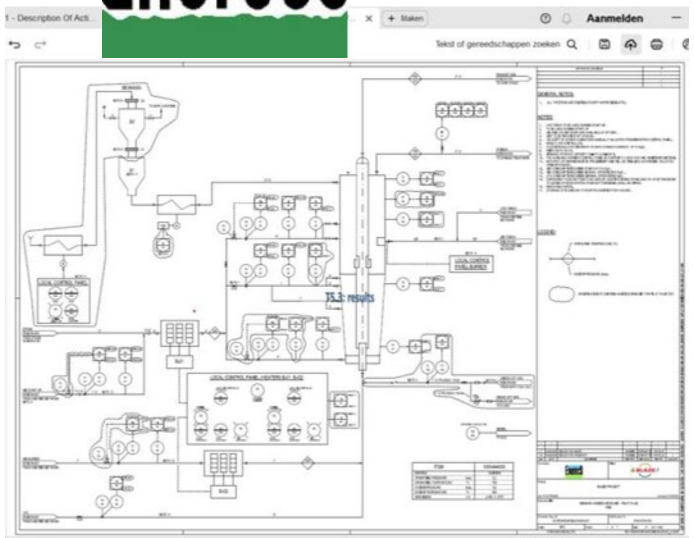
WP5 INTEGRATION

Horizon 2020
European Union Funding
for Research & Innovation

Overall CHP pilot system: Gasification unit + CHP sub-units

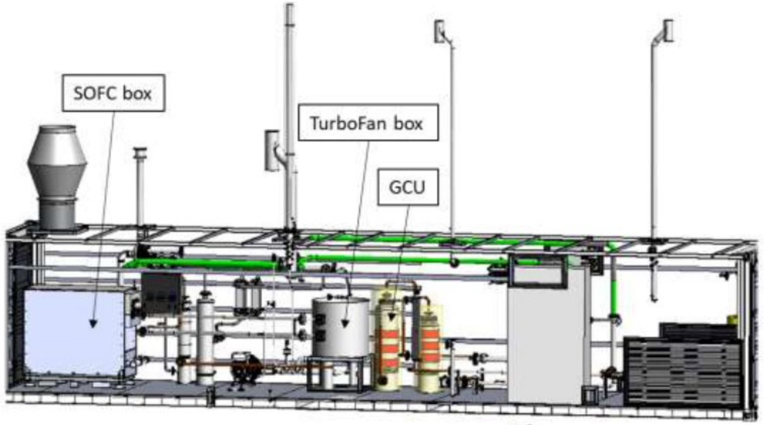


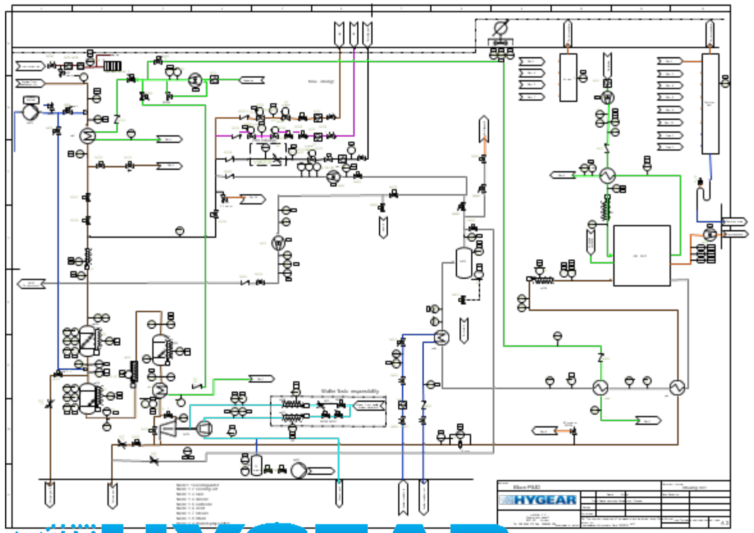




- Doubla Bubbling Gasifier/Combustor
- Gas cleaning unit (GCU)
- Turbo-fan/steam driven compressor (TF)
- 25 kWe Large Stack Module (LSM)
- Anode off gas post-processing section

BoP, PID, HAZID, HAZOP done!

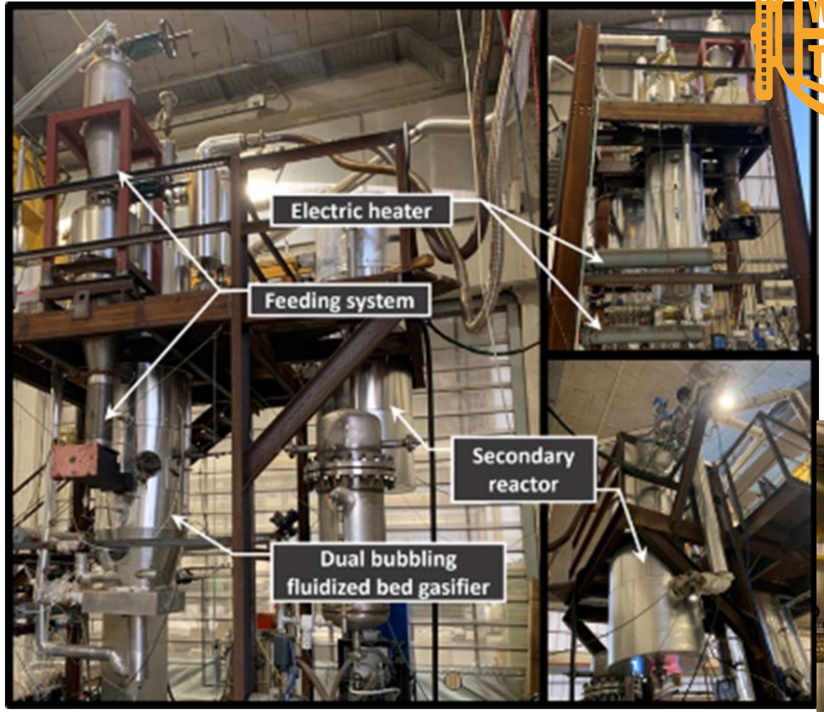


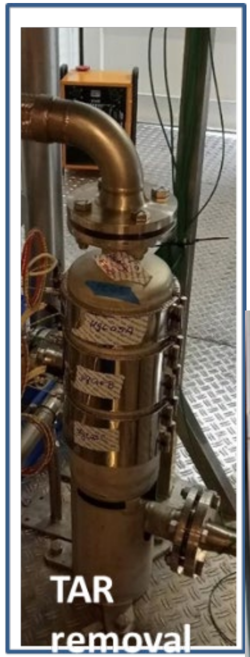


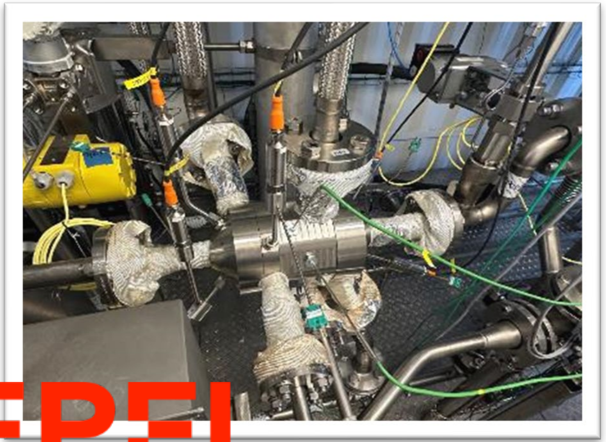
http://www.blazeproject.eu/

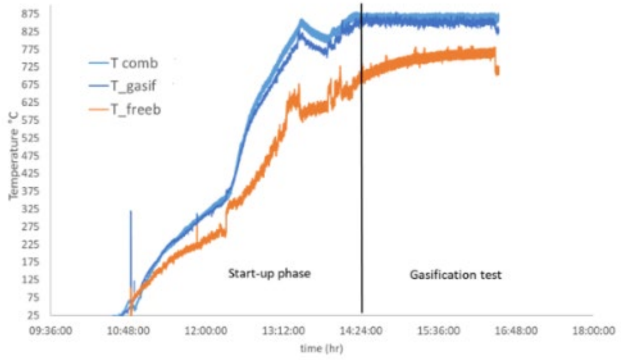
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 815284

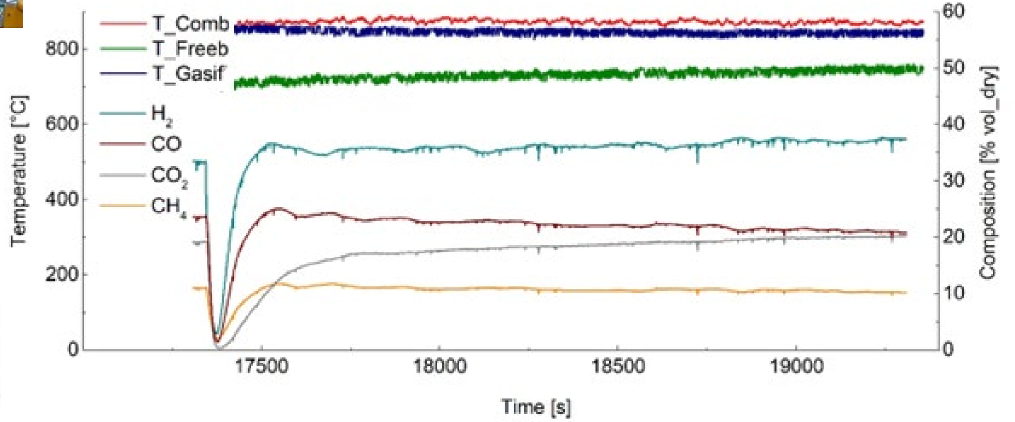
WP6 REAL ENVIRONMENT TEST





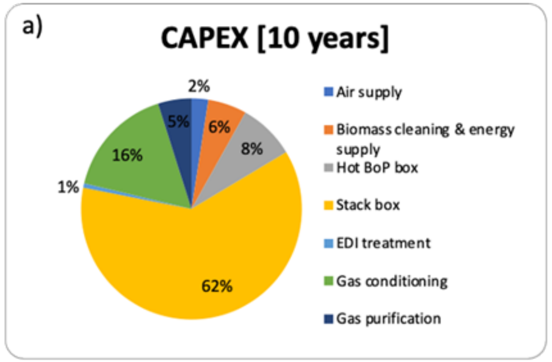


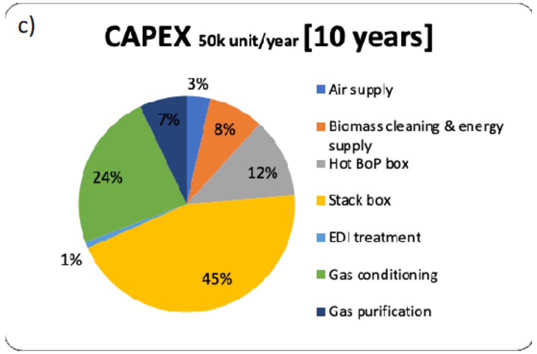


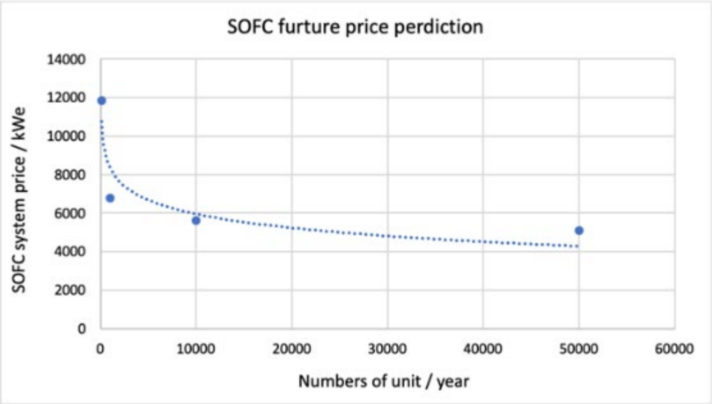


WP7: TECHNO-ECONOMIC, SOCIAL AND ENVIRONMENTAL ASSESSMENT

Horizon 2020 European Union Funding for Research & Innovation







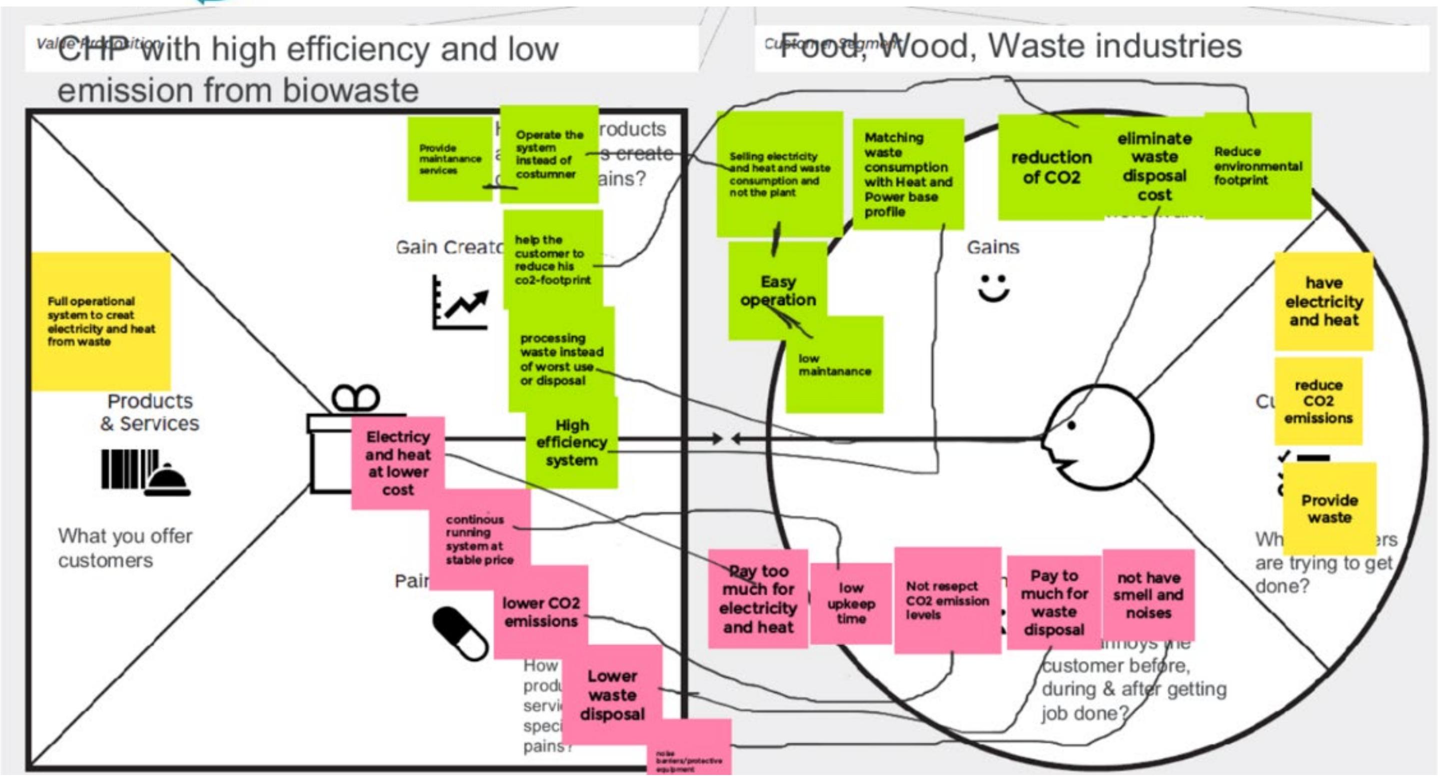
EPFL

	Unit	Conventional electricity plant	Rough SOFC system	Detailed SOFC System	SOFC in future based on database	Ideal case for BLAZE
Climate change impact	kg CO2 eq	0.77	0.32738	0.33863	0.32901	0.19498
Ecosystem quality	PDF.m2.yr	0.14441	-2.41656	-2.41444	-2.41358	-2.45441
Human health	DALY	1.96E-07	2.57E-07	2.77E-07	2.43E-07	3.49E-07
Water scarcity	m3 world-eq	0.04115	0.01948	-0.00355	0.02266	0.01825
Ozone layer depletion	kg CFC-11 eq	1.83E-07	5.76E-08	6.01E-08	5.81E-08	9.33E-09

	25 kW	50 kW	100 kW	500 kW	1 MW	5 MW	1 MW with 10 years stack lifetime	1 MW with 10 years stack lifetime+future price+2 years maintanence
No allocation - Do not consider co-generation feature								
CAPEX / 1 kWh electricity	0.390736	0.270921	0.249180	0.216878	0.208223	0.195363	0.104556	0.104556
OPEX / 1 kWh electricity	0.144339							0.094361
With economic allocation - Consider co-generation feature								
Electricity production								
CAPEX / 1 kWh electricity	0.259105	0.179653	0.165236	0.143816	0.138076	0.129549	0.069333	0.069333
OPEX / 1 kWh electricity	0.095714							0.062573
Heat production								
CAPEX / 1 kWh heat	0.084629	0.058678	0.053969	0.053969	0.045098	0.042313	0.022646	0.022646
OPEX / 1 kWh heat	0.031262							0.020437

- ✓ BLAZE pilot plant 0.31 kg CO2 – eq, 50 % reduction compared with mature electricity generation technology. After reasonable improvement, BLAZE emits 0.19 kg CO2 – eq. (better heat integration, self-produced **steam**, biofuel instead of **LPG**, renewable electricity, **catalyst** production and lifetime)
- ➢ Biomass and maintenance contribute the most in OPEX. Electricity contributes 66% of overall revenues. Economic allocation method is important and necessary to use. BLAZE system has the potential to reach 0.1 Euro/ 1 kWh electricity, 0.04 Euro/ 1 kWh heat (cheaper than the market price), reach BLAZE proposed target. BLAZE shows more competitivity marketplace when the plant size is big, and it can deliver heat and electricity continuously (CHP).

WP8: Dissemination and Exploitation



Strengths
- CHP is energy efficient
- Storage
- Blaze has good Bio CHP characteristics
- Smaller size

Weaknesses
- Complex plant (leading also to higher CAPEX and O&M costs)
- Limited no. of operational hours leading reliability
- Biomass supply

Opportunities
- Global energy crisis
- Local autonomy is trendy
- Reduction of CO2 and emissions
- Climate change increasingly actual

Threats
- Objections of decision-makers
- CAPEX of standard CHP

Business Case Wood Forniture Industry: Heat Demand 5.500 MWh/year, Electricity Demand 9.000 MWh/year
Sawdust waste-biomass 5.500ton/year 20.000 MWh/year

	CASE 1	CASE 2	CASE 3	CASE 4
Investment	€ 11,135,616.03	€ 8,814,258.58	€ 6,254,416.20	€ 11,135,616.03
Cash Flow (Year 1)	€ 1,919,304.22	€ 1,913,212.58	€ 1,567,033.89	€ 2,074,064.22
LSM cost replacement @y10	€ 7,950,000.00	€ 6,000,000.00	€ 3,900,000.00	€ 7,950,000.00
IRR (Internal Rate of Return)	0.09	0.15	0.19	0.11
NPV - Net Present Value	€ 20,957,466.77	€ 22,072,590.67	€ 18,701,478.17	€ 23,040,878.45

Technology roadmap: Reduce the plant and single equipment costs, Optimize the overall plant cost defining a modular standard size, Cumulate operational manhours for increasing reliability and availability, LSM costs drive the economics (LSM 4.000 €/kWe 5 years lifetime).
Business Model: ESCO Model seems to be a viable solution for medium scale plants and in general for customers like industries

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The official BLAZE website https://www.blazeproject.eu

Platform: www.blazeproject.eu/biocogen-2030/

BLAZE social media (Twitter, Linkedin and Facebook):

Blaze (@BlazeProject) Twitter / LinkedIn /Facebook

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