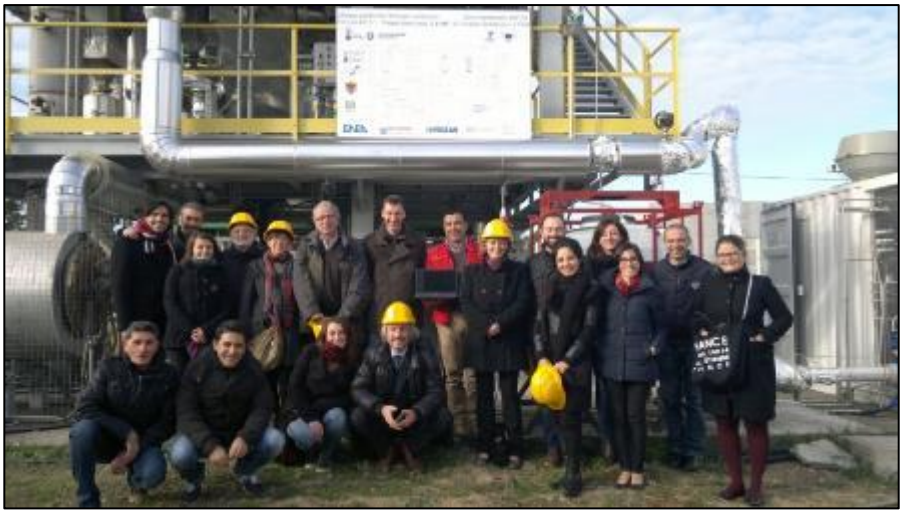
2.1 . FINAL PUBLISHABLE SUMMARY REPORT

2.1.1 Executive summary



UNIFHY is a 43-month collaborative research project started on September 1st 2012, with a total budget of Eur 3.3M. The project aims at developing cost competitive, energy efficient, sustainable, thermochemical hydrogen production process from various biomass feedstocks.
The project is based on the utilization of plant components of proven performance and reliability and well established processes (UNIQUE coupled gasification and hot gas cleaning and conditioning system, via one 100 kWth indirectly heated reactor and one 1000 kWth enriched air reactor, Water-Gas Shift, WGS and Pressure Swing Adsorption, PSA). The overall scope of UNIfHY is the integration of these components to obtain a continuous process for pure hydrogen production from biomass.
Almond shells have been chosen to be used in the beginning of the experimentation owing to the lower price respect pellets and greater bulk density versus wood chips.
Regarding the hydrogen production, UNIfHY intended to increase the gas production quantity and at the same time improve its purity, for this reason three kinds of filter candles (non catalytic, catalytic, with catalytic foam) have been tested at different filtration velocities and gasification conditions. By the tests it has been proved that the hydrogen production has risen to about 60%-vol, vs 38% in the tests with no candle (about 50% increase), with a reduction of methane (from 10 to 2%-v), tar (from 10 to 1 g/Nm^3), ammonia (from 3000 to 1500 ppm), and an increase in gas yields (from 1 to 2 Nm^3/kg daf) and water conversion (from 25% to 45%). Higher temperature, water content and ash/char accumulated increase the performance, as evidenced by experimental tests and CFD simulations.
About 150 ceramic alumina foams (two porosities: 45 and 30 ppi) were impregnated with cerium oxide to increase their specific surface area (from 0.5 m^2 /g to 5-15 m^2 /g) and iron and copper catalysts where developed to test WGS performance. The 45 ppi foams showed higher differential pressure (about 150 vs 50 mbar for a standard reactor), thus the 30 ppi foams where chosen to prevent exceeding the differential pressure limits. The optimized wet impregnation of iron and copper precursor (> 10 and 5%-wt, respectively) permits to obtain promising CO conversion (until 43%) with a residence time of 1s. These systems present a good lifetime and are resistant to sintering.
Bench scale tests and modelling of PSA showed that PSA performs well down to H2 concentrations of 34% at purity 5.0 with about 65% H2 yield (PSA at 6-7 bar, product H_2 at pressure of 3-4 bar). A sulphur guard bed (ZnO reactor), a WGS, a PSA have been built and integrated in a Portable Purification System. Extensive gasification test campaigns have been carried out in order to evaluate the performance of the two gasifiers without and with candle

filters. The startup time is about 5 and 24 hours for the 100 and 1000 kWth prototypes, respectively. Tests without candle filters at different gasification agents (steam/air/oxygen) and temperatures showed gas yield from 1.3 to 1.7 kg_{wet}/kg of dry biomass, hydrogen content from 7 to 35%-v dry, tars, as particulate, in the range of 10-20 g/Nm^3_{dry}, sulphur and chlorine compounds in the range of 50-90 ppm_v, ammonia up to 1600 ppm_v. Test with candle filters showed the efficacy of the in-situ HT filtration system in removing particulate from the produced gas, reduced down to about 30 mg/Nm^3_{dry} thus with a removal efficiency > 99%-wt. The system was proven to be operable stably and in continuous in experimental run lasting more than 12 h. Hydrogen production at concentration of 99.99%-v was achieved. The economic and LCA analysis showed that UNIfHY can match the hydrogen target cost and emission of 3-10 €/Kg and 0.0134 kg CO_2 per 1MJ H2 produced (0.3-3 t H_2/day), respectively.

2.1.2 Summary description of project context and objectives

The overall scope of UNIfHY project was the developing of a biomass steam gasification process coupled to syngas purification to produce pure hydrogen from biomass, increase well-to-tank efficiency and contribute to a sustainable energy portfolio, exploiting results obtained in past by R&D EU projects on hot gas catalytic conditioning. The project was based on the utilization of plant components of proven performance and reliability and well established processes (UNIQUE coupled gasification and hot gas cleaning and conditioning system, via one 100 kWth indirectly heated reactor and one 1000 kWth enriched air reactor, Water-Gas Shift, WGS, and Pressure Swing Adsorption, PSA). The overall scope of UNIfHY was the integration of these components to obtain a continuous process for pure hydrogen production from biomass.

Europe's energy system needs to be adapted into a more sustainable one, based on a diverse mix of energy sources, in particular renewables, and among them biomass, enhancing power generation efficiency, proposing new energy vectors to improve effectiveness of renewables; addressing the pressing challenges of security of supply and climate change, whilst increasing the competitiveness of Europe's industries.

Biomass gasification for production of hydrogen fuel is a very attractive technology in this sense, but unfortunately not yet enough developed. By analysing the European scenario, in fact, it is possible to note that almost none industrial scale plant based on biomass to hydrogen (BTH) technology are established[3]. UNIfHY project tried to overcome this shortcoming, since one of its main objectives regarding the multi annual plan MAIP 2008-2013 was the placing of Europe at the forefront of biomass to hydrogen (BTH) thermal conversion technologies worldwide (e.g. first continuous hydrogen production PEFC grade from biomass at industrial scale).

[3] University College London, A review of hydrogen production technologies for energy system models, 2012

Figure_ 1 UNIfHY 1000 kWth gasifier with the PPS

Figure_ 2 UNIfHY 100 kWth gasifier

Some other crucial targets of multi annual plan MAIP 2008-2013 addressed by UNIfHY were to evaluate the energy, environmental, economic and social sustainability of BTH thermal conversion technologies and also to increase their energy, environment and industrial competitiveness. As regards the efficiency of a such system, the speculative values reached in a baseline scenario are of about 54% for a plant with a biomass input rate higher than 35 t/day[4] and 50% for an input flow of 1.5-35 t/day[5]: the scope of UNIfHY was to rise up the efficiency to a simulated value of 70%, that is higher than the efficiency of 64% relative to all BTH conversion provided by the MAIP. Moreover, one of the important points of the UNIfHY project was to focus the attention on the small/medium scale biomass gasification plants in order to increase their sustainability and to respect the target given from the MAIP of 1.5 t/day for an industrial scale plant.

Both the reactors benefited from the integration of filter candles to obtain the maximum purity of hydrogen. The state of the art about the plant's capacity in terms of H_2 production reveals that centralised plants have a production capacity in the range of 35-160 t/day of H_2 [6], while for a distributed configuration it ranges between 1.5 and 30 t/day (speculative values)[5] [7]. The goal of UNIfHY was the production of 50-500 kg/day of H_2 in a distributed generation point of view. The MAIP 2008-2013 highlighted also the problem of the production cost of hydrogen from BTH technologies. Baseline data provided from FCH JU and NREL are in the range of 0.8 - 4.2[8][9] M€ per tons of hydrogen produced in a day, while MAIP objectives was to reach the value of 3.8 M€/(t/day). As regards the hydrogen specific cost, the same references show that it is 4.7 €/kg for a production capacity higher than 1.5 t/day[10] and 1.8 €/kg for a

[4] NREL/TP-510-44868, Hydrogen Production from Biomass via Indirect Gasification, 2009 and NREL/BK-6A10-51726, Hydrogen Production Cost Estimate Using Biomass Gasification, 2011

[5] University College London, A review of hydrogen production technologies for energy system models, 2012

[6] NREL/TP-510-44868, Hydrogen Production from Biomass via Indirect Gasification, 2009 and NREL/BK-6A10-51726, Hydrogen Production Cost Estimate Using Biomass Gasification, 2011; University College London, A review of hydrogen production technologies for energy system models, 2012

[7]

[8] FCH JU, Study on hydrogen from renewable resources in the EU Final Report, 2015

[9] NREL/TP-510-44868, Hydrogen Production from Biomass via Indirect Gasification, 2009 and NREL/BK-6A10-51726, Hydrogen Production Cost Estimate Using Biomass Gasification, 2011

[10] FCH JU, Study on hydrogen from renewable resources in the EU Final Report, 2015

production capacity higher than 35 t/day; MAIP 2008-2013 guidelines were limited to a more realistic cost of H_2 delivered to the hydrogen refuelling station (HRS) of 5€/kg, subsequently set at 13€/kg by the successive MAIP 2014-2020. UNIfHY scopes were to reach values of 3 M€/(t/day) and H_2 delivered to HRS cost lower than 5 €/kg, where the lower value is reached by decreasing oxygen production (e.g. membrane to separate oxygen from air), intensifying the process (combining steps and off gas and heat management), increasing catalyst lifetime and considering an electricity cost of 0.15 €/kWh.

Moreover, analysing biomass to hydrogen technologies scenario, it is revealed that none Regulation Codes and Standards (RCS) were drawn up on BTH thermal conversion technologies as well as none list of research and industries dealing with them were analysed. MAIP 2008-2013 required more information and RCS on BTH and expected to align efforts and leverage of industrial, European, national and regional RTD investments on BTH technologies: these requirements were fundamental UNIfHY aims.

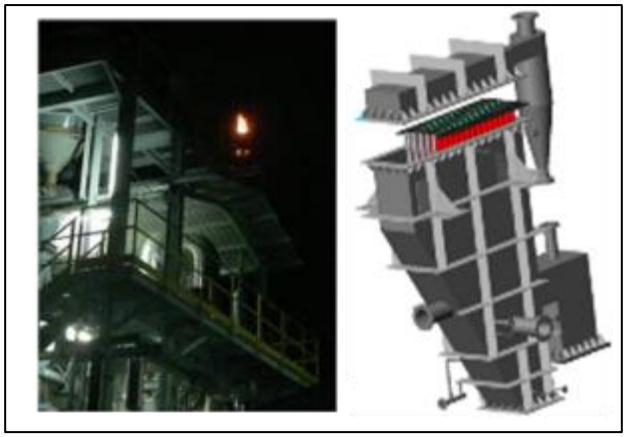


Figure_ 3 UNIfHY 1000 kWth and candles design

Figure_ 4 UNIfHY 100 kWth and candles

Concerning the 2011 AIP (topic SP1-JTI-FCH.2011.2.3-Biomass-to-hydrogen (BTH) thermal conversion process), the objectives addressed by UNIfHY were to carry out a feedstock (pre-treatment and economical assessment) analysis, develop biomass hydrogen production equipment (development and scale up activities on materials and reactors design in order to obtain a continuous process for hydrogen production from biomass), evaluate cost, efficiency and scalability of BTH thermal conversion technologies and finally to conduct a LCA/LCI analysis (ILCD compliant). As said before, UNIfHY objective was to provide a production capacity of 50-500 kg/day of hydrogen, complying with the MAIP target of 1.5 t/day, but also with the AIP 2011 target about minimum scalability value of 500 kg/day. Furthermore, durability required by AIP was lower than 10 years (8000 hours) and with an availability of 95%, values perfectly comparable with the UNIfHY scopes to reach 20 years (160000 hours) of durability and 95% of availability. Finally, analyzing CO_2 emissions relative to BTH thermal conversion technologies, 0.002 kg_{CO2}/MJ_{H2} are produced if farmed and waste wood is considered[11], while a range of -0.005-0.0185 kg_{CO2}/MJ_{H2} are produced considering forestry

[11] JEC-Joint Research Centre-EUCAR-CONCAWE collaboration, WELL-TO-TANK (WTT) Report. Version 4, 2014

and agricultural waste[12]. LCA analysis was an objective of UNIfHY project, in order to evaluate the real CO_2 emissions from the BTH technology studied.

[12] Moreno J, Dufour J. Life cycle assessment of hydrogen production from biomass gasification. Evaluation of different Spanish feedstocks. International Journal of Hydrogen Energy 2013;38:7616–22. doi:10.1016/j.ijhydene.2012.11.076

2.1.3 Description of the main S&T results/foregrounds

The UNIfHY project is divided into 7 work packages; in particular, 2 of the total 7 were carried out during the all length of the project: **WP1 management**, and **WP7 Dissemination and Exploitation** that include, respectively, the inward and outward measures, instruments and initiatives.
Beyond these two managerial and informative work packages, the more technical WPs are the following: **WP2 bench scale** including feedstock, candles, PSA, foams, catalysts and sorbents testing and characterization; **WP3 PPU unit** including design and construction of the PSA, WGS and PPU units; **WP4 UNIFHY 100** including candles design and construction, UNIFHY 100 tests, long term tests to demonstrate the feasibility of the process at pilot scale using the double fluidized bed steam and air gasification technology; **WP5 UNIFHY 1000** including operability and long term tests to demonstrate the feasibility of the process at industrial scale using the steam and oxygen fluidized bed gasification technology; **WP 6 Modelling** including kinetic modelling of WGS and CO2 capture, CFD candles modelling, global system simulation, and environmental analysis by LCA.

Every technical Work Package of the project has produced a series of scientific results that will be summarized and described in this section (for foregrounds see section 2). The main results obtained for each task of the work packages is ***highlighted in the text***.

2.1.3.1 Overview of the progress of the work

The overall strategy of the work plan (described in the Dow, here quoted again) is designed to:

a) carry out systematic investigations into each topic identified in section 1 of Annex 1 (DoW) as necessary to reach the project final goal, including the development of materials and the experimental verification of their effectiveness to improve gas quality, at real gasification conditions, at bench-to-pilot-scale (up to 100 kWth);
b) evaluate the purity of syngas against existing gas cleaning and conditioning systems, by means of fluidized bed reactor at a significant scale (1 MWth) to provide sufficient and reliable information for industrial applications;
c) assess technical feasibility of process simplification and intensification actions envisaged in this project, by operation of an integrated gasification and hot gas cleaning and conditioning fluidized bed prototype reactor (1 MWth).

According to this strategic approach, the work is planned to be divided into 5 work packages that relate to research/innovation activities, and 2 work packages (the 7th and 1st) that include, respectively, the outward (dissemination and exploitation of results, IP protection) and inward (consortium and project management) measures, instruments and initiatives, which altogether will characterize the organization and the policy of the UNIfHY consortium. All work packages are linked to each other by the overall aim to integrate the proved UNIQUE and hydrogen purification technologies, in order to increase process conversion efficiency in a cost effective way.

2.1.3.2 Work package 2: Feedstock, Catalysts, Sorbents and tests at bench scale

T2.1 Feedstock characterization (month 1-12)

Various biomass feedstocks have been characterized with respect to: ultimate and proximate analysis, heating value (HHV and LHV), and inorganic elements (Cl, S, major and minor elements). Wood chips, pellets, shells and refuse derived fuel (RDF) were characterized as feedstock to be used. All kinds of biomass can be assumed equivalent, meanwhile the RDF have a content of sulphur and chlorine elements ten times higher (about 0.4 versus 0.04%w dry). Thus, the RDF were considered to have possible detrimental effects on some of the sensitive plant components under development in the project, such as the WGS reactor and the ceramic filter candles.

Almond shells -were chosen to be used in the beginning of the experimentation owing to the ***lower price respect pellets and greater bulk density versus wood chips***. The feedstock chosen was then used for the gasification test campaigns to be carried out at both 100 kWth and 1000 kWth pilot plants.

Feedstock	% (w/w $_{dry}$)					
	C [a]	H [a]	N [b]	O [c]	Cl [d]	S [d]
Almond Shells	47.9	6.3	0.32	44.27	0.012	0.015
Wood Chips (Pine)	49.8	5.8	0.14	43.58	0.05	0.03
Wood Chips (Poplar)	49.4	6.1	0.3	42.27	0.03	0.04
Pellets 1 (commercial)	48.6	6.3	0.34	43.08	0.04	0.04
Pellets 2 (commercial)	49.9	6.2	0.51	42.43	0.022	0.037
Refuse Derived Fuel (RDF)	46.0	7.4	0.97	27.3	0.43	0.35

(a) Std%: ≤ 2 %; (b) Std%: 5 ÷ 10 %; (c) %O = 100 − (%C+%H+%N+%Cl+%S+%Ash); (d) Std%: 10 ÷ 15 %

Table 1. Feedstock characterization

T2.2 Bench scale tests to optimize the catalytic candles operation (month 1-18)

The optimization of the catalytic filter candle consisted of gasification tests with three different kinds of filter candles (non-catalytic, catalytic, with catalytic foam) at different filtration velocity and gasification condition.

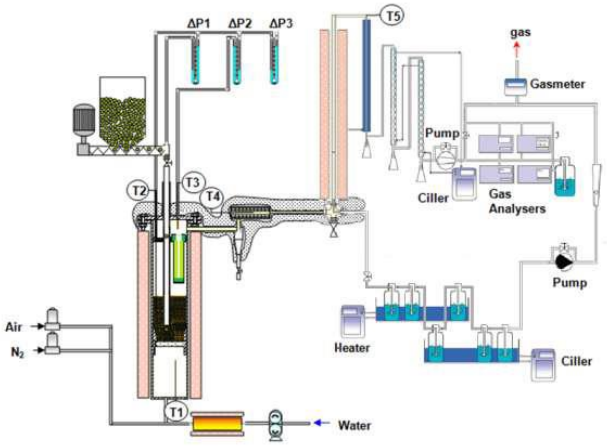


Figure_ 5 Bench scale gasification system used to test the catalytic candles

Concerning the gasification tests, all runs showed better performance in presence of the catalytic filter candle in respect to the case without candle (examined in a previous test

campaign). The main difference is observed in the hydrogen percentage in the product gas. ***The hydrogen concentration increases to about 60%-v, vs 38% in the tests with no candle*** (about 50% increase), with a reduction of methane (from 10 to 2%-v), tar (from 10 to 1 g/Nm^3), ammonia (from 3000 to 1500 ppm), and an increase in gas yields (from 1 to 2 Nm^3/kg daf) and water conversion (from 25% to 45%).
Higher temperature profile, water content and ash/char accumulated increase the performance, as better show the CFD simulations.
Furthermore, few tests were carried out focused on the pressure drop behavior in the case of the non-catalytic filter candles; the candles show a low-pressure drop that does not increase depending on temperature.

T2.3 Bench scale tests to verify PSA coupling (month 1-20)

During this task verification tests regarding the upgrading efficiency in terms of yield at specified purity and the validation of HyGear's in-house PSA model have been carried out. HyGear verified the coupling of the PSA to the different (simulated) streams of the outlet of the WGS by testing the PSA with different gas compositions. The verification tests gave fruitful results: ***bench scale tests showed that the PSA performs well down to H_2 concentrations of 34% at purity 5.0 with roughly 65-70% H_2 yield***.
At lower purity the yield increased from 65% to more than 75% yield at 99% purity (2.0 purity). At high N_2 concentrations and low H_2 concentrations in the feed gas the performance deteriorates; the H_2 yield is only 32% at purity 4.5. With regards to the required purity and overall system efficiency of the project aim, results show that it is more convenient to operate gasifiers under oxygen enriched conditions as this yields the highest H_2 yield at given purity. Based on the results it is recommended approximately 65% H_2 yield at H_2 purity 4.0 for the systems calculations of CIRPS. Moreover, the PSA model was validated and agreed with the experiments; the PSA model is used to define the design parameters for the PPS.

T2.4 Catalysts (Fe/Foam and Cu/Foam) and sorbents (Ni-Fe/CO2) realization and characterization (month 1-28)

An innovative catalytic system has been specifically developed for Water Gas Shift reaction. To prevent pressure drop along the process (gasification is operated at atmospheric pressure) and to increase the efficiency of the gas-solid contact (catalytic surface area) all the catalysts were supported on ceramic foams.
About 150 ceramic alumina foams (two porosities: 45 and 30 ppi) were impregnated with cerium oxide to increase their specific surface area (from 0.5 m^2/g to 5-15 m^2/g) and Fe and Cu catalysts to test the WGS performance. The 45 ppi foams showed higher differential pressure (about 150 vs 50 mbar for a standard reactor), thus the 30 ppi foams were chosen to prevent exceeding the differential pressure limit.
Reactivity tests were performed with a gas composition similar to that of gasifier outlet. Different parameters were varied: the H_2O/CO ratio (from 0.65 to 3), the residence time (from 0.38 s. to 1.5 s.), the temperature (300 to 600°C) and the catalyst's composition (different amounts of cerium oxide and Fe or Cu oxide). ***The best results were observed with the H_2O/CO ratio of 2*** to allow the Water Gas Shift reaction, remove the possible coke and avoid the over-reduction of the catalyst. The temperature should be at least 450°C, but it should not exceed 550°C to avoid a quick deactivation of the catalyst. The best results were obtained with a residence time of 1 to 1.5 seconds.

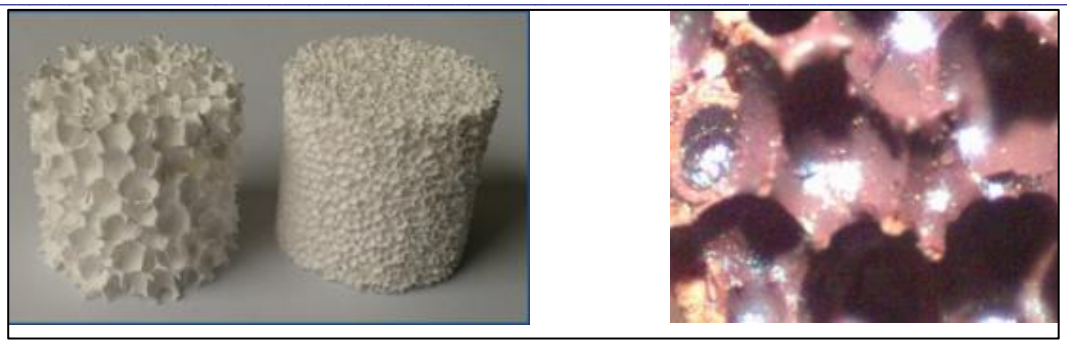


Figure_ 6 30 and 45 ppi foams; optical microscopy

The maximum CO conversion (42%) was obtained with a 5.2%-wt Cu/45 ppi foam. The 45 ppi foams showed higher activity but also higher differential pressure, thus the 30 ppi foams were chosen to prevent exceeding the differential pressure limits.
However, an ***increase in the residence time can lead to comparable CO conversions with the 30 ppi catalysts***, which shows a lower pressure drop.

This task is also focused on the study of Ca based CO2 sorbents and bi-functional materials using different synthesis methods: hydrothermal, co-precipitation, wet mixing. The most important features of the materials, like their structures, morphology and textural properties, are analyzed by different characterization methods, by means of specific surface area and pore distribution volume (BET-BJH), microscopy (SEM) and X-ray diffraction analyses.
These properties allow understanding the differences on the sorption and catalytic performances during CO2 capture tests and hydrocarbons steam reforming tests. In particular, ***mayenite, a ceramic stabilizing support for high temperature sorbents, is not only an efficient binder, but also shows catalytic properties in hydrocarbon reforming and cracking***.

T2.5 Bench scale tests to assess sorbent effectiveness (month 12-34)

Tests were carried out on the sorbent/catalysts realized with the thermogravimetric balance in order to identify the material with the best CO_2 capture performances. The sorption phase is performed at T = 640°C, with a heating ramp of 10°C/min, temperature reached the set point then a isotherm of 30 minutes is performed. The first calcination step and the regeneration one are performed under pure He flow whereas the sorption step under 10% CO2-He mixture. The number of cycles is fixed to 10.
A remarkably high sorption capacity is obtained by CaHS when it is previously calcined at T = 450°C (C56HS-450) and tested in TGA cycles (Tads = 650°C and 25% CO2-N2 mixture; Tdes = 850°C in pure N2 flow). This sample has Ca/Al molar ratio equal to 3 that corresponds to a content in CaO of 56%w and Ca12Al14O33 balance (44%w).
In a first attempt to study CaO/mayenite sorbent systems, two different CaO contents (56%-wt and 85%-wt) samples were synthesized by wet-mixing synthesis method and tested in TGA during 30 cycles, in order to evaluate the effect of CaO content as a function of cycles number.
The results obtained by C56IZ and C85IZ show that both sorbents display initial activation time. C85IZ has a deactivation trend during sorption cycles and, after 25 cycles, reaches the sorption uptake performed by C56IZ; the latter showed a quite stable behavior after the first 10th cycle.
The deactivation of C85IZ is likely due to the smaller amount of Ca12Al14O33 content than C56IZ.

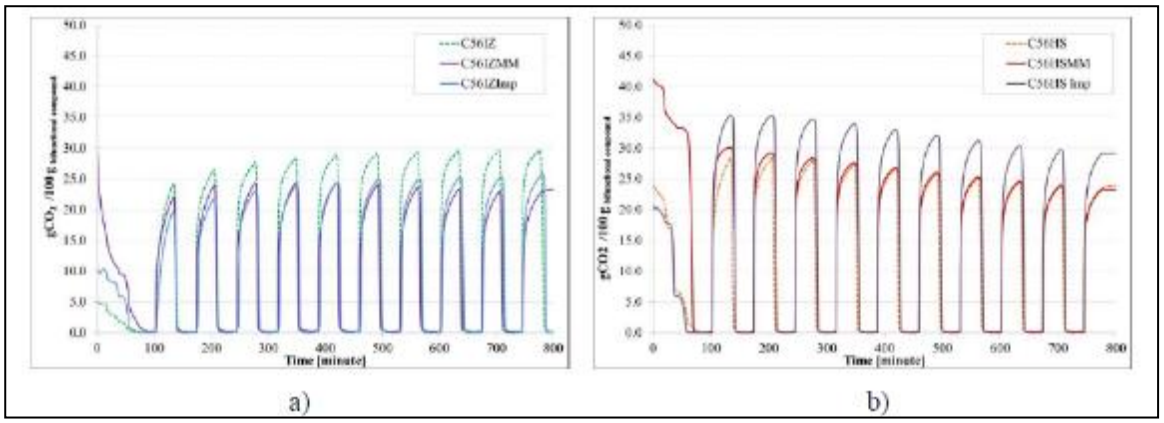


Figure_ 7 Cyclic CO2 sorption/desorption TGA tests on different sorbents

The best results after 10 cycles are shown by the wet mixing synthesized samples C56IZ (56% of CaO excess, synthesis method by Zamboni et al) with a sorption capacity of 6.6 molCO2/kg sorbent.

At last this task treated also the development of calcium based solid bi-functional catalyst/sorbents to perform catalytic tar steam reforming and simultaneously remove CO2. ***Different solid sorbent-catalysts containing Ca, Mayenite and Ni as active phase, were synthesized with different methods*** (mechanical mix, impregnation method, deposition) and characterized by means of XRD, SEM, BET and TPR analysis. For each synthesis method different amounts of Ca, Mayenite and Ni were used, generating thus at least four samples for each synthesis method (MM, Imp, DEP).

Every bi-functional compound was tested at 640°C with a constant flow rate of 6 Nl/h and the catalyst (Wcat) loading was varied in the range of 100– 500 mg depending on the catalyst nature, particle size and density, the height of the reactor keeping constant and equal to 1cm to assure a constant temperature value.
The results obtained for the mechanically mixed samples show that all the samples containing CaO show deactivation after maximum 50 minutes of test and CaOMM show a shorter activation time. The positive mayenite effect is clearly visible in May900MM that show a stable H2 production during 4 h of test.
The results of the impregnated samples show that CaOImp has a maximum H2 production rate at the beginning of the test, afterwards it slowly decreases. Until the end of the 3 hours test, it keeps almost a little activity, shown also by benzene production. C56HSImp is stable during 3 hours of reaction, it shows some little fluctuation, but a constant trend is delineated in both CO2 and H2 production rates. The average toluene conversion is equal to 75%.
For the deposited samples the effect of CaO loading is shown: the higher is the CaO amount and the better is the catalyst activity. CaODEP reaches almost the thermodynamic limit, after an activation time of 100 minutes in which benzene is produced.

Sample name	Toluene conversion at t = 15 min [%]	Toluene conversion at t = 240 min [%]
Mechanically mixed samples		
CaOMM	57	13
C56IZMM	100	0
C85IZMM	99	0
May900MM	100	100
Mayenite	/	/
Impregnated samples		
CaOImp	49	7
C56IZIMP	20	75
C56HSIMP	99	100
Mayenite750-900Imp	/	/
Deposited samples		
Ni-Olivine	25	100
CaODEP	7	100
C56IZDEP	16	14
C85IZDEP	53	72
May900DEP	/	/

Table 2. Toluene conversion summary

In every test neither CO nor hydrocarbons has been detected.
Every sample with a hydrogen production close to the thermodynamic limit value has shown almost total toluene conversion.
Every mechanically mixed compound with CaO was deactivated after maximum 50 minutes. May900MM showed stability during 4 h of test. Its stability behavior could be explained by the presence of free oxygen in the crystal lattice that could gasify deposited coke together with the fed of steam.
Among the impregnated samples May750-900Imp did not show activity because the Ni species are not reducible in situ in these conditions. C56IZImp showed fluctuating activity, whereas ***C56HSImp had stable activity during 4 hours, with a maximum toluene conversion***.
The difference between these two samples could be reasonably connected to the different Ni species formed on those samples and their reducibility.
The CaO rich deposited samples showed an activation time before starting to reform toluene, due to the mass diffusion resistance generated by the external sorbent shell. These compounds are not pre-reduced; hence the metal oxides present need time and higher temperature to be reduced, as shown by TPR analysis.

2.1.3.3 Work package 3: Portable purification unit

T3.1 Design and construction of the pressure swing absorber (PSA) unit (month 7-26)

This task consists in the development of the PSA unit; a ***3-dimensional model*** of the UNIfHY PSA section was developed.

HyGear is responsible for the assembly of the PSA unit integrated in the PPS which includes the selection and procurement of components and assembly of PSA weldments according to PED regulation (PSA operates at elevated pressure).

Figure_ 8 Filling of PSA vessel with PSA adsorbent material (left) and its installation in the PPS housing (right)

T3.2 Design and construction of the WGS unit (month 14-27)

This task describes the design and construction of the LT-WGS (Cu-ceramic foams) and HT-WGS (Fe-ceramic foams) provided by partners PALL and UNISTRA. Reactor dimensions were defined based on lab scale testing performed by partner UNISTRA and pressure drop evaluation performed by PALL.

Partner UNISTRA has performed lab scale tests to evaluate the influence of varying water concentration, residence time, number of pores per inch and/or temperature on catalytic activity of high temperature and low temperature water gas shift catalysts. The results have been shared with and evaluated by HyGear.

Based on the activity measurements as function of residence time performed by UNISTRA, HyGear estimated the required reactor volume for both the HTS and LTS reactors. PALL indicated that the maximum possible diameter manufactured would be approximately 300 mm Ø * 200 mm length per body in order to decrease as much as possible the pressure drop. To have sufficient conversion a ***reactor volume of 56 liters*** would be sufficient. The total dimension of the ***catalytic volume*** (containing 4 catalytic bodies) was therefore defined as ***300 mm Ø * 800 mm length***.

Calculations based on the feed flow to the reactor, higher because of addition of water upstream the PPS for gas cooling, showed that the pressure drop expected for the 45 ppi ceramic foams is far too high. It was thus decided to continue with the 30 ppi catalytic coated ceramic foams.

Due to the presence of hydrogen sulfide in the gasifier gas it was decided (between partners) that a ***ZnO guard bed would be included to increase lifetime of the LT-WGS catalyst***; as this would increase pressure drop considerably, the ***HT-WGS reactor was omitted*** from the PPS prototype.

By adding a guard bed upstream, the LTS reactor the life time of the LT-WGS catalyst would be increased to 8 years (considering 0.1 ppm H2S may leak through hot zinc oxide).

T3.3 Design, engineering and construction of the Portable Purification System (PPS) including PSA, WGS and complementary components (month 15-34)

This task deals with the design and construction of the (Trans) Portable Purification System (PPS). The PPS, consisting of the integrated ZnO reactor, water gas shift reactor (WGS), compressor and gas upgrading unit (PSA) has been set up to upgrade low hydrogen containing gasifier gas.

The syngas produced by biomass gasification enters the PPS between 500 and 600°C at approximately 15 – 20 $mbar_g$. This gas temperature is too high to enter either zinc oxide (ZnO) or Low Temperature Shift (LTS) reactor as it will decrease both selectivity and activity. Therefore, the gas is cooled prior to entering the PPS prototype using sprayed water to approximately 300°C.

In addition, the interface demands, alarm parameters and the Piping and Instrumentation Diagram were accomplished. After final assembly, the PPS was leak and pressure tested and was successfully PED approved by the notified body. ***The finalization of the assembly of the PPS was completed successfully***.

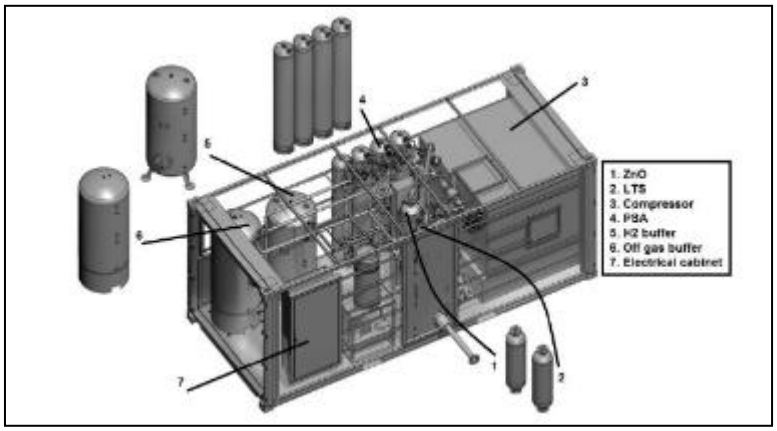


Figure_ 9 Exploded view of the PPS showing main components

2.1.3.4 Work package 4: UNIfHY 100

T4.1 Filter candles design and construction (month 1-24)

New ceramic filter candles for high temperature applications under reducing atmosphere has been integrated into the UNIfHY 100 kWth biomass gasifier at CIRPS in Civitavecchia. Non-catalytic filter candles of the new UHT (ultra-high temperature) support have been tested directly integrated into the gasifier.

Three filter candles with a special length of 500 mm and an outer diameter of 60 mm and an inner diameter of 40 mm have been installed in the gasifier.

The installation equipment as well as the blowback system has been designed.

The blowback system is composed by a vessel that contains nitrogen at a temperature of 400 °C for the back-pulsing with a volume of about 80 liters. The pressure vessel is equipped with a nitrogen inlet connection, an outlet connection linked to the back pulsing pipe to the filter candle and a connection as drain in case of overpressure into the vessel. Further connections are installed for temperature and pressure measurements into the pressure vessel. The entire back-pulsing period will be in the range of about 200 ms.

Furthermore, the clean gas piping system is equipped with trace heating to avoid condensation of steam and condensable hydrocarbons into the piping system.

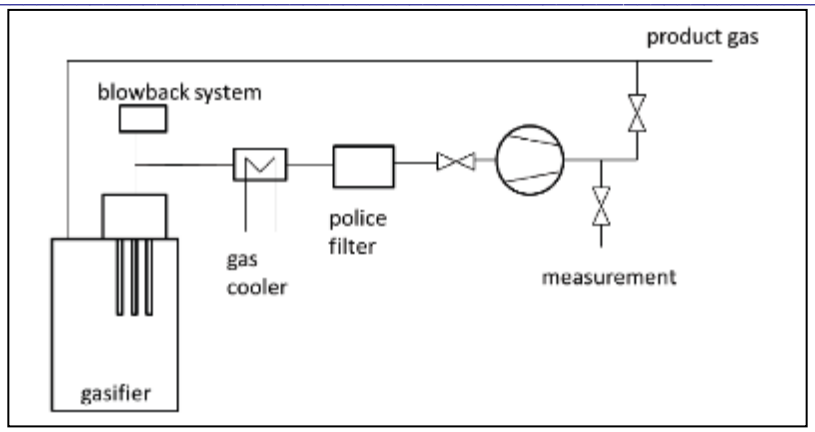


Figure_ 10 Scheme of the general slip stream arrangement

A product gas slip stream of about 6 Nm^3/h was taken over the filter candles to be downstream analyzed with regard to gas composition, tar and dust content.

T4.2 Test campaign with the prototype reactor (month 12-35)

Tests carried out show that the UNIfHY 100 gasifier installation in Civitavecchia has been developed up to the operational stage. Tests with only steam and steam + air were carried out with the 100 kWth prototype.

The tests were carried out using almond shells as biomass feedstock, with a feeding rate of 20 kg/h and a steam to biomass ratio of 0.5. Air and auxiliary fuel (diesel) were adjusted in the combustion chamber in order to keep the temperature at around 800 °C; steam is also injected in the siphons in order to guarantee the bed material recirculation.

During the gasification tests the gas composition (CO, CO2, H2, CH4) was evaluated online by a ABB analyzer; the determination of the tar content is carried out discontinuously, based on the tar protocol given by Neeft et al. (1999), CEN/TS 15439. Gas is pumped through impinger bottles where it is scrubbed by a solvent (2-propanol). The solvent is kept at a temperature of -10 °C in order to help tar condensation. The gas pump also contains a volume-meter and a thermometer to allow the normalization of the flow values. A sample of the 2-propanol phase from the impinger bottles containing condensed tar is taken for GC/MS analysis and thus for the determination of tar content in the syngas.

These two series of tests pointed out the difference between the composition of the syngas produced by a dual fluidized bed (steam tests) and a normal fluidized bed (steam + air tests). The fuel gas obtained with the dual fluidized bed reactor is characterized by a hydrogen content definitely higher than that obtainable with a single chamber reactor when both systems utilize air and steam as gasification agents.

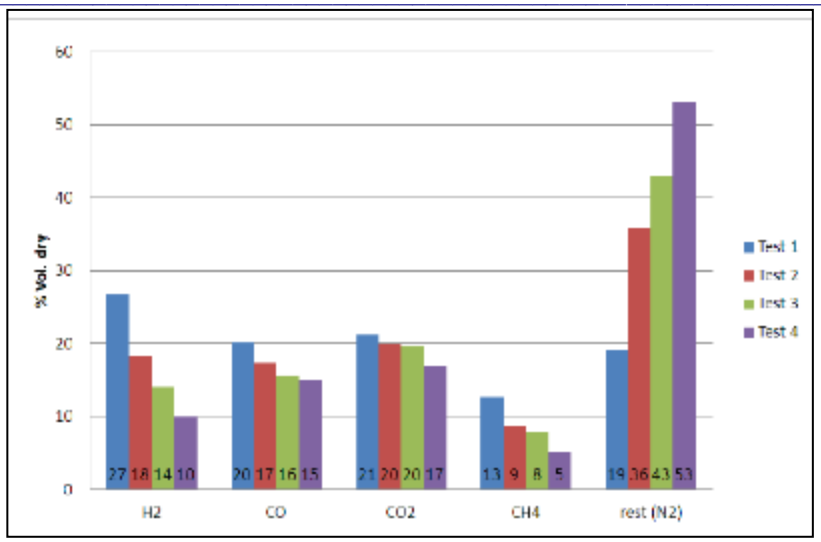


Figure_ 11 Dry gas composition (tests 1, 2, 3: steam gasification; test 4: steam+air gasification)

The steam-gasification tests showed a much higher hydrogen content compared to steam+air tests (steam + air: H2 = 10%; steam: H2 = 27%). Unfortunately, the syngas composition from the steam tests still contains a percentage of nitrogen, probably coming from ***leakages between the two chambers*** or from non-optimized design of the siphons. Furthermore, the tar content both in steam and in steam + air tests is still too high; the ***high tar content*** represents an important problem that must be solved by means of structural changes in the reactor.

A very important issue, also related to the high tar content, is the ***difficulty of reaching and maintaining the operation temperature*** during the tests (720-770°C instead of the desired 800°C). Some problems, that may be the cause of the temperature issue, were identified and a series of solutions were proposed.

	g/Nm3 dry
Toluene	10,9
Xylene	5,1
Styrene	2,5
Naphthalene	6,9
Phenol	10,1
Total	35,5

Table 3. Tar concentration during gasification tests

Some of the solutions proposed in order to better the gasifier were: hardware modifications, external thermal insulation of the reactor and changes in the geometry of the siphons.

This period of experimental activity of the 100 kWth prototype was thus useful to ***elaborate a new reactor design*** characterized by geometry and features studied to solve the operational problems encountered during the experimental activity.

T4.3 UNIfHY 100 long term test (month 25-43)

Further tests were carried out with the 100 kWth gasifier operated with air and steam in the dual fluidized bed mode. Tests of an overall duration of 15 hours were carried out at a temperature of about 770 °C, using a steam to biomass ratio equal to 0.5; the biomass used during the test is almond shell.
The gas composition in terms of H2, CO, CO2, CH4, N2 was analyzed with an ABB infra-red and tar were sampled as described above and their concentration analyzed with a GC-MS.

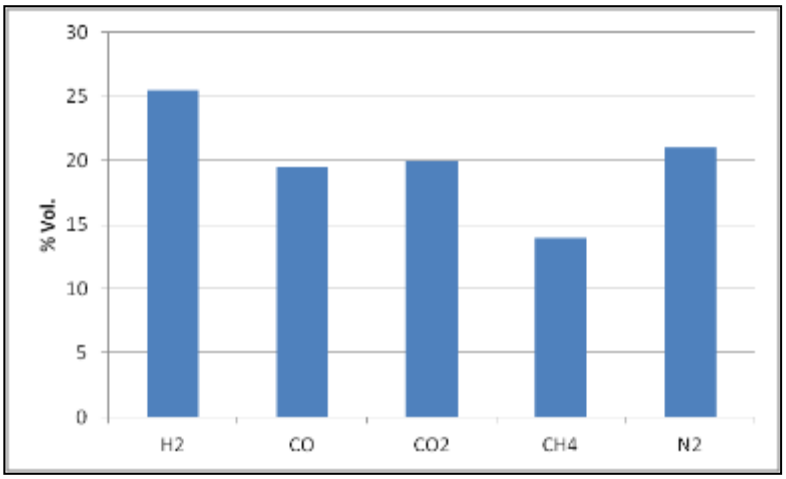


Figure_12 Average dry gas composition

The ***H2 content in the average gas composition was 25%***. There is a non negligible percentage of ***N_2 (about 20%)*** even if its amount is lower than those obtainable by conventional gasification with air.
The total ***tar content is still very high, of the order of tens of g/Nm^3***; this is probably due to the low gasification temperature, related to thermal dispersion problems in the gasifier.
The issues again noticed in this task led to the elaboration of a new design of double fluidized bed gasifier characterized by two concentric cylinders: gasification and combustion chambers. This configuration is very advantageous from a thermal point of view: the heat produced in the combustor (internal) is not dispersed towards the external environment but it is completely given to the gasification chamber (external) to help the endothermic reactions.
The new design also has a higher freeboard, in order to allow a higher residence time of the syngas and thus obtain a lower content of tar at the outlet.

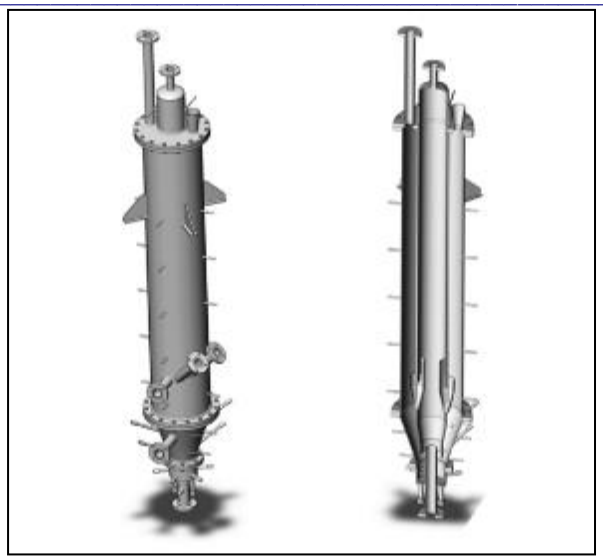


Figure_13 3D sketch of the new design of gasifier

A cold model of the new design gasifier was realized in scale in order to reproduce the same fluidization conditions of the real reactor; in this way it was possible to study and in case improve the fluidization regime and the recirculation of material, crucial problems in the old configuration.

A very important parameter for the correct operation of the system is the quantity of bed material circulating between the two chambers. In order to verify the circulation in the cold model, some tests were carried out using Particle Tracking Velocimetry (PTV) analysis: a CCD camera with high velocity and resolution was used for this scope. It was possible to evaluate the average velocity of the outgoing particles during time and thus to calculate the solid circulation flow rate in the gasifier, which resulted higher than the required.

Once verified the new configuration, the realization and the assembling of the real gasifier could start.

Figure_14 Assembly of the new design gasifier

2.1.3.5 Work package 5: UNIfHY 1000

T5.1 Operability and parameter tests (month 7-37)

Experimental tests campaign with the gasifier in its original configuration (without filter candles) were carried out in order to collect data on the performances of the 1000 kWth ICBFB (Internally Circulating Bubbling Fluidized Bed) pilot plant in the basic configuration. The tests were carried out in order to acquire data of reference to be used in the comparison with the gasifier in the advanced configuration.

An important goal of this activity was the identification of the process conditions at which the ceramic filter system has to operate and guarantee a proper particle filtration, reforming/cracking of tar and light hydrocarbons. To this aim, an extensive gasification test campaign was planned in order to evaluate the effect of some relevant process parameters on the produced gas and on the performance of the gasifier.

In order to evaluate the effects of using the steam/oxygen mixture as a gasifying medium on the quality of the produced gas in terms of gas composition and heating values, besides the tests with steam and pure oxygen, experiments with enriched air were also included. The following table shows the operating conditions utilized in the first test campaign.

Parameters	Gasifying agent		
	35%-wt O_2	50%-wt O_2	Steam/O_2
Biomass Feeding Rate (kg_{dry}/h)	130	130	125
Steam Feeding Rate (kg/h)	--	--	55
O_2 Feeding rate (kg/h)[a)]	22	31	38
O_2 Enrichment (%-wt)	36	48	100
S/B	--	--	0,4
ER	0.22	0.23	0.21
Gasification T (°C)	850-900	850-870	820-830
Pressure (bar_a)	1.0 – 1.1	1.0 – 1.1	1.0– 1.1

Table 4. Operating conditions adopted during gasification tests

The results in terms of composition are shown in the following chart.

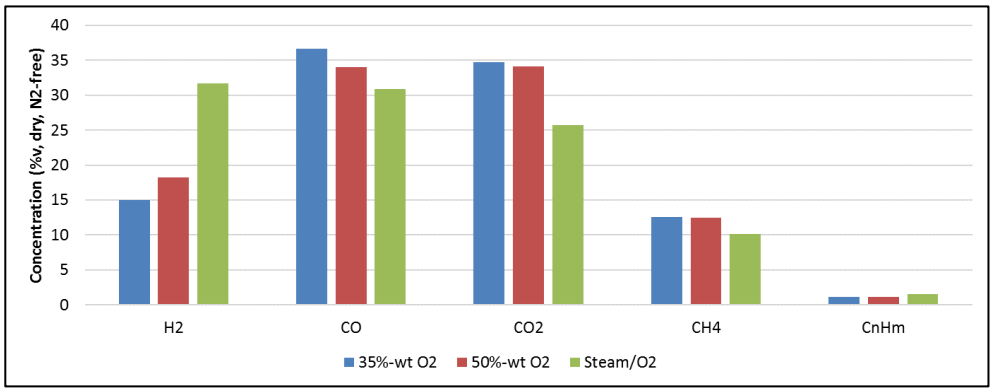


Figure_15 Dry and N2 free gas composition during gasification tests

By changing from enriched air to steam/oxygen mixture, the data confirmed the expected beneficial effect on the heating value of the product gas. The improvement in the gas quality was indeed not only an effect of the decreased amount of N2 (N2 = 5%), but also a result of ***the addition of steam which induced an H2 enrichment (H2 = 30%)*** by promoting reaction

of gas upgrading, such as water gas shift, char gasification and hydrocarbons reforming. Concerning tar, the GCMS analysis indicated the presence of many aromatic compounds, among which the most abundant were those with low molecular weight, such as benzene, toluene, phenol, indene and naphthalene. ***The total tar was about 18 g/Nm^3***.

After completing these campaigns, the gasifier was upgraded in order to convert the configuration in the advanced one. ***Sixty ceramic filter candles were housed in the freeboard*** of the reactor and the back pulse system was implemented. The detailed design of the integrated filter system resulted in a final layout number of 60 filter candles that were provided by PALL to ENEA. The filter elements were distributed in four rows of 15 elements each, and grouped in 5 blowback clusters.

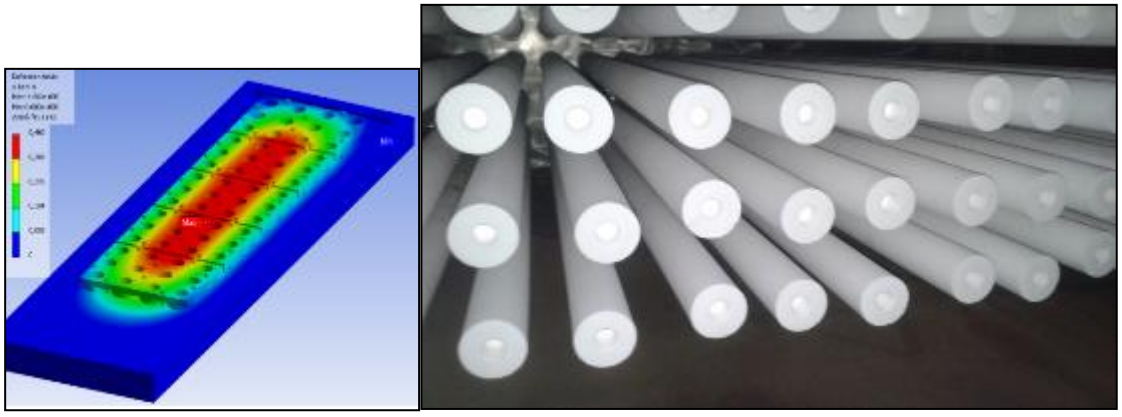


Figure_16 Design of the housing for ceramic filter candles and their integration in the freeboard of the gasifier

T5.2 Only gasifier long term tests and comprehensive evaluation of results (month 24-43)

These experimental activities were intended to check the efficiency of solid particle filtration and the effectiveness of the gas cleaning in the upgraded gasifier version with 60 ceramic filter candles inserted in the freeboard for several hours of operation. A fist test campaign was carried out using non-catalytic candles for the evaluation of the optimal parameter and the effectiveness of the filtration system. The second test campaign was instead performed with a catalytic filter system. As the catalytic candles were not installed in the gasifier the gasification runs were carried out including the use of catalysts for steam reforming and tar reduction: Ni-pellets was housed inside the non-catalytic ceramic candles in 2 of the 5 clusters.
During the gasification tests several on-line gas analyses were carried out on two streams:
On-line dry composition of the gas from the 3 non-catalytic clusters (NCC)
On-line dry composition of the gas from the 2 catalytic clusters (CC)
These different analyses were carried out to evaluate possible effect of the presence of Ni-pellets on the gas composition exiting the two types of clusters, non-catalytic and catalytic. The comparison shows minimal differences between the two gas compositions that were much more explainable with differences in the specific operating conditions rather than with an effect due to the Ni-catalyst. In the next table, as an example, range of gas composition measured in one of this comparison is presented.

Gas component	%-v (db)	
	NCC	CC

CO	28-33	32-35
CO2	23-25	23-26
CH4	8-10	8-9
CnHm	1.3-1.7	1.4-1.5
H2	32-36	29-33
O2	< 0.1	< 0.1
N2	< 0.1	< 0.1

Table 5. Comparison of dry composition relevant to the gas streams exiting the catalytic and non-catalytic ceramic filter clusters

Data in the table suggest that the expected catalytic effect was not observed: the most probable reason for such results was the low achievement in the in-situ activation of the catalyst pellets, too low for allowing measurable effects. Probably the gasification tests were not long enough to guarantee activation of the catalyst and the temperature in the freeboard was too low to show relevant effect. The acquired data indicated presence of significant content of tar in both the gas from Catalytic Clusters and the gas from Non-Catalytic Clusters: tar content varied between 5 and 11 g/Nm^3_{dry}, respectively. In both cases the most abundant tar molecules were single and double ring aromatic compounds (i.e. benzene, toluene, indene and naphthalene) and phenolic compounds (i.e. phenol and cresols). Possible explanation for the difference in the tar content could be found in the temperature profiles of temperature in the gasification reactor during the gas sampling which were somehow lower during the tar measurement carried out on the gas line from Non-Catalytic Clusters, although an effect of the presence of Ni-pellets inside the ceramic candles of clusters supplying the product gas to the PPS cannot be excluded. As final result longer time tests should be carried out to verify that Ni-catalyst could be activated. Consequently, some improvements in the gasifier design should be done in order to guarantee a higher freeboard temperature.

T5.3 UNIfHY 1000 gasifier plus PPS tests (month 30-43)

In view of the experimental campaign with the gasifier coupled to the portable purification station (PPS), two new piping lines at high temperature were realized, that is: a 4-inch piping line to allow the delivery of the produced gas to the vent during the start-up phase, thus avoiding excessive fouling of candles; a 3-inch piping line necessary to direct the produced gas coming from one of the 5 ceramic candles clusters to the PPS system.
The coupling of the PPS with the gasification plant was jointly defined by HyGear, ENEA and EPC, this latter also acting as team leader in a work of risk-assessment carried out before starting the experimental campaigns with the 1000 UNIfHY integrated system.

The main goal of this task was the coupling of the 1 MWth gasifier with the PPS. In order to achieve these results, many changes were realized to different parts of the systems. A new slip-stream from the cluster of filter candles to the PPS was realized; furthermore, a new by-pass pipeline was built and needed to be heated in order to keep a high temperature at the inlet of the PPS. For this reasons a heating system and thus some changes also in the electrical system were necessary.
The modifications described above also required the installation of new equipment for the control and the acquisition of the process variables.

A first test campaign was then started. The startup time for the experimental tests was about 24 hours. Among other results, during this experimental campaign it was shown the efficacy

of the in-situ HT filtration system in removing particulate from the produced gas, that was reduced down to about 30 mg/Nm^3_{dry} thus with a particulate removal efficiency > 99%-wt and provided a H2 concentration up to 99.5%-v, a methane concentration around 0.5%-v and others compounds concentration not detectable or lower than 0.1%-v. These results clearly were not matching yet the target of the project, even if provided evidence about the possibility of reaching the final goal. In fact, some issues probably related with the results obtained were identified: the gas temperature and the gas flow appeared too low at the inlet of the PPS, and too high-pressure drops were observed over the filter FgP01. In order to solve these problems, HyGear and ENEA performed hardware modifications concerning both the gasification plant and the PPS unit.

With this new configuration, a second test campaign was able to be performed.
The coupling of the gasifier with the PPS was successful: the system was proven to be operable stably and in continuous in experimental run lasting more than 12 h. At the end of the whole process hydrogen production at concentration of 99.99%-v with a hydrogen yield of at least 66% was achieved. These result is in very good agreement with that obtained on small scale.
The gas compositions at the PPS achieved during the last and most comprehensive process evaluation are presented in Figure_17 .

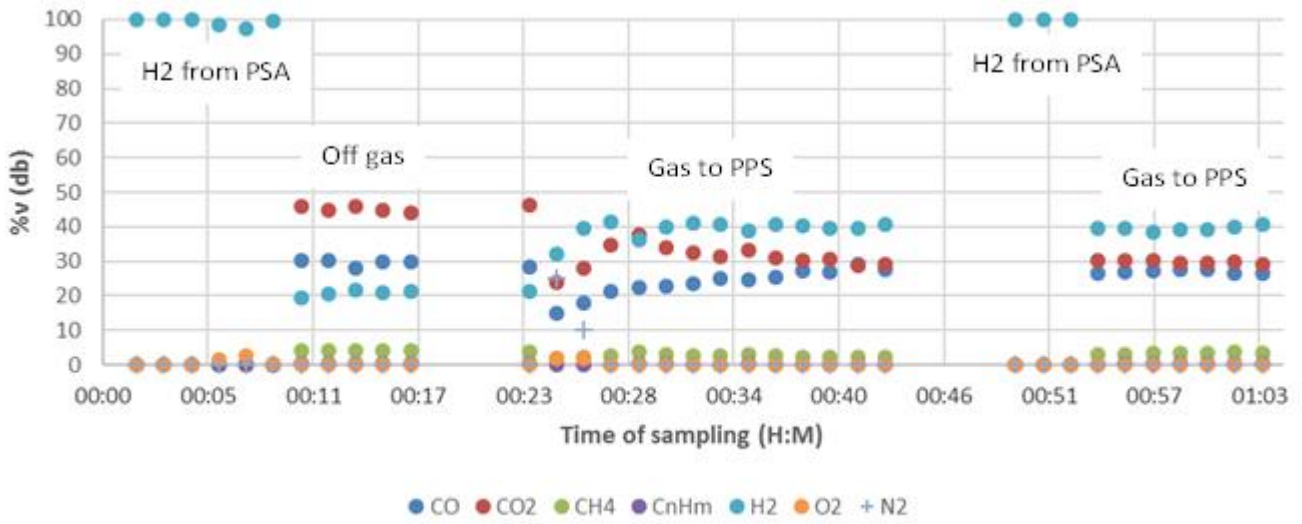


Figure_17 Production of H2 at 99.99%-v and trends in the gas composition of the produced gas supplied to the PPS

After receiving the PPS back at the premises of HyGear the unit was subjected to an end-of-life analysis:

- The PPS inlet piping was found to be partially clogged/blocked by huge amount of tar lying on the bottom of the piping, also blocking the inlet drain;
- The De-S material was found to be agglomerated and discolored with tar at the bottom of the vessel near the entrance;
- After opening the water gas shift reactor it was noted that the inner reactor housing and the foams were contaminated with tar;

- Interestingly it was observed that the coated foam had changed color during the gasifier runs from black to reddish, indicating a change into partially Cu active catalyst by reduction. This result indicates that it is possible to activate the low temperature WGS catalyst in situ

Results of the test campaigns showed that high purity hydrogen could be obtained by UNIfHY system, but tar still remains bottleneck of the process as the catalytic candles were not installed in the gasifier. Unfortunately the ceramic candles filled with Ni-catalyst pellets were not able to reduce tar to satisfactory level: this was almost due probably to the not enough activation of Ni catalyst during test and to the low temperature of the freeaboard. Improvement of this aspect could bring to satisfactory tests in the future, demonstrating the excellent results that were found in the lab test campaigns.

The experimental and simulation activities on UNIfHY 1000 e UNIfHY 100 were useful for the techno-economic analysis of the two UNIfHY prototypes. It involves the assessment of the technical performance (efficiency, reliability, maintenance, etc) at a component level (gasifier, catalytic filter candles, PSA, WGS) and global level (efficiency, operating hours) of the systems.
The assumptions made to analyze the global costs are:

- Engineering and design (13% total installed cost-DOE)
- Purchasing and construction (14% total installed cost-DOE)
- Personnel: 5 per year (8 hr/day, 3000€/month)
- Maintenance: 2% total CAPEX
- Insurance and taxes: 2% total CAPEX
- Fuel: 75 €/ton
- Annual operating hours: 7000 h
- VAT free
- Electrical energy 0.08 €/kWh
- Purchase electricity price 0.08 €/kWh

Results show that the costs of personnel and PPS are the largest in the two configurations (100 kWth, 1 MWth). In comparison with other costs which are actually unchanged, the costs of personnel and PPS can be decreased to reach a propitious level. Moreover, H2 production via 1 MWth indirectly heated can be the most affordable with the specific cost of 8.2 €/kg. Therefore, from economic and technical point of view, it can be the best configuration, even if the difference in efficiency and cost are not so relevant.

Hardware costs [k€/year]						
	S/B=0.5	S/B=1.5	S/B=0.5	S/B=1.5	S/B=0.5	S/B=1.5
	100 kWth		1 MWth		10 MWth	
Gasifier	25	26	71	75	348	368
PPS	26	26	98	98	303	303
Engineering Costs [k€/year]						
Engineering and design	6	6	20	21	78	80
Purchasing and construction	7	7	22	23	85	87
Total CAPEX	63	64	211	216	813	838

OPEX [k€/year]						
Personnel	0	0	180	180	180	180
Maintenance	13	13	38	39	138	140
Insurance	13	13	38	39	138	140
biomass	10.5	10.5	105	105	1050	1050
Electricity	3.7	3.7	37	37	370	370
Total OPEX	40	40	398	400	1876	1880
Total cost	103.2	104.2	609	616	2689	2718
Hydrogen production [Ton/year]	8.0	10.6	80.5	106.4	805	1064
Hydrogen production cost [€/kg]	**13**	**9.8**	**7.6**	**5.8**	**3.3**	**2.6**

Table 8. Global cost of plant under different S/B ratios and sizes (H2 production only)

A sensitivity analysis was carried out on the indirectly heated configuration, varying the steam to biomass ratio (0.5-1.0-1.5) and the size of the plant (10 kWth-1 MWth-10 MWth) at the best operating temperature (850°C). A higher S/B ratio allows H2 production to increase by 32% keeping a comparable OPEX cost, while the CAPEX cost depends particularly by the oversized steam generator, but this increment is about 3% and does not influence the final production cost.

The other scenario which can be adapted under S/B=0.5 (800°C) is the state that surplus of offgas is turned into both heat and electricity via ICE. Considering potential of power plant to produce electricity, it will definitely be able to meet its electricity demand and totally cut related cost. In order to better show the impact of the energy produced on the hydrogen cost, we subtract the energy revenue (calculated per kg of hydrogen) to hydrogen production cost. As a result, cost of hydrogen can drop by 18%, 26% and 20% for 10 MWth, 1 MWth and 100 kWth, respectively. All the results explained before are summarized below:

		100 kWth	**1 MWth**	**10 MWth**
H2 production only (optimized configuration)				
Hydrogen production cost S/B=1.5-850°C	[€/kg]	**9.8**	**5.6**	**2.8**
CHP mode				
Thermal energy	[kWth]	20	200	2000
Electrical energy	[kWe]	10	100	1000
Cost revenue[13]	[€/kg]	2	1.5	0.2
Total H2 estimated cost S/B=0.5-800°C	[€/kg]	**10.4**	**5.6**	**2.7**

Table 9. CHP and not CHP configuration

[13] ICE cost 1500 €/kWe for 10 kWe, 1000 €/kWe for 100-1000 kWe Electricity selling price 0.05 €/kWh for 700-7000 MWh/a (1-10 MWth), 0.20 €/kWh buying price for 70 MWh (0.1 MWth) [29], thermal energy buying price 0.08 €/kWh for 140 MWh (0.1 MWth), selling price 0.04 €/kWh (1-10 MWth) up to 1400 MWh [30].

The trend of the cost between the two configuration depends particularly by the hypothesis accounted for the electricity, heating and ICE cost, the assumptions are listed below:

- *ICE* cost 1500 €/kWe for 10 kWe, 1000 €/kWe for 100-1000 kWe
- *Electricity* selling price 0.05 €/kWh for 700-7000 MWh/a (1-10 MWth), 0.20 €/kWh buying price for 70 MWh (0.1 MWth)
- *thermal energy* buying price 0.08 €/kWh for 140 MWh (0.1 MWth), selling price 0.04 €/kWh (1-10 MWth) up to 1400 MWh

2.1.3.6 Work package 6 Modeling at different scales

T6.1 Kinetic modeling of water gas shift reactions (month 1-34)

The objective of this task was the kinetic study of the complex heterogeneous reactions taking place during the WGS reaction in presence of the catalytic Fe/foam and Cu/foam; the main aim was to propose a kinetic model of the reactions in the HT-LT Water Gas Shift reactors and determine the kinetic parameters in presence of these developed catalysts. For that, two power law models were established to fit with our experimental results in various conditions of temperature, H2/CO ratio and foam porosity with Fe/foam and Cu/foam catalysts, respectively. Different kinetic models of WGS reaction could be used as the base of the kinetics study: equilibrate reaction with first order regarding to CO and zero order regarding to the reactants or the Temkin model (redox mechanisms of the solid/catalyst). Other more sophisticate models used in the literature and derived from the Langmuir's model were also studied like the power law model. The comparison of experimental results and theoretical results obtained with the equilibrium model leads to the conclusion that it does not permit to model our WGS results at 400 and 450°C with 45 ppi or 30 ppi foam. The Temkin model leads to a good fit of the experimental results of WGS at 400 and 450°C with a 45 ppi foam and for the different H2O/CO ratios. The power law model can be adopted as a kinetic model of the WGS at 450°C and may be considered for other temperature and conditions.

This study has permitted to establish two power-law rates for the high temperature (450°C) and the low temperature (300°C) Water Gas Shift reaction.

$$r = 1.45 \times 10^{-4} \times (CO)^{0.80} \times (H_2O)^{0.83} \times (CO_2)^{-0.12} \times \left(1 - \frac{P_{H_2} \times P_{CO_2}}{K \times P_{CO} \times P_{H_2O}}\right) \quad \text{at } 450°C$$

$$r = 9.69 \times 10^{-4} \times (CO)^{0.70} \times (H_2O)^{0.4} \times \left(1 - \frac{P_{H_2} \times P_{CO_2}}{K \times P_{CO} \times P_{H_2O}}\right) \quad \text{at } 300°C$$

These rates are dependent to the reactants concentration with exponents empirically determined. The power-law rate is well appropriated to this study but is still associated to the catalysts and reactivity conditions.

T6.2 Kinetic modeling of hydrocarbon reforming with CO2 capture (month 1-41)

In this deliverable hydrodynamics and kinetics interacting in the fluidized bed reactor have been considered. A two-phase model has been implemented in order to predict the dynamics of a fluidized bed reactor where the production of hydrogen by steam methane reforming and CO2 uptake occur simultaneously. The ***kinetic model implemented in the solution*** of the reactive system is primarily based on a grain model regarding the CaO-carbonation and

Numaguchi and Kikuchi kinetics with regard to catalytic methane steam reforming and water gas shift reactions.

The present model incorporates the main parameters of syngas decarbonisation including steam flow rate, initial charge of CO2 acceptor inside the reactor and catalytic agent.

Method of lines was used to solve the PDEs governing the presented one dimension time-dependent model. Good agreement between experimental data and numerical results has been obtained.

Finally, ***3D simulations of reforming of hydrocarbons with CO2 capture*** have been presented and evaluated by means of an Eulerian-Lagrangian approach using the commercial software Barracuda ®.

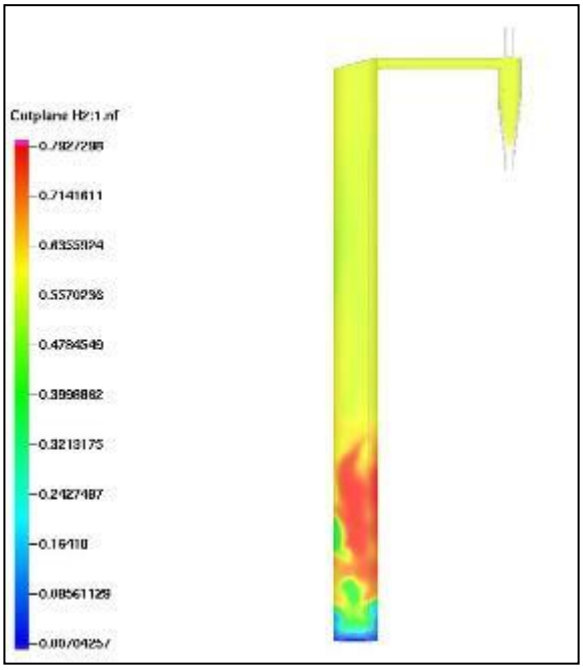


Figure_18 Contours map of H2 mole fraction

The Numaguchi and Kikuchi model modified according to De Smet model has been used for the simulation of SMR and WGS reaction whereas the separation of the CO2 has been simulated via the Stendardo and Foscolo grain model.

T6.3 CFD modeling (month 7-35)

A CFD model was developed to allow the simulation of the operation of the catalytic filter candles integrated in the reactor freeboard; the activity of the filters has been analyzed by studying the trends of temperature, gas velocity and tar and CH4 conversion through the filter candle.

The control volume consists in a cylindrical axial-symmetric volume with the real dimensions of the candle. The equations for mass, momentum, chemical species and energy conservation are solved for the gas phase in the freeboard volume, in the catalytic porous zone and in the empty volume.

The components considered and included in the model are methane (CH4) and tar compounds that appear in major quantity: benzene (C6H6), toluene (C7H8) and naphthalene (C10H8). The chemical reactions considered in the model were the steam reforming of the mentioned compounds and the Water Gas Shift reaction. The kinetics of the chemical reactions inserted in the model were taken from literature.

The model was validated by comparing the simulation outputs with experimental results of tests on a bench scale gasifier containing a ceramic catalytic filter. The model was then used to study the main parameters that have an influence on the performance of the catalytic filters. In particular the variables were temperature (750–850°C) and filtration velocity (70–110 m/h).

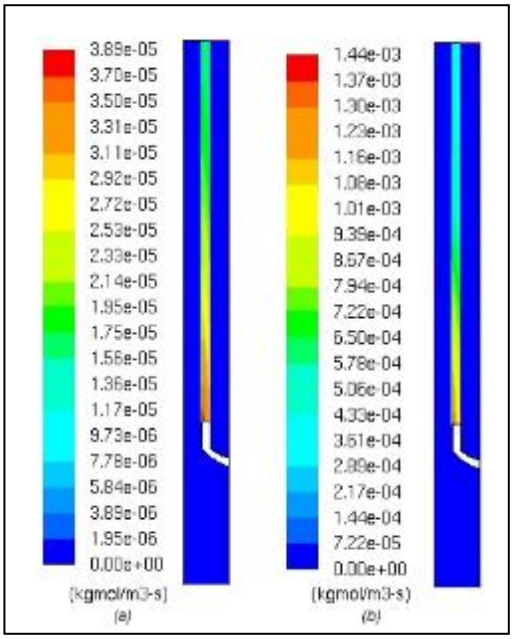


Figure_19 Reaction rates of C_6H_6 (a) and CH_4 (b) steam reforming (T=800 °C, v filtr = 90 m/h)

A stronger temperature dependency on the conversion of some hydrocarbons has been observed; in particular by increasing the temperature of 100°C the conversion of CH4 and C7H8 rises of approximately 2 times, while the conversion of C6H6 and C10H8 rises of approximately 4 times. ***The best conditions for the conversion of tar and methane appear to be highest temperature (850°C) and lowest filtration velocity (70 m/h)***. In this case the ***conversion obtained*** for methane and tar are about ***33% for CH4, 41% for C6H6, 75% for C7H8 and 85% for C10H8***.

T6.4 Global system simulation (month 1-43)

The entire UNIfHY system has been simulated on the basis of the experimental results within the Project. Models of the dual fluidized bed steam gasifier, catalytic filters candles, ZnO guard bed, LT-WGS reactor and PSA have been developed. Different values of S/B ratio, WGS residence time and operating temperature have been considered.

The comparison between the simulated and experimental data shows that ***the model predicts gas composition and product yields with a very good accuracy***. In particular, the difference between simulated and experimental data is lower than 2% for the gas composition, and lower than 5% for gas product yields. Regarding the TAR concentrations, the results confirms that benzene, the lowest molecular weight compound, is the greater aromatic compound representative, showing that it amounts for about 60% of the total aromatic compounds concentrations. The model and experimental results confirm that the heavier tars are reformed at high temperature more than the lighter tars.

Global simulations were carried out for the two different configurations: dual fluidized bed and steam/oxygen fluidized bed gasifier. The two different technologies can produce comparable results even if ***the chemical efficiency of the dual fluidized bed (DFB) system is slightly higher***, in particular in the DFB system the chemical efficiency is ***34% (around 10.5***

kg/h of hydrogen produced) against 31% for the Steam/oxygen fluidized bed gasifier (9.3 kg/h of hydrogen produced). This result can be explained by the use of pure steam in the DFB case that favors the reactions that produce hydrogen already in the gasifier section.

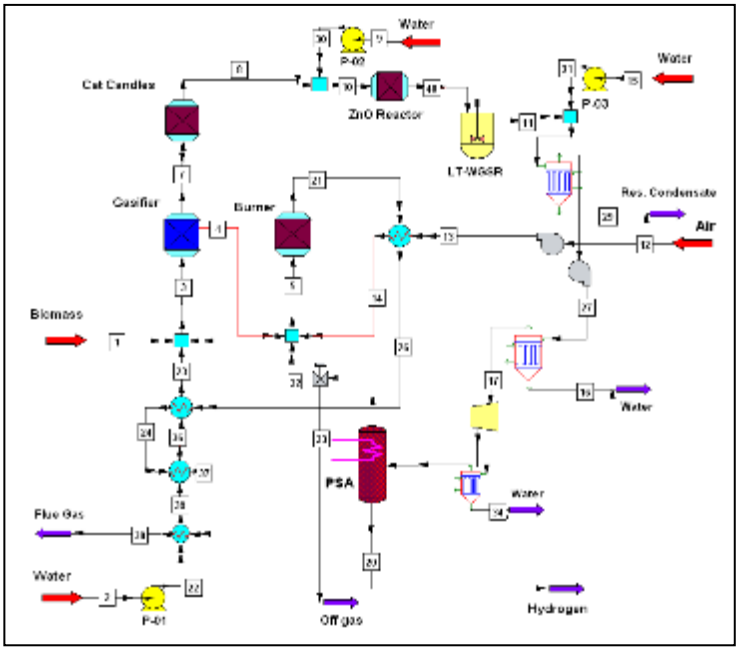


Figure_20 Flowsheet of the global system

Furthermore, ***a sensitivity analysis for the Dual Fluidized Bed*** system was carried out varying different parameters. A very important value is the hydrogen chemical efficiency of the whole plant. Thanks to the higher S/B and the higher amounts of extra steam/water, more steam can react in the different reaction processes, producing more hydrogen. The efficiency is influenced by S/B, showing asymptotic trend and quite considerable increase. Nevertheless, the ***maximum efficiency based on HHV obtained is 59.3%.***

The global simulation of the entire plant requires also an evaluation of the electrical consumptions, in order to determinate which are the best configuration and conditions even from an energetic point of view. The electrical consumption of the main electrical devices of the plant for the different steam to biomass considered has been analyzed. The electrical consumptions of all components increase with an increasing steam to biomass ratio, since higher total flows are managed from the different devices. ***The total consumption of the plant varies between 69 kW to 74 kW***. The main consumptions are those relative to the PSA intercooler compressor, the air blower and the syngas blower.

T6.5 Environmental analysis by LCA (month 1-43)

The Life Cycle Assessment has been developed for the UNIfHY model 1000 kWth, as well as for the 100 kWth. The UNIfHY models have been defined in GaBi ts software, by using the data collected from the project partners, LCA databases (Ecoinvent and GaBi) and data from literature. The results presented below have the purpose to highlight the environmental potential impacts of the new proposed technology and to identify the hotspots.

The first step of modeling phase concerns the calculation of all flows entering and leaving the system. Data refer to a time period equal to the expected lifetime of the plant (that is 20 years). In primary report, environmental impacts have been computed referring to 1MJ of syngas produced due to lack of data required from PPS unit.

During the Life Cycle Impact Assessment phase (LCIA) phase, the potential environmental impacts arising from inputs and outputs of system are quantified.
Impact categories to be considered have been defined according to FC-HY Guide, as listed below:

- Global Warming Potential (GWP)
- Acidification Potential (AP)
- Eutrophication Potential (EP)
- Photochemical Ozone Creation Potential (POCP).

The results of primary report have been brought into figures below.

Figure_21 Characterized and Normalized data for UNIfHY 1000 kWth

In the final report, assessment of different configuration indicates that ***UNIfHY technology with indirectly heated gasifier can act more efficiently and properly than the one with steam/oxygen gasifier. (***S/B: 0.5, T = 800°C, 1MWth).
In addition, evaluation of different scenarios relates that ***Scenario B (S/B:1.5) can be confidently introduced as the best scenario from environmental, energy demand and life cycle energy efficiency point of view.***

Scenario	Scenario base	Scenario A	Scenario B
Life cycle energy efficiency	0.28	0.40	0.43

Table 10. Energy efficiency under different scenarios

With the recovery of the calorific power of the syngas to produce the steam necessary for the gasification, ***the Unifhy 100 environmental performance could improve up to an 80% for the categories Photochemical Ozone Creation Potential and Primary energy from renewable resources that where influenced by the steam production. Eutrophication***

Potential and Global Warming Potential can drop up to a 50% considering this new configuration

		100 kWth prototype	100 kWth optimized	1 MWth	10 MWth
Acidification Potential (AP)	[kg SO2-Equiv.]	3,92E-04	6,07E-05	3,82E-05	3,55E-05
Eutrophication Potential (EP)	[kg Phosphate-Equiv.]	4,69E-05	2,72E-05	2,57E-05	2,54E-05
Global Warming Potential (GWP 100 years)	[kg CO2-Equiv.]	4,31E-01	2,85E-01	2,80E-01	2,80E-01
Photochem. Ozone Creation Potential (POCP)	[kg Ethene-Equiv.]	1,05E-03	8,66E-04	8,40E-04	8,40E-04
Primary energy from not renewable resources (net cal. Value)	[MJ]	1,61E+00	3,02E-01	2,16E-01	2,04E-01
Primary energy from renewable resources (net cal. value)	[MJ]	5,26E+00	4,50E+00	4,46E+00	4,45E+00

Table 11. Unifhy 100 Scenario Analysis

A simple optimisation for UNIfHY 1000 can result significant advantages that reach up to a 50% for Acidification Potential, Photochemical Ozone Creation Potential and Primary energy from non-renewable resources.

		Unifhy 1000 kWth	Unifhy 1000 kWth Optimized
Acidification Potential (AP)	[kg SO2-Equiv.]	4,03E-04	2,32E-04
Eutrophication Potential (EP)	[kg Phosphate-Equiv.]	1,84E-04	1,71E-04
Global Warming Potential (GWP 100 years)	[kg CO2-Equiv.]	5,16E-01	4,69E-01
Photochem. Ozone Creation Potential (POCP)	[kg Ethene-Equiv.]	7,93E-04	4,00E-04
Primary energy from not renewable resources (net cal. Value)	[MJ]	1,87E+00	9,43E-01
Primary energy from renewable resources (net cal. value)	[MJ]	7,55E+00	7,23E+00

Table 12. Unifhy 1000 Scenario Analysis

2.1.3.7 Work package 7 Dissemination and exploitation of project results

Here is quoted the results of D7.5 (Exploitation business report). For detailed dissemination and exploitation activities see section 2 (e.g. list of papers, conferences, patents).

Exploitation business report:

The partners have been engaged in defining a Commercial strategy to promote project results and fostering industrial exploitation of outcomes by arranging commercial presentations, attending international fairs, submitting patents to competent offices.

Regarding IP rights, one patent has been submitted. More in detail, in March 2016 Prof. Enrico Bocci, Res. Andrea Di Carlo and Prof. Pier Ugo Foscolo submitted the patent "Internal Circulating Dual Bubbling Fluidized Bed Gasifier" to the Italian Ministry of Economic Development. This invention pertains to an innovative small dual fluidized bed reactor for biomass steam gasification, a process which allows to produce syngas derived from an organic substrate.

The Exploitation business report was focused on the social and economic potentialities of the green H_2 market. A variety of application fields (green industrial processes, green chemistry, transportation) were evaluated, firstly by carrying out a study aimed to quantify the hydrogen market and focusing the attention about how it is employed, therefore by dividing the total amount per segment: industry, mobility, power to gas. For each one, it was intended to get which is the demand by sub-segment and sector, so that it could be possible to estimate size and plant numbers required. In fact, the biggest hydrogen market share was represented by industry sector with 90%, in particular chemical reactant for ammonia production, followed by methanol, nylon and polyurethane, whereas fuel treatment, metal processing and stationary generation account for a negligible part. Mobility is developing during the last years, hydrogen could be a valuable candidate to decrease pollution and fossil fuel dependence, therefore must be payed attention to this segment, thus power to gas is currently viable provided to ensure a maximum hydrogen level of 2%-v into the gas network. For each kind of final user, it has been found the typical hydrogen consumption used as feedstock in the industry process, this is a useful data to understand the gasifier power capacity that better fits to the particular customer needs. Regarding the hydrogen use in mobility application, the standards of purity in PEM-FC have been defined, then were listed all the specification inherent the Portable Purification System own of SNG treatment.

The two principal competitors of biomass gasification for H_2 production are Steam Methane Reforming and Water Electrolysis, they are mature technologies used for long time in the industry, in particular for refineries, metal processing, food, etc. Today, biomass gasification by means of indirect heating is not still competitive, but thanks to the innovations introduced by UNIfHY, it has been possible to change this affirmation. As you can see in the next table, in 2015 our simulations can demonstrate the potential in terms of Hydrogen production cost is very high especially in low plant-scale generation, because beyond 3.6 t_{H2}/day (that correspond to 10 MWth HI gasifier), SMR and WE production cost fall sharply, whereas biomass gasification supplied by waste and agricultural residues is not very affordable in these large-scale plant sizes.

Distribution	Dimension	Gasification	SMR	WE
	[t_{H2}/d]	[€/kg_{H2}]	[€/kg_{H2}]	[€/kg_{H2}]
Local (small)	0.036	9.8	12.7	12.7
Local	0.36	5.6	5.5	7.3
Semi-central	3.6	2.8	4.0	4.3

Table 6. Final Hydrogen production cost comparison

Relating to hydrogen production by biomass, on the basis of FCH-JU studies, the final production cost range with timeline 2030 is around 3.4-5.8 €/kg_{H2}, slightly higher than the benchmark cost of hydrogen by electrolysis or SMR, as you can see in the chart below.

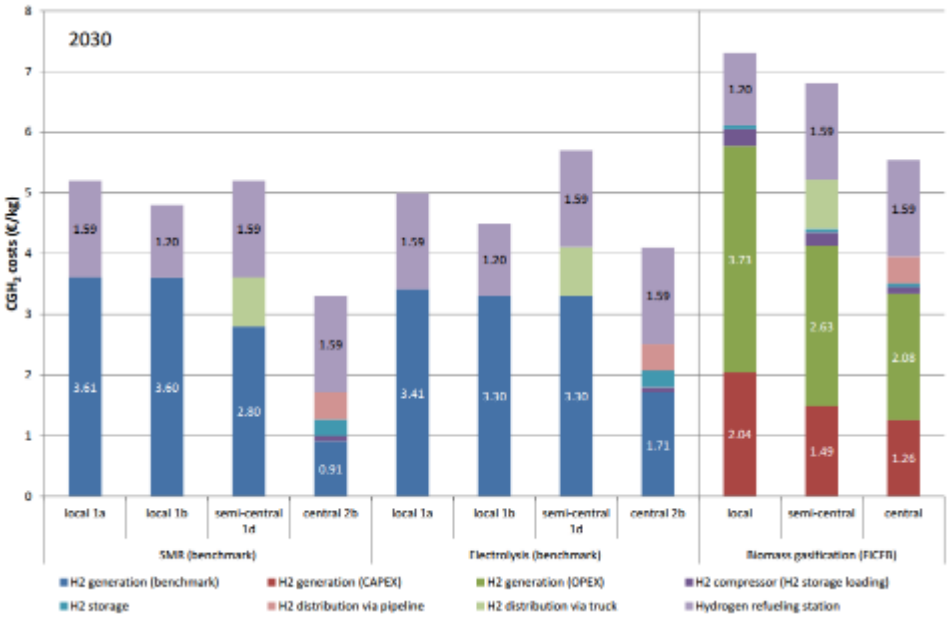


Figure_22 Costs of hydrogen from biomass gasification 'well-to-tank' benchmarked against hydrogen from SMR and water electrolysis

Summarizing what was described above it is possible to assess that the project UNIfHY succeeded in conceiving a low cost and energy efficient system to produce hydrogen from solid biomass.

Nevertheless, it has to be highlighted that current data for BTH (detailed in other sections of this deliverable) are more similar to the EU 2030 target than the costs related to SMR or WE. FCH asserts they are as the more convenient hydrogen production technologies for the future. If the new solutions in biomass gasification is develop, likely it will become more competitive in the future, even better than the 2030 forecasting, since it has a smaller cost reduction to gap over the next decade than WE or SMR. Moreover, the advantage of production of hydrogen via biomass gasification is advantageous in terms of emissions and environmental impact, granting the lowest GHG emission amongst the analyzed production technologies. Under the best scenario, UNIfHY technology with indirectly heated gasifier, releases 0.0134 kg CO_2 per 1MJ H_2 produced (0.3-3 t_{H2}/day) (see D.6.5 and D.5.3). CO_2 emission released by conventional process of hydrogen production (SMR) has been estimated 0.1kg/MJ_{H2} (0.4-2 t_{H2}/day) including natural gas supply. Therefore, H2 production via biomass gasification based on UNIfHY technology can save 0.08 kg CO_2 per 1 MJ of H_2 (87% reduction compared to SMR). By way of our elaborations we can claim taking into account only the total agricultural residues in Europe are able to satisfy over 520 MWth. For techno-economic reasons not all the biomass is exploitable, in fact searching the average power of gasifier supplied by wood-chip in Europe it shows, the value ranges between 3 MWth and 57 MWth, this means again not large-scale plant may be built. Finally, joying the average biomass power plant with the average customer demand shown in the next table, the applicability by sector is immediately highlighted.

Hydrogen market			Power [MWth]	
sector	**segment**	**subsegment**	**min**	**max**
Actual industry	chemical	ammonia	540	1081
		methanol	2501	
	refineries		68	1023
	metal processing		0.34	6.77
Actual mobility	retail stations	small	No local production	
		medium	0.4	
		large	0.7	
Foreseen mobility		small	1.37[3]	
		medium	3.43[4]	
		large	8.58[5]	

Table 7. Typical power of gasifier plant by sector

In order to evaluate potentials following the geographic distribution a more detailed analysis should be done. Nevertheless, not only this analysis is out of project scope but overall it has to be done when the plants are really planned. However, the table shows the limits and the potential of this technology and it provides interesting perspectives above all in mobility segment where the decentralized UNIfHY is more suitable for this purpose.
This achievement, main scope of the project, was obtained by designing, building and operating reactors to be coupled with the biomass gasifier in order to guarantee a continuous hydrogen production in distributed hydrogen generation, with high integration to minimize the use of external heating, increasing the overall efficiency and improving the current state of art of pilot plants. The feasibility of the whole process was assessed taking into account the purity of the hydrogen produced (PEMFC grade), the undesired by-products and the effluents.

2.1.3.8 Main R&D results conclusions

In conclusion the main technical results of the project can be summarized as follows:

- Different biomass feedstocks were characterized in order to choose the most suitable. Beyond the lignocellulosic biomass, that can be assumed equivalent, almond shells have been chosen owing to the lower price and greater bulk density;
- Three different kinds of filter candles (non-catalytic, catalytic and with catalytic foam) have been tested at different operative conditions (temperature, filtration velocity, gasification conditions). It has been noticed that the pressure drop is low and not depending on temperature; the H2 content increases from 38% to 60%, CH4 decreases from 10% to 2%, tar decreases from 10 to 1 g/Nm^3, the gas yield increases from 1 to 2 Nm^3/kg daf and the water conversion increases from 25% to 45%. Higher temperature, water content and ash/char accumulated increase the performance, as evidenced by experimental tests and CFD simulations;
- 150 ceramic alumina foams with 2 different porosities (30 and 45 ppi) were realized and impregnated with cerium oxide, in order to increase their specific surface area. They were impregnated with iron and copper catalysts to be used in the WGS reactor. 30 ppi foams were chosen because characterized by lower pressure drops. The optimized wet impregnation of

iron and copper (10% and 5% respectively) allowed to obtain a CO conversion of 43% with a residence time of 1 s;

- Bench scale tests on the PSA showed that it has good performance down to H2 concentrations of 34% at purity 5.0 with about 65% H2 yield;
- A ZnO guard bed was integrated in the PPS unit upstream the WGS reactor in order to remove the H2S content;
- Test campaigns were carried out with the 2 gasifiers in order to evaluate their performance with and without the catalytic candles. The startup time is about 5 and 24 hours respectively for the 100 and 1000 kWth prototypes. Tests without filter candles at different gasification agents (steam/air/oxygen) and temperatures showed gas yield from 1.3 to 1.7 kg/kg of dry biomass, hydrogen content from 7 to 35%-v dry, tars, as particulate, in the range of 10-20 g/Nm^3_{dry}, sulphur and chlorine compounds in the range of 50-90 ppmv, ammonia up to 1600 ppmv. Tests with filter candles showed the efficacy of the in-situ HT filtration system in removing particulate from the produced gas, reduced down to about 30 mg/ Nm^3_{dry} thus with a removal efficiency > 99%. The system operated in experimental runs for more than 12 hours. The H2 production at a concentration of 99.99%-v was achieved. The economic and LCA analysis showed that UNIfHY can match the H2 target cost of 5-10 €/kg and 1.6 kg CO2/kg.

The technical results above reported allowed the achievement of the following global results:

- A low cost and energy efficient system to produce hydrogen from solid biomass was conceived;
- The system consists in a steam gasifier with catalytic filter candles integrated, coupled with a Portable Purification System for the upgrading of the syngas;
- Two gasifiers of different sizes (100 kWth and 1000 kWt) were realized and operated in order to produce 50 and 500 kg H2/day, respectively;
- A Portable Purification System (PPS) was realized and operated. It was composed by a ZnO reactor for the H2S removal, a WGS reactor for the increase of the H2 content, and a PSA reactor for the separation of high purity hydrogen from the rest of the gases;
- The PPS has been coupled to UNIfHY 1000 producing continuous PEFC grade hydrogen with no use of external heating.
- The experimental efficiency reached was 38%, the simulation efficiency calculated was 50%;
- The H2 flow produced for the two sizes of systems are 36 and 360 kg/day (data based on the best scenario);
- The CAPEX calculated in the best scenario are 2 and 22 M€/(t/day) respectively for the 10 MWth and 0.1 MWth plants;
- The cost of H2 at the refueling station is 2 and 10 €/kg for the indirectly heated configuration, respectively for the sizes of 10 MWth and 0.1 MWth;
- The LCA analysis showed a CO_2 emission releases of 0.0134 kg CO2/MJ H2.

2.1.4 Potential impact, main dissemination activities and exploitation of results

The world is facing a massive energy and environmental challenge, a challenge that is particularly acute for Europe. According to the International Energy Agency world energy demand is set to increase by more than 50% by 2030; demand for oil alone is expected to grow by 41% during the same period. Oil and gas reserves are increasingly concentrated in a few countries that control them through monopoly companies. The dependence of Europe on imported oil and gas is growing: we import 50% of our energy, and it will be 65% by 2030 if we don't act. If oil price increases to 100$ per barrel by 2030, the EU annual energy import bill will increase by more than 350€ for every EU citizen, and none of this would bring additional jobs and wealth to Europe.

This scenario is not just a threat to the economy: the world emissions of CO2 (which accounts for 75% of all greenhouse gases) will increase by 55% by 2030, while EU emissions are set to increase by 5% during this period. If we let this happen, the results on our environment (climate change) and our way of life will be tremendous.

The **European Strategic Energy Technology** (SET) Plan has identified fuel cells and hydrogen among the technologies needed for Europe to achieve the targets for 2020-20% reduction in greenhouse gas emissions; 20% share of renewable energy sources in the energy mix; and 20% reduction in primary energy use – as well as to achieve the long-term vision for 2050 towards decarbonisation. This is in line with the Commission's Communication, "Energy for a Changing World – An Energy Policy for Europe", the goals of the Lisbon Strategy and the European Council's Conclusion on a European Energy Strategy for Transport, 29 May 2007.

A very big opportunity for research and technological development is facing us: the EU is in the position to take global leadership in catalyzing a new industrial revolution accelerating the change to low-carbon growth and increasing the amount of local low-emission energy that is produced and used.

Today the cost of renewable energy is generally speaking more expensive than "traditional" energy sources; this is truer speaking of fuel derived from renewable. However, the global market for renewable energy is expanding exponentially and the European Union is already leader in many of these areas (the EU renewable industry accounts for a turnover of 10 billion€ and employs 200000 people). The present energy policy of the Commission allows flexibility to Member States: each country should have a legally binding national renewable energy target but within this they are free to develop the type of renewable energy best suited to their own particular circumstances (renewable electricity, biomass for heating and cooling, biofuels, etc.). This directive implies increased competition in the development of efficient and cost-effective renewable energy systems especially in the broad and open field of power generation where the share of renewables is and is projected to be higher than for the overall energy consumption and modern biomass thermo-chemical conversion technologies are confronted mainly with wind and hydraulic systems. Among renewable energies, the most important source in the EU-28 was biomass and renewable waste, accounting for just under two thirds (64.2 %) of primary renewables production in 2013[14]. In the renewable electricity generation the share of biomass is 16% in 2005 about the same as that of wind. Europe's will to substitute solid biomass energy consumption (principally wood and wood waste, but also straw, crop harvest residues, vegetal

[14] Source: State of play on the sustainability of solid and gaseous biomass used for electricity, heating and cooling in the EU

and animal waste) for a part of that of fossil fuel origin is beginning to pay off. Solid biomass consumption is expected to rise to 107.3 Mtoe in 2030 and 115 Mtoe in 2050 according to reference scenario while under the 30% RES decarbonisation scenario a higher increase in solid biomass consumption is expected with 125.6 Mtoe in 2030 and 134.4 Mtoe in 2050. Domestic solid biomass production in EU 28 is expected to reach 89.2 Mtoe in 2030 and 91 Mtoe in 2050 according to reference scenario while under the 30% RES decarbonisation scenario no further change is expected after reaching 102 Mtoe in 2030.The EU owes this principally to the development of electricity resulting from CHP (combined heat and power) production.

UNIfHY is well harmonized with the main issues of the European energy policy here summarized in brief. The objectives and the content of this project are seen to be exactly in line with the overall objective FCH JU annual implementation plan: "The various thermal conversion technologies for hydrogen production from CO2-neutral precursors need to be addressed in terms of cost, efficiency and scalability, especially for the application to decentralized production schemes. In order to achieve maturity, hydrogen production equipment based on the use of biomass has to be further developed. Under this topic development of BTH thermal H2 production methods in order to allow hydrogen production from biomass, increase well-to-tank efficiency and contribute to a sustainable energy portfolio, is foreseen.".

More specifically, the following issues, among those set in the Work Programme, are addressed directly:

- Conception of low cost and energy efficient systems to produce hydrogen from solid biomass.
- Design and build a reactor for the continuous production of hydrogen at a pre-commercial scale, improving with respect on the current state of the art and pilot plants
- Feasibility assessment of the process taking into account the purity of the hydrogen produced (PEMFC grade), by-products (flue gas and off-gas) and effluents (heat from heat exchanger to cool gas)

the overall project objective is the development and scale up activities on materials and reactors design in order to obtain a continuous process for hydrogen production from biomass.

In particular regarding material:

- new catalytic filter candle already tested and optimized in previous EU project UNIQUE permitted to obtain a high purity syngas for the downstream hydrogen purification system, syngas free of tar, particulates and detrimental trace elements.
- new materials like Cu/Foam catalyst was tested and permitted to obtain high efficient H2 purification by means of WGS (water gas shift) also at atmospheric pressure, this was a constrain for small size, but sustainable, application like that required by the call;

while regarding reactors design:

- A new concept of biomass gasifier (UNIQUE technology) was utilized in the project, this new concept integrated in one reactor vessel the fluidized bed steam gasification of biomass, the hot gas cleaning and conditioning system and the reforming of residual methane, reducing thermal losses, thus keeping high the thermal efficiency, in a very compact system and in a cost-effective way. This technology was validated at bench scale during past UNIQUE project, while its feasibility was demonstrated also at

industrial scale. Considering results obtained, this new concept can be truly scaled-up and that it can operates in a continuous process for hydrogen production.
- New PSA for small scale application is interfaced for the complete purification of hydrogen for PEM application.

It is expected that this technology will have a noticeable impact to allow the production of a gas with the specifications required for use in PEM fuel cells in a cost-effective way, thus impacting in the all FCH program. Indeed, the final output of this technology will be the realization of a system in order to produce hydrogen in the forecourt size in the range of 0.1-10 MWth for a hydrogen filling station (from 36-3600 kg/day) with high integration thus to avoid the use of external heating and to increase the overall efficiency. Thanks to the high level of integration, the heating value of the gas, including purification, related to heating value of the feedstock is expected to be 50%. Thanks to the modulability of the various devices, a scalability to at least 500 kg/day as a project target is feasible and it is considered in the deliverable 5.3. Thus the project will impact also on the demonstration of large hydrogen production facilities and filling stations, like the topics 2.1 and 2.2 of "Hydrogen Production & Distribution" area and the topic 1.1 in the "Transportation & Refueling Infrastructure" area of this call. Moreover, the proposal impacts, as already mentioned in the point 1.1 and 1.2 of the section 1, on the Stationary Power Generation & CHP area, and specifically on the topic "Proof-of-concept fuel cell systems", e.g. close interaction with the research proposed in BIOFICIENCY, a proposal in this topic coordinated by ENEA aimed at Stand-alone decentralized generation using the same UNIQUE gasifier. In particular, the coordinator, CIRPS, has already in his Hydrogen Lazio Center, a hydrogen bus and a hydrogen filling station (electrolyser and fuel cell by Hydrogenics; dispenser, compressor, etc by the project partner Air Liquide), and he is involved in the demonstration of hydrogen vehicles in the Lazio region (the European region who owns the great bus fleet, managed by COTRAL). Thus the development of the UNIfHY technology will have also a first direct application on the Lazio Region existent and planned hydrogen filling stations (e.g. the UNIfHY 100 applied to the CIRPS-COTRAL hydrogen filling stations).

The gasifier UNIfHY 100 will be exploited:

- by CIRPS-USGM in the 3emotion FCH-JU project involved in applying hydrogen produced by biomass gasification integrated PPS in order to produce hydrogen for feeding refuelling stations for PMFC bus.
- also by UNIVAQ in a HBF2.0 (HyBioFlex 2.0: Flexible Hydrogen production from Biomass) it's Italian MiSE project. This project targets syngas production to feed internal combustion engine to produce thermal and electric power. (non risulta molto chiaro la flexible hydrogen production con il target indicato di produzione di syngas per la produzione di elettricità e calore in ICE)

The gasifier UNIfHY 1000 will be exploited:

by ENEA in the Italian BioSNG MiSE project in order to produce SNG from residual feedstocks via biomass gasification with the HT filtration system for in-situ particulate removal;

The projects involved in designing and operating biomass gasification and hydrogen production plants that are at the forefront of the technology in Europe and a primary world leader in gas cleaning and conditioning systems and hydrogen purification system together with universities and research centres either well recognized for their distinguished record of scientific contributions to the field and having the potential to develop first class research and innovation: an important and well balanced competence network, fully qualified to perform the ambitious research programme and provide technological enhancement worthy of commercial exploitation in the medium term. Furthermore, the core technologies utilized in UNIfHY were tested and validated during previous EU projects, UNIfHY now propose their integration to demonstrate the feasibility of the overall system and that the system is ready for commercialization by 2020. Because the high level of experience of the partners involved in project in themes of biomass gasification and hydrogen purification, and because most of the device are already commercialized (Filter candle, PSA) a durability of 20 years (140,000 h) with availability of 95% is expected for the complete system. Evidences of this were supplied during the project, thanks to the experimental activities as well to dedicated studies. Via the high integration of the subsystems as well as the high level of development, UNIfHY demonstrated that low system cost, also below 5 €/kg of H2 for 1-10 MWth, including CAPEX, is possible. Indeed, not only the technology is integrated and cost effective, but especially, utilizes low cost solid biomass wastes, thus preliminary analyses indicate a hydrogen cost of 2-11 €/kg, depending on the biomass cost.

Finally, a major general goal of UNIfHY is to contribute to the creation of a critical mass of resources and the integration and coherence of research efforts on the European scale. These are in fact the primary objectives of this consortium which is made of applicants established in four EU different countries. In addition, some of the partners are co-operating in this field of research since many years, and others are new-comers contributing to better address the original expertise to the specific topics of this project: a well assorted and established partnership, with the purpose to bring together academic, industrial and research organizations at the EU level to integrate them in a specific project well fitted into the FCH priorities. In more general terms, development of efficient biomass energy conversion to fuels can also provide a contribution to the agriculture sector, especially at this stage of the European policy that is considering and applying radical changes in the criteria to sustain food crops with financial incentives. A substantial increase in biomass energy production would require the development of energy crops which could contribute towards a solution of the agricultural over-production crisis. With many research programs presently in progress in U.S.A. with funding from the DOE and private companies and other countries such as Japan it is therefore extremely important and urgent to combine the efforts and capabilities available in Europe in order to maintain competitiveness on the global market. Due to the variety and complexity of the problems, capabilities and know-how, either scientific or technological, which are necessary for implementation of the technology, the project aims can only be fulfilled by the active collaboration of all the members of this consortium. The level of excellence in the consortium cannot be found at a single national level and is an example of the importance of an integrated European research area.

2.1.5 Web site and Relevant contact details

The project web site was designed and developed during the first part of the project but it was continuously updated till the project's ending. Being one of the major channels for visibility of the UNIfHY project, both the Coordinator and the other Beneficiaries have update including information also after the project ending. The project web site also serves as an interactive tool for internal and external communication. It provides virtual space to share documents and information, updates on the current research phases and results, information on further developments and advices about upcoming events open to the public. The restricted private area has been used by partners to share documents. The website was regularly updated during the first and second part of the project's lifetime (for more details see D7.2).

Project Public website: http://www.unifhy.eu/

Name, title and organisation of the scientific representative of the project's coordinator:

Prof. Enrico Bocci, Università degli Studi Guglielmo Marconi

Tel: + 39 06 37725341

Fax: +39 06 37725212

E-mail: e.bocci@unimarconi.it; progettieuropei@unimarconi.it

Hereafter is shown the list of all beneficiaries with the corresponding contact names. We specify only the main scientific persons, checking the following conferences, papers, patents lists and the names in the deliverables is possible to identify the specific activity of each person.

PARTNER	***ADDRESS***	***PERSON***	***MAIL***	***PHONE NUMBER***
1 PROJECT COORDINATOR USGM Università degli studi Guglielmo Marconi	www.unimarconi.it Via Plinio, 44 - 00193 Roma Lab: Via Paolo Emilio,29 - 00192 Roma	ENRICO BOCCI	e.bocci@unimarconi.it	0039 0637725341
		MATTEO MARTINI	m.martini@unimarconi.it	0039 0637725542
		ALESSANDRO DELL'ERA	a.dellera@unimarconi.it	0039 0637725268
2 CIRPS-DIMA Centro Interuniversitario di Ricerca Per lo Sviluppo sostenibile	www.cirps.it Piazza San Pietro in Vincoli, 10 - 00184 Roma Via Eudossiana, 18 - 00184 Roma	VINCENZO NASO	vincenzo.naso@uniroma1.it	0039 06.44585271
		GABRIELLA CALDERARI	gabriella.calderari@uniroma1.it	0039 0644585245
3 UNIVAQ Università degli studi dell'Aquila	www.univaq.it Via Giovanni Di Vincenzo 16/B, 67100 L'Aquila	PIER UGO FOSCOLO	Pierugo.foscolo@univaq.it	0862434214
		ANDREA DI CARLO	andrea.dicarlo79@gmail.com	
		KATIA GALLUCCI	katia.gallucci@univaq.it	0039 0862434230
4 ENEA	www.enea.it Lungotevere Thaon di Revel, 76 - 00196 Roma Trisaia Research Center Via Giacomo Matteotti, 75026 Rotondella MT	DONATELLA BARISANO	donatella.barisano@enea.it	+ 39 0636272674
		STEFANO STENDARDO	stefano.stendardo@enea.it	+39 0636272674
		PIERLUIGI PORTA	pierluigi.porta@enea.it	+39 0516098475
		PAOLO MASONI	paolo.masoni@enea.it	+39-0516098454
		CONCETTA TRIPEPI	concetta.tripepi@enea.it	+39 051 6098472
		GIACOBBE BRACCIO	giacobbe.braccio@enea.it	+39-0835-974387
5 PALL Filtersystems GmbH Werk Schumacher	www.schumacher-filters.de Zur Flügelau 70 - 74564 Crailsheim, Germany	STEFFEN HEIDENREICH	steffen.heidenreich@europe.pall.com	0049 7951 302
		MANFRED NACKEN	manfred.nacken@europe.pall.com	
6 UNISTRA Université Louis Pasteur	www-chimie.u-strasbg.fr Université de Strasbourg 4 rue Blaise Pascal CS 90032 F-67081 Strasbourg cedex	ALAIN KIENNEMANN	kiennemann@chimie.u-strasbg.fr	
		CLAIR COURSON	claire.courson@unistra.fr	+33-368852770

7 HYGEAR	www.hygear.nl Industrial Parc Kleefse Waard Westervoortsedijk 73, 6827 AV Arnhem	MARCO REP	marco.rep@hygear.nl	0031 889494324
		ELLART DE WIT	ellart.de.wit@hygear.nl	0031889494306
8 EPC	www.epc4h2.com c/o Dehnen, Rechtsanwalte, Prinz-Georg-Strasse, 91 - 40479 Dusseldorf Germany	JOHN CORNISH	jcornish@epc4h2.com	7209741709
9 AIR LIQUIDE	75 Quay d'Orsay, 75321 Paris cedex 07 www.france.airliquide.com	CHARLINE DUBOIS	charline.dubois@airliquide.com	+33 4 76 43 62 94
		LOUIS SENTIS	louis.sentis@airliquide.com	+33 4 76 43 64 12

2.2 USE AND DISSEMINATION OF FOREGROUND

2.2.1Section A (public)

2.2.1.1 PUBLICATIONS LIST

TEMPLATE A1: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES

Project Publications (Peer reviewed publication)

	D.O.I.	Title	Author(s)	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Date of publication	Relevant pages	Open access is/will be provided to thispublication
1	10.1016/j.pecs.2014.06.002	New concepts in biomass gasification	Steffen Heidenreich , Pier Ugo Foscolo	Progress in Energy and Combustion Science	Vol. 46	Elsevier BV	Netherlands	01/02/2015	72-95	No
2	10.1016/j.energy.2016.03.011	High quality syngas production via steam-oxygen blown bubbling fluidised bed gasifier	Stefano Stendardo , Pier Ugo Foscolo , Mirko Nobili , Silvera Scaccia	Energy	Vol. 103	Elsevier Limited	United Kingdom	01/05/2016	697-708	No
3	10.1016/j.fuproc.2015.06.008	Steam/oxygen biomass gasification at pilot scale in an internally circulating bubbling fluidized bed reactor	D. Barisano , G. Canneto , F. Nanna , E. Alvino , G. Pinto , A. Villone , M. Carnevale , V. Valerio , A. Battafarano , G. Braccio	Fuel Processing Technology	Vol. 141	Elsevier	Netherlands	01/01/2016	74-81	No
4	10.1016/j.ijhydene.2014.09.022	Biomass to fuel cells state of the art: A review of the most innovative technology solutions	E. Bocci , A. Di Carlo , S.J. McPhail , K. Gallucci , P.U. Foscolo , M. Moneti , M. Villarini , M. Carlini	International Journal of Hydrogen Energy	Vol. 39/Issue 36	Elsevier Limited	United Kingdom	01/12/2014	21876-21895	No
5	10.1016/j.ijhydene.2015.04.044	Development of a CFD model for the simulation of tar and methane steam reforming through a ceramic catalytic filter	E. Savuto , A. Di Carlo , E. Bocci , A. D'Orazio , M. Villarini , M. Carlini , P.U. Foscolo	International Journal of Hydrogen Energy	Vol. 40/Issue 25	Elsevier Limited	United Kingdom	01/07/2015	7991-8004	No
6	10.1016/j.ijhydene.2016.05.171	Influence of the main gasifier parameters on a real system for hydrogen production from biomass	M. Moneti , A. Di Carlo , E. Bocci , P.U. Foscolo , M. Villarini , M. Carlini	International Journal of Hydrogen Energy	Vol. 41/Issue 28	Elsevier Limited	United Kingdom	01/07/2016	11965-11973	No
7	10.1016/j.ijhydene.2015.01.065	Improvement of steam reforming of toluene by CO2 capture using Fe/CaO–Ca12Al14O33 bi-functional materials	Ingrid Zamboni , Yvan Zimmermann , Alain Kiennemann , Claire Courson	International Journal of Hydrogen Energy	Vol. 40/Issue 15	Elsevier Limited	United Kingdom	01/04/2015	5297-5304	No
8	10.1016/j.ijhydene.2015.03.169	Gas conditioning in H2 rich syngas production by biomass steam gasification: Experimental comparison between three innovative	A. D'Orazio , S. Rapagnà , P.U. Foscolo , K. Gallucci , M. Nacken , S. Heidenreich , A. Di Carlo , A. Dell'Era	International Journal of Hydrogen Energy	Vol. 40/Issue 23	Elsevier Limited	United Kingdom	01/06/2015	7282-7290	No

	D.O.I.	Title	Author(s)	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Date of publication	Relevant pages	Open access is/will be provided to thispublication
		ceramic filter candles								
9	10.1016/j.ijhydene.2015.05.128	Reforming of tar contained in a raw fuel gas from biomass gasification using nickel-mayenite catalyst	Andrea Di Carlo , Domenico Borello , Mario Sisinni , Elisa Savuto , Paolo Venturini , Enrico Bocci , Koji Kuramoto	International Journal of Hydrogen Energy	Vol. 40/Issue 30	Elsevier Limited	United Kingdom	01/08/2015	9088-9095	No
10	10.1016/j.apcata.2014.10.038	Catalytic conversion of methane over a biomass char for hydrogen production: deactivation and regeneration by steam gasification	A. Dufour , A. Celzard , V. Fierro , F. Broust , C. Courson , A. Zoulalian , J.N. Rouzaud	Applied Catalysis A: General	Vol. 490	Elsevier	Netherlands	01/01/2015	170-180	No
11	10.1016/j.apcatb.2013.02.046	Simultaneous catalytic H2 production and CO2 capture in steam reforming of toluene as tar model compound from biomass gasification	I. Zamboni , C. Courson , D. Niznansky , A. Kiennemann	Applied Catalysis B: Environmental	Vol. 145	Elsevier	Netherlands	01/02/2014	63-72	No
12	10.3390/en6073167	Hydrogen-Rich Gas Production by Sorption Enhanced Steam Reforming of Woodgas Containing TAR over a Commercial Ni Catalyst and Calcined Dolomite as CO2 Sorbent	Mario Sisinni , Andrea Di Carlo , Enrico Bocci , Andrea Micangeli , Vincenzo Naso	Energies	Vol. 6/Issue 7	Molecular Diversity Preservation International	Switzerland	01/07/2013	3167-3181	Yes
13	10.1016/j.egypro.2014.01.027	State of Art of Small Scale Biomass Gasification Power Systems: A Review of the Different Typologies	E. Bocci , M. Sisinni , M. Moneti , L. Vecchione , A. Di Carlo , M. Villarini	Energy Procedia	Vol. 45	Elsevier BV	Netherlands	01/01/2014	247-256	Yes
14		Air-Steam Biomass Gasification in a Fluidised Bed Reactor in Presence of Ceramic Filters	Sergio Rapagnà, Giacomo Spinelli	Chemical Engineering Transactions	43	null		03/10/2015	397-402	Yes
15	10.1016/j.crci.2014.12.004	High-temperature Water–Gas Shift catalysts for hydrogen enrichment of a gas produced by biomass steam gasification	Charlotte Lang , Xavier Secordel , Yvan Zimmermann , Alain Kiennemann , Claire Courson	Comptes Rendus Chimie	Vol. 18/Issue 3	Elsevier Masson SAS	Italy	01/03/2015	315-323	No
16		Hydrogen rich gas from catalytic steam gasification of biomass in a fluidized bed containing catalytic filters	S. Rapagnà, A. D'Orazio, K. Gallucci, P. U. Foscolo, M. Nacken, S. Heidenreich	Chemical Engineering Transactions	37	null		07/07/2014	157-162	Yes
17	10.1016/j.egypro.2014.01.002	Production of Gaseous Carriers Via Biomass Gasification for Energy	D. Barisano , G. Canneto , F. Nanna , A. Villone , E. Alvino , M. Carnevale , G. Pinto	Energy Procedia	Vol. 45	Elsevier BV	Netherlands	01/01/2014	2-11	Yes

	D.O.I.	Title	Author(s)	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Date of publication	Relevant pages	Open access is/will be provided to thispublication
		Purposes								
18	10.1007/s11356-016-6444-4	Catalytic gasification of biomass (Miscanthus) enhanced by CO2 sorption	I. Zamboni , M. Debal , M. Matt , P. Girods , A. Kiennemann , Y. Rogaume , C. Courson	Environmental Science and Pollution Research	0	Ecomed Publishers	Germany	21/03/2016	1-14	No
19	10.1016/j.fuproc.2015.01.020	New DeTar catalytic filter with integrated catalytic ceramic foam: Catalytic activity under model and real bio syngas conditions	Manfred Nacken , Gino V. Baron , Steffen Heidenreich , Sergio Rapagnà , Annalisa D'Orazio , Katia Gallucci , Joeri F.M. Denayer , Pier Ugo Foscolo	Fuel Processing Technology	Vol. 134	Elsevier	Netherlands	01/06/2015	98-106	No
20	10.3390/su6085463	Goal and Scope in Life Cycle Sustainability Analysis: The Case of Hydrogen Production from Biomass	Milena Stefanova , Concetta Tripepi , Alessandra Zamagni , Paolo Masoni	Sustainability	Vol. 6/Issue 8	MDPI AG	Switzerland	01/08/2014	5463-5475	Yes
21	10.1088/1742-6596/655/1/012034	Influence of temperature on oxygen permeation through ion transport membrane to feed a biomass gasifier	T Antonini , P U Foscolo , K Gallucci , S Stendardo	Journal of Physics: Conference Series	Vol. 655	Institute of Physics Publishing	United Kingdom	16/11/2015	012034	Yes
22	10.1016/j.cep.2014.11.009	Oxygen transport by ionic membranes: Correlation of permeation data and prediction of char burning in a membrane-assisted biomass gasification process	Tania Antonini , Katia Gallucci , Valentina Anzoletti , Stefano Stendardo , Pier Ugo Foscolo	Chemical Engineering and Processing	Vol. 94	Elsevier	Netherlands	01/08/2015	39-52	No
23	10.1016/j.egypro.2015.11.790	The Case Study of an Innovative Small Scale Biomass Waste Gasification Heat and Power Plant Contextualized in a Farm	Mauro Villarini , Enrico Bocci , Andrea Di Carlo , Elisa Savuto , Vanessa Pallozzi	Energy Procedia	Vol. 82	Elsevier BV	Netherlands	01/12/2015	335-342	Yes
24	10.12988/ces.2015.56191	Simulations of a plant with a fluidized bed gasifier WGS and PSA	L. Vecchione, M. Moneti, S. Cocchi, M. Villarini, M. Sisinni, A. Micangeli	Journal of Agricultural Engineering	44	page press		24/05/2015	587-590	Yes
25	10.4081/jae.2013.s2.e116	Parametric experimental tests of steam gasification of pine wood in a fluidized bed reactor	L. Vecchione , M. Moneti , S. Cocchi , M. Villarini , M. Sisinni , A. Micangeli	Journal of Agricultural Engineering	Vol. 44/Issue 2s	page press	Italy	09/06/2013	587-590	No

Project Publications (Article/Section in an edited book or book series)

N°	D.O.I.	Title	Author(s)	Title of the book (series)	Volume	Date of publication	Publisher	Publisher location	Relevant pages	Open access is/will be provided to this publication
1	10.1007/978-3-642-39643-4_20	Technical-Economic Analysis of an Innovative Cogenerative Small Scale Biomass Gasification Power Plant	Enrico Bocci , Andrea Di Carlo , Luigi Vecchione , Mauro Villarini , Marcello De Falco , Alessandro Dell'Era	Computational Science and Its Applications – ICCSA 2013	Vol. 7972	01/01/2013	Springer Berlin Heidelberg	Berlin, Heidelberg	256	No
2		Hydrogen rich gas from catalytic steam gasification of biomass in a fluidized bed containing catalytic filters	S. Rapagnà, A. D'Orazio, K. Gallucci, P. U. Foscolo, M. Nacken, S. Heidenreich;	Chemical Engineer Transactions	37	07/07/2014	Italian Association of Chemical Engineering - AIDIC	Italy	157-162	Yes

2.2.1.2 LIST OF ALL DISSEMINATION ACTIVITIES

TEMPLATE A2: LIST OF ALL DISSEMINATION ACTIVITIES, STARTING WITH THE MOST IMPORTANT ONES								
N°	**Type of activities**	**Main leader**	**Title**	**Date/Period**	**Place**	**Type of audience**	**Size of audience**	**Countries addressed**
1	Oral Presentation to a scientific event	Enea	24th European Biomass Conference and Exhibition 1000 kWth Gasification Pilot Plant with In-vessel high Temperature Gas Filtration	June 6th-9th, 2016	Amsterdam, The Netherlands	Scientific community (higher education, Research) Industry Civil society Policy makers	2000	International
2	Oral Presentation to a scientific event	Enea	23rd European Biomass Conference and Exhibition (2015) Steam/oxygen biomass	June 1st-2nd, 2015	Wien, Austria	Scientific community (higher education, Research) Industry	2000	International

			gasification in a 1000 kWth pilot plant			Civil society Policy makers		
3	Oral Presentation to a scientific event	Enea	22nd European Biomass Conference and Exhibition (2014) Biomass to hydrogen thermal conversion process modeling and simulation activities in the UNIfHY project	June, 23th-26th, 2014	Hamburg, Germany	Scientific community (higher education, Research) Industry Civil society Policy makers	2000	International
4	Oral Presentation to a scientific event	CIRPS-LA Sapienza	21st European Biomass Conference and Exhibition (2013) Steam Gasification of Pine Wood in a Fluidized Bed Reactor: Model Development and Validation at Different Operating Conditions	June, 3th-7th 2013	Copenhagen, Denmark	Scientific community (higher education, Research)	1800	International
5	Oral Presentation to a scientific event	USGM	10th Conference on Sustainable Development of Energy Water and Environment Systems – SDEWES Hydrogen production from biomass gasification: techno-economic analysis of innovative prototype	September 29th, 2015	Dubrovnik, Croatia	Scientific community (higher education, Research)	1000	International
6	Oral Presentation to a scientific event	CIRPS-LA Sapienza	The European Fuel Cell Technology & Applications-Piero Lunghi Conference Biomass to fuel cells state of the art: A review of the most innovative technology solutions	December 11th-13th,2013	Rome, Italy	Scientific community (higher education, Research)	1800-	International
7	Oral Presentation to a scientific event	Enea	3rd International Energy, Life Cycle Assessment, and Sustainability Workshop & Symposium (ELCAS3) LCA AND LCSA of hydrogen production from biomass	July 7th-9th, 2013	Nisyros, Greece	Scientific community (higher education, Research) Industry Civil society Policy makers	1500	International
8	Oral Presentation to a	UNIVAQ	BioEnergy IV: Innovations in Biomass Conversion for Heat,	June 9th-14th, 2013	Otranto, Italy	Scientific community (higher education,	1000	International

	scientific event		Power, Fuels, and Chemicals			Research) Industry Civil society Policy makers		
9	Oral Presentation to a scientific event	UNISTRA	EuropaCat-XI International Congress of Catalysis	September 1st-6th, 2013	Lyon, France	Scientific community (higher education, Research) Industry Civil society Policy makers	1000	International
10	Oral Presentation to a scientific event	UNISTRA	GDRI International Group of Research "Catalysis for Environment, Depollution, Renewable Energy"	September 9th-13th, 2013	Wierzba, Poland	Scientific community (higher education, Research) Industry Civil society Policy makers	1000	International
11	Oral Presentation to a scientific event	UNISTRA	EHEC European Hydrogen Energy Conference 2014	March 12th-15th, 2014	Sevilla, Spain	Scientific community (higher education, Research) Industry Civil society Policy makers	1000	International
12	Oral Presentation to a scientific event	UNISTRA	PREPA11 11th International Symposium "Scientific Bases for the Preparation of Heterogeneous Catalysts	July 6th-10th, 2014	Louvain, Belgium	Scientific community (higher education, Research)	1000	International
13	Oral Presentation to a scientific event	UNISTRA	AWPAC 2014 3rd International symposium on air & water pollution abatement catalysis	September 1st-5th 2014	Cracow, Poland	Scientific community (higher education, Research)	1000	International
14	Oral Presentation to a scientific event	UNISTRA	SFGP 2013 Société France de Génie des Procédés	October, 8th-10th, 2013	Lyon, France	Scientific community (higher education, Research)	1000	France and francophones countries
15	Oral Presentation to a scientific event	UNISTRA	GECAT Groupe d'Etude en Catalyse	May 12th-15th, 2014	Cluny, France	Scientific community (higher education, Research)	1000	France and francophones countries
16	Oral	UNISTRA	GECAT Groupe d'Etude en	May 26th-29th,	Obernai, France	Scientific community	1000	France and

	Presentation to a scientific event		Catalyse	2015		(higher education, Research)		francophones countries
17	Oral Presentation to a scientific event	UNISTRA	Congrès de la Société Chimique de France – 2015	July 5th-9th, 2015	Lille, France	Scientific community (higher education, Research)	1000	France and francophones countries
18	Oral Presentation to a scientific event	HyGear	Hannover Messe 2013	April 8th-12th, 2013	Hannover, Germany	Scientific community (higher education, Research) Industry	6550	International
19	Oral Presentation to a scientific event	ENEA	iSGA-4 4th International Symposium on Gasification and its Applications	September 2nd – 4th, 2014	Wien, Austria	Scientific community (higher education, Research) Industry	1000	International
20	Oral Presentation to a scientific event	USGM	Programme Review Days	November, 17th-18th 2015	Brussels, Belgium	Scientific community (higher education, Research)	1000	International
21	Oral Presentation to a scientific event	CIRPS	Programme Review Days	November, 10th-11th 2014	Brussels, Belgium	Scientific community (higher education, Research)	1000	International
22	Oral Presentation to a scientific event	CIRPS	Programme Review Days	November, 11th and 12th 2013	Brussels, Belgium	Scientific community (higher education, Research)	1000	International
23	Oral Presentation to a scientific event	Enea	Biomass valorisation for energy production-technological solutions	February 2nd, 2013	Turin, Italy	Scientific community (higher education, Research)	100	International
24	Oral Presentation to a scientific event	CIRPS-La Sapienza	SEP – Green R-evolution Exhibition	March 19th-22nd, 2013	Padova, Italy	Scientific community (higher education, Research) Industry Civil society Policy makers	20000	International
25	Web sites/Application	CIRPS/USGM	UNIfHY Web Site	01/09/2012 – 31/03/2016	Rome	Scientific community (higher education, Research) Policy makers	More than 500	International

26	Web sites/Application	USGM	UNIfHY Newsletter	March 2016	Rome	Scientific community (higher education, Research) Policy makers	More than 100	International
27	Flyers	CIRPS-USGM	UNIfHY Brochure	16.04.2014 01.09.2015 08.03.2016	Rome	Scientific community (higher education, Research) Policy makers	More than 500	International

2.2.2Section B (public)

Part B1

2.2.2.1 LIST OF APPLICATIONS

Regarding the patents, despite the Annex I provided that five new patents were expected (one on 100 kWth gasifier, two on catalysts and sorbents, one on WGS and one on PPS units), one patent on the first version of UNIfHY 100 kWth and another on catalytic candles was submitted. As anticipated, in March 2016 Prof. Enrico Bocci, Res. Andrea Di Carlo and Prof. Pier Ugo Foscolo submitted the patent "Internal Circulating Dual Bubbling Fluidized Bed Gasifier" to the Italian Ministry of Economic Development. This invention pertains to an innovative small dual fluidized bed reactor for biomass steam gasification, a process that allows to produce syngas derived from an organic substrate. A new patent is going to be submitted in a short time, it will focus on the re-designed UNIfHY 100 kWth, as the first patents, it will be submitted to the Italian Ministry of Economic Development. Pall Corporation possess several international patents on the whole gasification system among which the ceramic catalytic candles, Pall registered the first patent in 2008, but they were accepted and registered within the second period of UNIfHY.

In same way it is expected a further patent on catalysts, while sorbents, WGS and PPS, follow the final achievements obtained at the end of the project, see paragraph 1.2.2.7.

TEMPLATE B1 : LIST OF APPLICATIONS FOR PATENTS, TRADEMARKS, REGISTERED DESIGNS, ETC.					
Type of IP Rights	**Confidential Click on YES/NO**	**Foreseen embargo date dd/mm/yyyy**	**Application reference(s) (e.g. EP123456)**	**Subject or title of application**	**Applicant (s) (as on the application)**
Patents	NO	01/11/2016	Application n°102016000033240 submitted to the Italian Ministry of Economic Development	Internal Circulating Dual Bubbling Fluidised Bed Gasifier	Andrea Di Carlo Enrico Bocci Pier Ugo Foscolo Università degli Studi Guglielmo Marconi
Patents	NO	21/10/2014	BRPI0810731	Gasification apparatus and method for generating syngas	Pall Corporation

				from gasifiable feedstock material	
Patents	NO	22/10/2013	US8562701	Gasification apparatus and method for generating syngas from gasifiable feedstock material	Pall Corporation

Part B2:

2.2.2.2 FOREGROUND

TEMPLATE B2: OVERVIEW TABLE WITH EXPLOITABLE FOREGROUND								
Type of exploitable foreground	**Description of exploitable Foreground**	**Confidential Click on YES/NO**	**Foreseen embargo date dd/mm/yyyy**	**Exploitable product(s) or measure(s)**	**Sector(s) of application**	**Timetable, commercial use**	**Patents or other IPR exploitation (licences)**	**Owner & Other Beneficiary(s) involved**
Commercial exploitation of R&D results	Gasifier plant: 1. IH: Internal Circulating Dual Bubbling Fluidized Bed Gasifier 2. OX: Oxygen Fluidized Bed Gasifier	NO		Gasifier	1. CHP 2. Biofuels	**2018**	IH: Application submitted; application new version in submission phase OX: patented before UNIfHY	IH: Foscolo, Di Carlo, Bocci, USGM, OX: Foscolo, Germanà, Braccio, ENEA Poss. licensing to OEM as Walter Tosto
Commercial exploitation of R&D results	Hot gas conditioning system through catalytic candles	NO		Catalytic candles	1. CHP 2. Fuels 3. Chemical	**2018**	Old version patented before UNIfHY; application new version is foreseen	Foscolo, Rapagnà, Nacken, Pall Schumacher, Poss. licensing to OEM as Pall Schumacher, Haldor-Topsoe, etc
Commercial exploitation of R&D results	Low Pressure WGS	NO		1. Catalytic foam 2. Reactor	1. Fuels 2. chemical	**2018**	Catalytic foam application foreseen	UNISTRA (catalyst)– Pall Schumacher (foam) – HyGear (reactor)
Commercial exploitation of R&D results	CO2 capture system	NO		Sorbents	CO2 capture	**2020**	Sorbents application foreseen	UNISTRA – ENEA - UNIVAQ
Commercial exploitation of	Gas conditioning system	NO		PPS	Hydrogen production	**2020**	Foreseen when will be a market	HyGear
Commercial exploitation of R&D results	Biomass to Hydrogen plant	NO		UNIfHY plant	Hydrogen production	**2020**	Foreseen when will be a market	USGM, UNIVAQ, HYGEAR

EXPLOITABLE FOREGROUNDS DETAILLED

Gasifier plant:

UNIVAQ intends to exploit the gasifier in HBF2.0 (HyBioFlex 2.0: Flexible Hydrogen production from Biomass) Italian MiSE project (2016-2019); moreover, it has been furtherly improved with new design, characterized by two concentric cylinders: gasification and combustion chambers. This configuration is very advantageous from a thermal point of view: the heat produced in the combustor (internal) is not dispersed towards the external environment but it is completely given to the gasification chamber (external) to help the endothermic reactions not to mention the better re-circulation of inert material and the less nitrogen leakages from the combustor to the gasifier and the higher freeboard that guarantee a better accomplishments of the secondary reactions and the better placement of the filter candles.

The gasifier UNIfHY 1000 will be exploited by ENEA in the Italian BioSNG MiSE project in order to produce SNG from residual feedstocks via biomass gasification with the HT filtration system for in-situ particulate removal; BioSNG requires syngas with high hydrogen content and purity, thus UNIfHY gasifier fits very well with these purposes.

The first version of the UNIfHY 100 kWth IH gasifier has been submitted for Italian patent (owner Di Carlo, Bocci, Foscolo, USGM, 2016 application number 102016000033240) and it is in submission a patent request for the second version. The second patent regards the new design of DFBG. The gasifier has been tested intensively this led to a new design, thereby it could be marketable only after the test in HBF2.0, thus the commercial use is foreseen in 2018-2019. The oxygen gasifier has been already patent (number ITRM20080022 of 2009) by Braccio, Canneto, Foscolo, Germanà, (ENEA, UNIVAQ).

Being UNIfHY gasifiers managed by research centers (owing to the research activities) in UNIfHY consortium is missing a gasifier company. Thus, the patent cannot be exploited directly by one of the partners. The inventors are working for a technology transfer company (as the one, i.e. ENERTECNA, involved in the related Regional (HBF) and National (HBF2.0) projects, or licensing to companies from the large enterprise involved in HBF2.0, Walter Tosto, to a plethora of Italian and European gasifier companies and even also some of same size pellet boiler companies, sector in which Italy has the European leadership.

Further research is needed not only to demonstrate at pilot scale (0.1 - 1 MWth) that the gasifiers are able to reach stable optimal values (e.g. 850°C gasifier temperature, S/B=1.5, availability 95%, 2-20 h starting time) but overall to overcome shortcomings highlighted during the tests (thermal control, thermic dispersions, etc.) and further improvements (e.g. sorbents, etc.).

The potential impact of the IH and OX gasifiers is high owing not only to the future use following the global topic goals (produce pure hydrogen from biomass in continuous mode and at pilot/industrial scale) but overall to the actual use (after UNIfHY project) of the two pilot/industrial scale facilities in order to produce, respectively, CHP and SNG. Indeed, in these two new projects, there are in the consortiums power plant / chemical companies interested in developing commercially the gasifiers. Thus, it is possible to foreseen not only an impact on the advancement of these technologies within the related papers and conference (see related tables) but also an impact on the market if the technology transfers or the licensing activities foreseen will be successful.

Hot gas conditioning system:

The purpose of the hot gas conditioning system is to remove the main pollutants from the syngas generated in the gasifier. The filter candles are designed to physically remove the solid particulate and, thanks to the catalytic action, to promote the reactions of tar and methane reforming. In this way tar and particulate can be removed and the syngas upgraded directly in the freeboard of the gasifier (without or at least reducing following gas cleaning/upgrading equipment that can account for greater space and cost of the gasifier itself).

In the project it was foreseen that PALL should have designed and realized catalytic filter candles for lab scale and for plant scale tests. The lab scale catalytic filter candles were realized and delivered to UNIVAQ; they were tested in a bench scale reactor and gave good results in terms of tar, methane and ammonia reduction, providing also increase in gas yields and water conversion. From the tests was observed a low propensity in Methane reforming, thereby there are two alternatives: developing another catalytic composite which take into account also the Methane in addition to Tar, or developing a secondary SMR working after the current catalytic candles. Concerning the plant scale catalytic filter candles, only the non-catalytic candles were realized and delivered to ENEA and CIRPS-USGM; for this reason the plant scale tests were realized with the non-catalytic filter candles filled with commercial catalyst pellets. Moreover, during the integrated configuration test on UNIfHY 1000, some temperature problems (excessive decrease) caused a malfunction of the filter candles. Further developments in this field can be the realization and tests on plant scale catalytic filter candles in order to analyze their performance with raw syngas from plant scale biomass gasification. Moreover, further research on new types of catalysts that can be more suitable for tar and methane reforming and can be less affected by the degradation phenomena like carbon deposition, sintering and Sulphur poisoning have to be done.

The catalytic candles have been patented (from the US patent US20070915447P of 2007 and International WO2008EP03523 of 2008, to the US8562701 of 2013 and the European Bibliography Patent BRPI0810731 of 2014) by Pall corporation, Heidenreich, Nacken, Foscolo, Rapagnà (a patent of Pall corporation with the two Pall persons and the Professors Foscolo and Rapagnà involved in UNIQUE and UNIfHY projects). The catalytic candles patents should be exploited by Pall corporation but owing to the reduced involvement of Pall in this sector, see 1 and 2 UNIfHY amendments, it can be foreseen also an exploitation by other sector companies as Haldor Topsoe, foreseen a licensing from Pall or new patents of these companies (related to the improvements described before: changes of catalysts and supports; or following similar products of these companies). Owing to the further research needed and the reduced Pall involvement (Pall commercializes non catalytic candles, Haldor Topsoe very different catalytic candles) timetable for commercial use in the sector of chemical plants of these catalytic candles can be probably around 2018.

The potential impact of the catalytic candles is high owing not only to the future use following the global topic goals (produce pure hydrogen from biomass in continuous mode and at pilot/industrial scale) but overall to the actual use (after UNIfHY project) of the candles in the two pilot scale facilities in order to produce, respectively, CHP and SNG. Indeed, the biomass CHP, bioSNG and biofuels markets will foster the commercial application of this technology respect to the use for pure hydrogen production. Thus, it is possible to foreseen not only an impact on the advancement of this technology within the related papers and conference (see related tables) but also an impact on the market if the exploitation of Pall or other companies, via licensing, will be successful.

Low pressure WGS:

The main aim of the low pressure WGS system is to realize a WGS catalytic reactor operable at almost atmospheric pressure and thus applicable to small scale gasification plants. The operation at atmospheric pressure could be possible thanks to the ceramic foams impregnated with Cu and Fe catalysts, which can also increase the efficiency of the gas-solid contact (catalytic surface area). The purpose of this component is to convert CO in order to obtain a higher H2 content in the syngas. The tests carried out at lab scale on the WGS foams gave good results but the tests on the integrated configuration (gasifier+PPS) showed that the WGS reactor did not operate as expected owing to temperatures too low for operation of the WGS and catalyst not sufficiently activated. Thus further research is needed to replicate on pilot scale the good results obtained in the bench scale tests and to optimize the integrated configuration.

The low pressure WGS foam and reactor realized should be patented by PALL, UNISTRA and HyGear who participated at the realization and tests. In particular, the WGS reactor could soon be exploited (probably around 2018) directly by HyGear or licensed to other companies of the small scale chemical/fuel production sectors. Also in this case bioSNG and biofuels market in general will foster the commercial application of this technology respect to the only pure hydrogen market.

CO2 capture system:

The aim of CO2 capture systems via absorption enhanced reforming is to take advantage from coupling multiple catalytic reactions (tar and methane steam reforming and water gas shift) with the non-catalytic gas-solid reaction that allows for CO2 uptake by a solid sorbent. This system could allow to produce a syngas rich in H2 directly inside the gasifier and to capture and sequestrate CO2 from biomass syngas in one single reactor.

Bench scale tests demonstrated that the technology is effective and high performing. The project did not foresee the integration of sorbents in the reactor, thus the materials were synthesized, characterized and tested, in this project, only at a lab scale. Future developments are surely focused on the integration of these materials in a dual bed gasification system (as in the AER GAS I&II projects but integrated with the UNIfHY hot gas conditioning system for hydrogen production) in order also to check the mechanical resistance. The possible successful achievements of the integration of the sorbents in the bed of the gasifier could bring several advantages, such as process simplification and intensification (not to mention the advantages of reach high H2 % in the syngas without high gasification temperatures and high steam to biomass ratio).

The CO2 capture sorbents should be patented by UNIVAQ and ENEA. At the moment the results are used, by ENEA, the coordinator, and UNIVAQ, in ASCENT (2014-2018), a European project focused on the study of catalyst-sorbent materials. The CO2 capture system could be exploited (probably around 2020), after several performance analyses, by sector companies, as the one in the ASCENT project were the project targets is to develop products that partners would be ready to commercialize as extension of the actual portfolio or as new lines. The impact is high because not only it can improve the hydrogen production efficiency but also can reduce the energy penalty associated with capturing carbon dioxide during power generation, and create a sustainable market for low carbon emission power with low associated energy penalties.

Gas conditioning system:

The purpose of the gas conditioning system is to upgrade the syngas generated from biomass gasification in order to obtain pure H2 from renewable energy sources. It mainly consists of a

ZnO desulfurization reactor, a WGS reactor and a Pressure Swing Adsorber (PSA) where all the components can fit inside a container, make it portable (Portable Purification System, PPS).

The experimentation of the PPS coupled with the gasification system showed that the PSA was able to produce H2 with at least a purity of 99.99%-v and an H2 yield of at least 66.4%. Nevertheless the catalytic candles and WGS malfunctioning at pilot/industrial scale affected the performance of the entire PPS and his life. Future developments can be thus focused on obtaining the WGS lab scale performance also at pilot/industrial scale and on longer tests of the global system in order to verify the maintenance items (catalysts, valve seals, etc.) and reduce the cost (also because of improvements as CO2 capture or methane reforming which reducing flow, reduce size and increase efficiency).

The PPS should be patented and exploited, after the further research described above, by HyGear, probably around 2019. At the moment the results can be useful for other research projects such as 3Emotion, a European project focused on H2 buses demonstration and related refueling stations. The exploitation of PPS could have a strong impact on the development of H2 refueling stations sector and, in particular, could help the diffusion of biomass to hydrogen technologies and thus the increase of the utilization of hydrogen as energy vector.

Biomass to Hydrogen plant:

The main current customers, who could be interested to these technologies for BTH are now largely represented by industry sector, in particular chemistry, refineries, metal processing. They consume 90% of total hydrogen in Europe and use fossil fuel as main feedstock source, therefore whether they want to take part to ETS market foreseeing more restricted policies inherent carbon dioxide emissions, this one will be a compulsory way. The industry market segment is the most effective, because a lot of studies confirm the real economic feasibility to cover a partial or total Hydrogen demand especially in ammonia production plant, it accounts for 53% of total industry demand in Europe (2013). Power to gas network is today technically feasible (870 MtH2/year) but it needed of incentives as well as mobility through fuel cell.

Mobility market does not exist today, but is envisioned a rapid rise in the next future, demand of product will depend on roll-out and legislation around FCEV's. This market is the most promising because it fits better with the concept of the decentralized production and the UNIfHY sizes chosen, moreover has been showed local and semi-central production can compete with WE and SMR. For this reason, the short-medium term potential in mobility is really high, especially for the small plant scale 100 kWth-1 MWth.

The waste biomass availability fulfils the Hydrogen demand, D7.5 shows the potential in terms of thermal power may exceed 500 MWth in Europe (considering only agricultural residues); the problem consists of its fitting with the local demand in geographical terms, but comparing the current biomass plant is possible to affirm that, where there is a large availability, several gasifiers plants of 1 MWth to 50 MWth could be built.

At the moment, the best market is the cogeneration, thus not coupling the gasifier with a PPS but with an ICE (or mGT or FC in future), even if, it is possible to foreseen a short-medium term future market on cogeneration and hydrogen production in this sector.

Overall, regarding H2 well to tank global cost, we have only two possibility relative to the three size of UNIfHY: 0.1 MWth and 1 MWth refer to local distribution in refueling stations, metal processing or other applications which require low H2 quantity, while 10 MWth (and larger size,

provided the local biomass availability and sustainability), being part of semi-central production could be useful for refineries, long term large H2 mobility, partial implementation in ammonia production plants etc. The reason is quickly said, because of high distribution, transportation cost, added to refueling station infrastructure cost, the sizes below 1 MWth became not so convenient, they can raise the cost around 8 €/kgH2 (by means of tanks). In other words, they make it two times higher than the production cost, thus the two plant sizes will be competitive with WE and SMR only if the hydrogen is produced on site, in this way we have 9.8 and 5.8 €/kgH2 for 0.1 MWth and 1 MWth respectively in 2015, against FCH projection at 2030 of WE and SMR which account for 4.5-5.5 €/kgH2 (always without distribution but for larger size). Concerning the 10 MWth production plant we may choose two ways, either an integration with the Industry with a high H2 demand, or a local distribution through a refueling station as in 1 MWth plant, and a contemporarily supply of tube trailers or pipiline. This allow 10 MWth plant to reach a total well to tank cost of 3.9 €/kgH2, considering a tube trailer /pipeline cost of 1.3 €/kgH2 (see D7.5). As already said as the gasifier size rises, the CAPEX sharply decreases (see D5.3), since that UNIfHY is addressed to small-scale plant this factor prejudges the final H2 cost. Thanks to the carbon tax and the ability of UNIfHY to provide low carbon dioxide emissions than SMR (the main technology used for this purpose), the system's competitiveness is further increased.

Finally, UNIfHY 100 will be exploited by CIRPS-USGM in the 3emotion FCH-JU project in order to produce hydrogen for the 3emotion Italian HRS. In particular, CIRPS-USGM is involved in the demonstration of hydrogen vehicles in the Lazio region (via the main Lazio and Rome transport companies, COTRAL and ATAC). Thus the development of the UNIfHY technology will have also a first direct application on the Lazio Region existent and planned hydrogen filling stations (e.g. the UNIfHY 100 applied to the Italian 3emotion hydrogen filling station).

EXPLOITABLE FOREGROUNDS GLOBAL

Purpose

The main aim is developing new plant solutions aimed to improve the competitiveness of biomass gasification against the other two technologies: WE and SMR. The commercialization of a product will be the final step, further demonstration activities is required, but at the moment only some individual parts of the production plant are ready to enter into the market.

Exploitation activities

The results are mainly exploited in further research and demonstration projects:

1. The gasifier UNIfHY 100 will be exploited by CIRPS-USGM in the 3emotion FCH-JU project in order to produce hydrogen for the 3emotion Italian HRS
2. by UNIVAQ the gasifier will be exploited in HBF2.0 (HyBioFlex 2.0: Flexible Hydrogen production from Biomass) Italian MiSE project;

3. The gasifier UNIfHY 1000 will be exploited by ENEA in the Italian BioSNG MiSE project in order to produce SNG from residual feedstocks via biomass gasification with the HT filtration system for in-situ particulate removal;
4. Regarding filter candles Pall despite the leadership in the ceramic filter candles sector, seems not interested, at the moment, to commercialize catalytic version meanwhile Haldor-Topsoe and other sector companies are commercializing similar products. Thus the results (the main results are the lab scale tests) will be exploited within these other companies;
5. Regarding the PPS (WGS, PSA, etc.) the main exploitation will come from the partner HyGear but, it is not expected a short/mid-term commercialization.

As an accompanying measure to better allow the exploitation of project results:

6. The maximum use of researcher mobility actions will be encouraged, within and out of the consortium (joint PhD courses are already run by some of the project partners), finalized to strengthen competence exchange at European level.
7. Thanks to ALAB's experience, it has been carried out a report to identify the potential targets for the roll out of the UNIfHY integrated system for the supply of hydrogen to the mobility market. The objectives concern of customer profile and typology of site suitable for UNIfHY.
8. Regarding the key parameters for a successful roll out of UNIfHY, in collaboration with ALAB, a techno-economical study has been carried out in terms of H_2 distribution and production cost, as well as H_2 purity for each final application.
9. Commercial promotion has been made participating to international fairs and addressing commercial presentations to key customers and institutions. Media campaigns have been developed for a general purpose target and also within each business sector of competence. To promote interest for investment and exploitation of the innovative methodologies, the dissemination activity envisioned a website and a project brochure, the latter one has been delivered to each stakeholder identified.

The partners have been engaged in defining a Commercial strategy to promote project results and fostering industrial exploitation of outcomes by arranging commercial presentations, attending international fairs, submitting patents to competent offices.

IP Rights

The first version of the UNIfHY 100 kWth Internal Circulating Dual Bubbling Fluidized Bed Gasifier has been submitted for Italian patent (European patent foreseen) and it is in submission a patent of the second version. Being the UNIfHY gasifier managed by research centers (owing to the research activities) in UNIfHY consortium is missing a gasifier company. Thus, the patent cannot be exploited directly by one of the partners. The inventors are working for a technology transfer to company (as the one involved in the related Regional (HBF) and National (HBF2.0) projects, or licensing to companies (from the large enterprise involved in HBF2.0, Water Tosto, to a plethora of Italian and European gasifier companies and even also some of same size pellet boiler companies, sector in which Italy has the European leadership).

The direct heated gasifier with Oxygen has been already patented by ENEA before the UNIfHY project, regarding its exploitation it goes the same as previously said.

The ceramic catalytic candles own a previous patent antecedent UNIfHY project, some improvements have been applied on it about the catalytic composition, therefore a new patent version is foreseen.

The PPS and the two kind of ceramic foams (Fe/Foam and Cu/Foam) are potentially eligible for a specific patent individually, but at the moment each partner who has developed these innovations considers untimely them registration. UNISTRA will patent the catalyst, while Pall Schumacher and HyGear will patent the foam and the reactor respectively.

The sorbents and UNIfHY will be patented only after further research, because the sorbents are still under testing, whereas UNIfHY needs the completion of previous patents and all the boundary architecture as, for instance the automatic control system.

Further research

UNIfHY is still a pilot plant, although further research has to be undertaken (for example in CO_2 removal by means of sorbents into the gasifier), nowadays the lab tests show that high efficiency and reliability for individual component has been reached, the catalytic candles and ceramic foam (the most innovative parts of UNIfHY) demonstrate high conversion of Tar content into the SNG. The IH BFB gasifier of 1 MW_{th} during the test campaigns operated continuously for 12 hours (120 h in total), it is able to work at 850°C, but the S/B ratio did not rise over 1, the optimal value with the purpose of get maximum chemical efficiency referred to S/B=1.5. This means the next goal will consist of testing the possibility to reach over 7000 operative hours per year and the right S/B in order to ensure the maximum chemical efficiency.

The shortcomings highlighted during the tests was mainly imputable to the thermic dispersion, this issue compromised the operability of all downstream components, a study aimed to give some improvements in this sense will be a compulsory way.

Another action regards the catalytic candles, by the tests was observed a low propensity in Methane reforming, thereby there are two alternatives: either developing another catalytic composite which take into account also the Methane in addition to Tar, or developing a secondary SMR working after the current catalytic candles.

Expected impact

The main current customers, who could be interested to these technologies for BTH are largely represented by industry sector, in particular chemistry, refineries, metal processing. They consume 90% of total hydrogen in Europe and use fossil fuel as main feedstock source, therefore whether they want to take part to ETS market foreseeing more restricted policies inherent carbon dioxide emissions, this one will be a compulsory way. The industry market segment is the most effective, because a lot of studies confirm the real economic feasibility to cover a partial or total

Hydrogen demand especially in ammonia production plant, it accounts for 53% of total industry demand in Europe (2013). Power to gas network is today technically feasible (870 Mt_{H2}/year) but it needed of incentives as well as mobility through fuel cell, because, at the moment, the green Hydrogen is too much expensive to compete with this market segment Commercial application of gasification technology depends on need of renewable H_2. Such market does not exist today, but is envisioned a rapid rise in the next future, demand of product will depend on roll-out and legislation around FCEV's. This market is the most promising because it fits better with the concept of the decentralized production and the UNIfHY sizes chosen, moreover it has been showed local and semi-central production can compete with WE and SMR. For this reason, the potential in mobility is really high, especially for the small plant scale 100 kWth-1 MWth now (future refueling station will need higher H2 production), the mobility will be the best final BTH market.

Stationary generation is directly correlated with FC development, today in the market some power unit are already commercially available, hence it is prospected a wide spread in the near future, the Green Hydrogen delivered to FC fits better with UNIfHY in terms of environmental respect and distributed generation.

The waste biomass availability fulfils the Hydrogen demand, D7.5 shows the potential in terms of thermal power may exceed 500 MWth in Europe (considering only agricultural residues); the problem consists of its fitting with the local demand in geographical terms, but comparing the current biomass plant is possible to affirm that several gasifiers plants of 1 MWth to 50 MWth could be built.

At the moment, the best market, regarding this size, is the cogeneration, thus not coupling the gasifier with a PPS but with an ICE or mGT or FC, even if, it is possible to foreseen a near term future market on cogeneration and hydrogen production in this sector.

Overall, regarding H_2 well to tank global cost, we have only two possibilities relative to the three sizes of UNIfHY: 0.1 MWth and 1 MWth refer to local distribution in refueling stations, metal processing or other applications which require low H_2 quantity, while 10 MW_{th} being part of semi-central production could be useful for refineries, foreseen mobility, partial implementation in ammonia production plants etc. The reason is quickly said, because of high distribution, transportation cost, added to refueling station infrastructure cost, the sizes below 1 MWth became not so convenient, they can raise the cost around 8 €/kg_{H2} (by means of tanks). In other words, they make it two times higher than the production cost, thus the two plant sizes will be competitive with WE and SMR only if the hydrogen is produced on site, in this way we have 9.8 and 5.8 €/kg_{H2} for 0.1 MWth and 1 MWth respectively in 2015, against FCH projection of WE and SMR which account for 4.5-5.5 €/kg_{H2} (always in local production). Concerning the 10 MWth production plant we may choose two ways, either an integration with the Industry with a high H_2 demand, or a local distribution through a refueling station as in 1 MWth plant, and a contemporarily supply of tube trailers. This allow 10 MWth plant to reach a total well to tank cost of 3.9 €/kg_{H2}, considering a tube trailer cost of 1.3 €/kg_{H2} (see D7.5). As already said as the gasifier size rises, the CAPEX sharply decreases (see D5.3), since that UNIfHY is addressed to small-scale plant this factor prejudges the final H_2 cost. Thanks to the carbon tax and the ability

of UNIfHY to provide low carbon dioxide emissions than SMR (the main technology used for this purpose), the system's competitiveness is further increased.

2.3 REPORT ON SOCIETAL IMPLICATIONS

A General Information *(completed automatically when **Grant Agreement number** is entered.*	
Grant Agreement Number:	299732
Title of Project:	UNIfHY-UNIQUE gasifier for hydrogen production
Name and Title of Coordinator:	Prof. Enrico Bocci

B Ethics	
Did you have ethicists or others with specific experience of ethical issues involved in the project?	***0 Yes*** ***X No***
2. Please indicate whether your project involved any of the following issues (tick box) :	
RESEARCH ON HUMANS	
• Did the project involve children?	NO
• Did the project involve patients?	NO
• Did the project involve persons not able to give consent?	NO
• Did the project involve adult healthy volunteers?	NO
• Did the project involve Human genetic material?	NO
• Did the project involve Human biological samples?	NO
• Did the project involve Human data collection?	NO
RESEARCH ON HUMAN EMBRYO/FOETUS	
• Did the project involve Human Embryos?	NO
• Did the project involve Human Foetal Tissue / Cells?	NO
• Did the project involve Human Embryonic Stem Cells?	NO
PRIVACY	
• Did the project involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?	NO
• Did the project involve tracking the location or observation of people?	NO
RESEARCH ON ANIMALS	
• Did the project involve research on animals?	NO
• Were those animals transgenic small laboratory animals?	NO
• Were those animals transgenic farm animals?	NO
• Were those animals cloned farm animals?	NO
• Were those animals non-human primates?	NO
RESEARCH INVOLVING DEVELOPING COUNTRIES	
• Did the project involve the use of local resources (genetic, animal, plant etc)?	NO
• Was the project of benefit to local community (capacity building, access to healthcare, education etc)?	NO
DUAL USE	
• Research having direct military use	0Yes X No
• Research having the potential for terrorist abuse	

C Workforce Statistics

3. Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis).

Type of Position	Number of Women	Number of Men
Scientific Coordinator	0	2
Work package leaders	2	3
Experienced researchers (i.e. PhD holders)	4	16
PhD Students	4	
Other		

4. How many additional researchers (in companies and universities) were recruited specifically for this project?	3
Of which, indicate the number of men:	2

D Gender Aspects

5. Did you carry out specific Gender Equality Actions under the project?	○	Yes
	X	No

6. Which of the following actions did you carry out and how effective were they?

	Not at all effective				Very effective
❑ Design and implement an equal opportunity policy	○	○	○	○	○
❑ Set targets to achieve a gender balance in the workforce	○	○	○	○	○
❑ Organise conferences and workshops on gender	○	○	○	○	○
❑ Actions to improve work-life balance	○	○	○	○	○

○ Other:

7. Was there a gender dimension associated with the research content – i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?

○ Yes-please specify

X No

E Synergies with Science Education

8. Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint projects)?

X Yes-please specify

Joint PhD within University of Aquila and Strasbourg university (1 PhD has been devoted to UNIfHY activities), 10 thesis and master's degree thesis (at Marconi, Sapienza, Aquila and Strasbourg universities)

○ No

9. Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?

X Yes-please specify

UNIFHY web site also in researchgate and academia.edu, video, materials for lessons in energy systems and thermochemical courses

○ No

F Interdisciplinarity

10. Which disciplines (see list below) are involved in your project?

☒ Main discipline: Engineering and Technology

☒ Associated discipline: Other Engineering Sciences

G Engaging with Civil society and policy makers

11a Did your project engage with societal actors beyond the research community? *(if 'No', go to Question 14)*	X	Yes
	○	No

11b If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)?

○ No

○ Yes-in determining what research should be performed

○ Yes-in implementing the research

X Yes, in communicating /disseminating / using the results of the project

11c In doing so, did your project involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?	○ X	Yes No

12. Did you engage with government / public bodies or policy makers (including international organisations)

○	No
○	Yes-in framing the research agenda
○	Yes-in implementing the research agenda
X	Yes, in communicating /disseminating / using the results of the project

13a Will the project generate outputs (expertise or scientific advice) which could be used by policy makers?

○	Yes – as a **primary** objective (please indicate areas below-multiple answers possible)
X	Yes – as a **secondary** objective (please indicate areas below-multiple answer possible)
○	No

13b If Yes, in which fields?

Agriculture	X	Energy	X	Human rights	
Audiovisual and Media		Enlargement		Information Society	
Budget		Enterprise		Institutional affairs	
Competition		Environment	X	Internal Market	
Consumers		External Relations		Justice, freedom and security	
Culture		External Trade		Public Health	
Customs		Fisheries and Maritime Affairs		Regional Policy	
Development Economic and Monetary Affairs	X	Food Safety		Research and Innovation	
Education, Training, Youth	X	Foreign and Security Policy		Space	
Employment and Social Affairs		Fraud		Taxation	
		Humanitarian aid		Transport	

13c If Yes, at which level?

- ○ Local / regional levels
- ○ National level
- X European level
- ○ International level

H Use and dissemination

14. How many Articles were published/accepted for publication in peer-reviewed journals?	**27**
To how many of these is open access[15] provided?	**10**
How many of these are published in open access journals?	**10**
How many of these are published in open repositories?	
To how many of these is open access not provided?	**17**
Please check all applicable reasons for not providing open access:	
X publisher's licensing agreement would not permit publishing in a repository ❑ no suitable repository available ❑ no suitable open access journal available X no funds available to publish in an open access journal ❑ lack of time and resources ❑ lack of information on open access ❑ other[16]: ……	

15. How many new patent applications ('priority filings') have been made? *("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).*		**3**
16. Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).	Trademark	**0**
	Registered design	**0**
	Other	**0**
17. How many spin-off companies were created / are planned as a direct result of the project?		**1**
Indicate the approximate number of additional jobs in these companies:		**2**

18. Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:

☒	Increase in employment, or	☒	In small & medium-sized enterprises
❑	Safeguard employment, or	❑	In large companies
❑	Decrease in employment,	❑	None of the above / not relevant to the project
❑	Difficult to estimate / not possible to quantify		

[15] Open Access is defined as free of charge access for anyone via Internet.

[16] For instance: classification for security project.

19. For your project partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent (*FTE = one person working fulltime for a year*) jobs:	*Indicate figure:*
Difficult to estimate / not possible to quantify	☒

I Media and Communication to the general public

20. As part of the project, were any of the beneficiaries professionals in communication or media relations?

○ Yes X No

21. As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?

○ Yes X No

22 Which of the following have been used to communicate information about your project to the general public, or have resulted from your project?

❑	Press Release	❑	Coverage in specialist press
❑	Media briefing	❑	Coverage in general (non-specialist) press
❑	TV coverage / report	❑	Coverage in national press
❑	Radio coverage / report	❑	Coverage in international press
X	Brochures /posters / flyers	X	Website for the general public / internet
X	DVD /Film /Multimedia	X	Event targeting general public (festival, conference, exhibition, science café)

23 In which languages are the information products for the general public produced?

❑	Language of the coordinator	X	English
❑	Other language(s)		