Proposal title:

"Advanced direct biogas fuel processor for robust and cost-effective decentralised hydrogen production" BioRobur^{Plus}

Topic: FCH-02-2-2016. Development of compact reformers for distributed bio-hydrogen production

Funding scheme: Collaborative project

Start date of project: 1st January 2017

Duration: 42 months

Deliverable: 12M coordination and management report, including a disclosable version

Organisation name of lead contractor for this deliverable: POLITO

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Dissemination level: Public

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1. Introduction

The present deliverable "D1.3: 12-month coordination and management report, including a disclosable version" is part of the work package 1 (WP1), which ensure the coordination and management of BioRobur^{plus} project. This workpackage is split into two tasks, both under the responsibility of POLITO. The objectives of the WP1 are:

- Co-ordination, monitoring and reporting of the project
- Administrative and financial management of the project
- Networking activities that will foster exchange with other related projects to identify and ensure potential synergies
- Perform risk/SWOT analyses of the BioRobur^{plus} R&D activities
- Conceive contingency plans on a regular basis to maximize chances of success

2. Technical progress

The Gantt of the project is provided hereafter, (M0-12) highlighted in orange.

Feedback activity
Milestone

Workpackages and Tasks		Duration (months)						
WP 1	**Project coordination and management (Responsible: POLITO)**	**0-6**	**7-12**	**13-18**	**19-24**	**25-30**	**31-36**	**37-42**
T 1.1	*Coordination and management*							
T 1.2	*Risk analysis and contingency plans conception*							
WP 2	**Catalysts & catalytic reactors (Responsible: IRCE)**	**0-6**	**7-12**	**13-18**	**19-24**	**25-30**	**31-36**	**37-42**
T 2.1	*Concept design of catalytic reactors series*							
T 2.2	*Catalysts selection, characterisation & optimisation*							
T 2.3	*Coke formation analysis & detailed modelling, including conception of associated reformer operating strategies*							
T 2.4	*Structured supports development*							
T 2.5	*OSR reactor development/adaptation*							
T 2.6	*Catalytic wall flow reactor development/adaptation*							
T 2.7	*WGS reactor development*							
T 2.8	*Detailed design of catalytic reactors series*							
T 2.9	*Catalytic reactors assembly and precertification*							
WP 3	**Advanced integrated hydrogen purification (Responsible: HST)**	**0-6**	**7-12**	**13-18**	**19-24**	**25-30**	**31-36**	**37-42**
T 3.1	*Purification system concept design*							
T 3.2	*Sorption materials and fluids selection, characterisation & optimisation*							
T 3.3	*Detailed modelling & quantification of regeneration strategies*							
T 3.4	*Evaluation of possible integration with alternative purification routes*							
T 3.5	*Detailed design of full scale integrated purification system*							
T 3.6	*Integrated purification system assembly and precertification*							
WP 4	**Off-gas burner enthalpy valorisation (Responsible: KIT)**	**0-6**	**7-12**	**13-18**	**19-24**	**25-30**	**31-36**	**37-42**
T 4.1	*Off-gas burner concept design*							
T 4.2	*Development of burner structured components*							
T 4.3	*Detailed combustion modelling & conception of burner operation/control strategies*							
T 4.4	*Prototype burner assembly and testing*							
T 4.5	*Detailed design of final off-gas burner including integrated heat transfer systems*							
T 4.6	*Integrated final off-gas burner assembly and precertification*							

WP 5	Complete biogas-to-hydrogen fuel processor (Responsible: HST)	0-6	7-12	13-18	19-24	25-30	31-36	37-42
T 5.1	*Fuel processor specifications*							
T 5.2	*System modelling and concept design*							
T 5.3	*Overall fuel processor detailed design*							
T 5.4	*Feed & control system adaptation*							
T 5.5	*Procurement/adaption of complementary BOP components*							
T 5.6	*Biogas processor assembly and indoor certification*							
T5.7	*Biogas processor operation and testing in real environment*							
WP 6	**Prenormative, LCA, safety and market studies (Responsible: POLITO)**	**0-6**	**7-12**	**13-18**	**19-24**	**25-30**	**31-36**	**37-42**
T 6.1	*LCA & prenormative studies*							
T 6.2	*REACH and safety analyses*							
T 6.3	*Scale-up/marketing and exploitation plan*							
WP 7	**Dissemination & Training (Responsible: POLITO)**	**0-6**	**7-12**	**13-18**	**19-24**	**25-30**	**31-36**	**37-42**
T 7.1	*Dissemination*							
T 7.2	*Training*							

The following analysis performed individually for each WP, provides a more detailed study on the progress of the BioRobur^{plus} project in the first 12 months.

2.1. WP1 - Project coordination and management (Leader: POLITO)

This Work Package is devoted to the coordination and management of the BioRobur^{plus} project. The co-ordinator of the project, Prof. Debora Fino from POLITO deals with financial and administrative issues, technical and research activities within the project.

POLITO as coordinator distributes all necessary information in the entire and collects the contributions to prepare progress reports. POLITO is committed to promoting an active and holistic collaboration and communication between the project partners. This good and fluid approach takes place constantly via regular electronic (e-mail, teleconference, skype, etc.) and physical discussions (technical meeting, etc.). Additionally, during the project meetings, the minutes are written and disseminated among the partners along with a list of actions to be performed for the coming months. POLITO is also often in contact with all partners regarding contractual and financial information.

On the other hand, the Biorobur^{plus} website created by the coordinator, in addition to facilitating the dissemination of the objectives and results of the project, has a private area to share information between the partner and to distribute the documents produced during the project period, including the administrative presentations. Documents and ppt templates were designed and shared with the consortium in order to have consistent formats of the different project documents.

During the KOM in Torino, explanations between FP7 and H2020 programme were given (indirect costs, reimbursement rates, CFS needed, etc.).

The final version of the Consortium Agreement was signed on the 27 January 2017. During the 6M meeting held in Lyon last July the coordinator distributed the contract with the original signatures of all partners.

The UE transferred to POLITO the net pre-financing of € 1.448.186,89 on the 24th January. The pre-payment was distributed on 9Th February on the base of Polito's proposal and collectively approved through the signatures of the Consortium Agreement. Moreover, POLITO collects the cost monitoring data every 6 months.

List of dates and place of progress general meetings:

- Kick off Meeting – Torino (POLITO), 24-25th January 2017
- 6M Meeting – Lyon (IRCE-CNRS) 10-11th July 2017
- 12M Meeting – Thessaloniki (CERTH – CPERI) 15-16th January 2018

Deliverables at M12

DEL. N.	DELIVERABLE TITLE	RESPONS. PARTNER	WP	DATE (MONTH)
D5.2	System model and conceptual design	POLITO	5	~~10~~**13**
D1.3	12 month coordination and management report including an updated risk analysis and contingency plan	POLITO	1	12
D1.9	First annual data reporting (deadline April 2018)	POLITO	1	12
D2.2	Different structured supports optimized for the selected BioRoburplus catalytic reactions with catalyst deposits.	ENGICER	2	12
D3.2	Commercial sorption materials and fluids characterized	POLITO	3	~~12~~**16**
D3.3	Sorption and desorption unit models available and validated	POLITO	3	~~12~~**16**
D3.4	Assessment of the evolution of alternative purification routes	DBI	3	12

D5.2 was postoponed due to the revisited schematic of the BioRoburplus concept.
D3.2 and 3.3 was postoponed due to a light delay in the experimental characterization of soprtion materials, and the corresponding models associated. This is expected neither to impact in the development of the equipment, nor to delay any Partner's activity.

Milestone at M12

M5.1	Specifications for the BioRoburPlus H_2 production system defined	HST	5	6

The BioRobur^{plus} consortium is continuously advised and developing technological solutions to minimize the risks for the adaptation and interconnection of the core and peripheral components and their implementation at the ACEA site.
Partners are working hard to deliver work according to proposal. On the system level, the progress beyond the state of the art is being achieved through the tailored design, intelligent combination and control of the components, especially allowing almost complete heat recuperation as well as utilization of the heating value of the low calorific value off-gases.

2.2. WP2 - Catalysts & catalyst reactors (IRCE)

This WP aims to optimize and test all the proposed catalyst formulations with respect to the BioRobur^{plus} operating conditions at lab-scale. In addition, optimized structured supports are being developed and the optimized catalyst formulations will be coated onto the supports. The design and assembly of the catalytic reactors for the overall processor will be carried out also within this WP. Coke formation will also be studied at a practical and fundamental level.

2.2.1. T 2.1 Concept design of catalytic reactors series (Involved partners: DBI, SUPSI, JM, IRCE, CPERI; duration: months 1-6)

The innovative catalyst configurations developed within previous project BioRobur are one of the key components of BioRobur^{plus}. The most stable PGM-free nickel-based catalyst formulation was a Rhodium doped Nickel catalyst supported by a spinel consisting on $MgAl_2O_4$. Therefore, this formulation has been the base for start catalyst investigations within BioRobur^{plus}.

The catalysts must guarantee some important features such as being less prone to coking and easily adaptable to any change in biogas inlet composition. The best formulation is selected based on the robustness, methane conversion and hydrogen yield. The tests are performed at different residence time, defined by the gaseous hourly space velocity (GHSV), steam to carbon ratio (S/C) and oxygen to carbon ratio (O/C). Within the BioRobur project, at a pilot scale level, the conventional foam structure and the rotated cubic lattice (111) had the best performance by comparison to the other lattice structures (T_{in} = 600 °C, O/C = 1.1, S/C = 2.0). A maximum methane conversion up to 98% were achieved within a GHSV of 6,000 to 8,000 h^{-1}, and with GHSV more than 10.000 h^{-1} for rotated cubic cell and conventional foam, respectively. Within the BioRobur^{plus} project, a lower GHSV is expected due to higher S/C ratio and lower O/C ratio. These parameters are results of investigations from the first six months of BioRobur^{plus}, whereby an optimized thermal interconnection has been developed, which is explained in the WP3.

Several activation procedures were investigated to reconversion into metallic nickel within BioRobur. Nickel based catalysts are passivated by forming nickel monoxide on contact with oxygen. Hydrogen mixed with nitrogen or steam were checked and the most appropriate H_2/N_2-mixture for a successful activation was selected. The same procedure is being used within the BioRobur^{plus}.

Volumetric limitations must be considered according to the specifications of the project proposal.

The ground for the final design of the reactors (Task 2.8) and their structure supports carried out by SUPSI was prepared. The catalyst formulation developed in BioRobur were tested under BioRobur^{plus} conditions and the performances were compared with those obtained with conventional industrial catalysts (nickel-based, PGM-based). Results are encourage.

2.2.2. T 2.2 Catalysts selection, characterization & optimization (Involved partners: IRCE, JM, DBI, MET; duration: months 1-12)

During the first 12 months the required reforming and WGS catalysts were tested on lab scale and further optimized to meet the BioRobur^{plus} specifications.
IRCE has tested the same catalyst of Biorobur (monolith samples received from MET in May 2017) in the initial Biorobur^{plus} conditions. Twelve smalls SiC monoliths (Ø2.5 x h1.1 cm) with octet cells were coated with X-Y/$MgAl_2O_4$ catalyst. The results show a methane conversion of 100% over more than 50 h of time on stream (at GHSV= 20000 h^{-1}). It was also tested at higher CO_2/CH_4 ratio, successfully. Dry reforming is relevant only if low steam is present. OCR and SCR were varied, but SCR seems to be enough at lower values than 3. Instead, JM has developed noble metal-based catalyst for the biogas reformer. Moreover, the catalysts were separately developed and optimized for the partial oxidation and steam reforming stages.

JM has completed the benchmarking with a total of 8 JM industrial catalysts studied. The catalyst selection was based on:

- ✓ Volume of H_2 produced.
- ✓ Catalyst bed temperature.
- ✓ Outlet dry CO concentration.

Catalyst for the WGS reactors have being also studied using different temperatures and GHSV values as shown in Table 1. The behavior was evaluated by comparing CO conversion calculated from measurement data and thermodynamic equilibrium related to the outlet temperature.

Table 1. Conditions used for WGS reaction testing.

	1st WGS	2nd WGS
GHSV [h^{-1}]	10,000 – 50,000	5,000 – 50,000
T [°C]	300 - 375	200 - 325

Some formulations reached the thermodynamic equilibrium when high GHSV values were used.

2.2.3. T2.3 Coke formation analysis & detailed modelling, including conception of associated reformer operating strategies (Involved partners: CPERI, IRCE, JM, DBI; duration: months 4-18)

Investigations concerning carbonaceous deposits has been started. Carbon formation are investigated at APTL/CPERI and IRCE. Furthermore, catalysts are characterized experimentally at DBI as described before. This offers the opportunity to verify own results on samples tested externally.

Elemental carbon is one of the natural by-products of the reforming sub-reactions whereby a subsequent conversion into carbon oxides takes place under optimal conditions. The following equilibrium reactions lead to the carbon formation:

- Methane dissociation $CH_4 \leftrightarrow C + 2H_2$
- Boudouard reaction $2CO \leftrightarrow C + CO_2$
- Heterogeneous water-gas-reaction $CO + H_2 \leftrightarrow C + H_2O$

The consideration of these reactions indicates an optimal conversion of carbon under the sufficient presence of water and/or carbon dioxide. Both are contained in excess within the OSR due to high Steam-to-Carbon-ratio as well as a high content of carbon dioxide in the biogas (> 40 vol.-%). Nonetheless, other aspects can promote carbonaceous deposits.

The equilibrium carbon range for steam reforming of biogas depending on S/C-ratio and reaction temperature. It is clearly visible that a sufficient S/C-ratio prevents carbon formation at typical reforming temperatures. However, this is an ideal consideration of thermodynamic equilibrium. In general, catalyst structures are composed of inhibitors as well as promoters and differ depending on producer. There are catalysts that inhibit carbon formation reactions although they are operated within the thermodynamic C-window. On the other hand, some catalysts promote carbon formation outside the C-window.

- Analysis of the kind and amount of carbon formed under certain reaction condition will be analyzed. So far, only an investigation about the kind of technology available to perform the proper analysis have been identified.

2.2.4. T 2.4 Structured supports development (Involved partners: MET, ENGICER, SUPSI, KIT, IRCE; duration: months 1-12)

The main goal of task 2.4 is the production of lab-scale and full-scale catalyst supports and the delivery of the same to the partners responsible for catalyst coating.

- EngiCer has produced and delivered to the partners several small and full-scale catalyst support samples for the optimization of the catalyst coating procedure and following testing of the performances.
- These activities are performed by incorporating knowledge from the previous project BioRobur and by further optimizing design and production of the supports.

2.2.5. T 2.5 OSR reactor development/adaptation (Involved partners: MET, DBI, IRCE, CPERI, ENGICER, SUPSI, JM; duration: months 7-18)

- In order to identify the optimal heat profiles to facilitate the endothermic reforming reactions and minimize the operating expenses, a detailed modeling of the OSR process is being carried out
- The model aims to optimize the catalyst loading, size, length to avoid hot spots and reach equilibrium within the minimum length.
- Modelling of the monolith channel including porous catalytic washcoat zone have been performed.
- Optimization of the modelling has been carried out by using numerical solution.

The modelling prerequisites are:

- Appropriate correlations of mass and heat transfer;
- Design considerations: monolith features (channels, sizes), catalyst support geometry);
- Flow rates and compositions;
- Start-up schedule;
- Effective porous zone properties (diffusivities, heat conductivities); and,
- Reaction kinetics

An optimal utilization of monolith (catalyst loading / monolith extent) under design constraints for a target value of variables of interest will be performed in the next months.

2.2.6. T 2.6 Catalytic wall-flow reactor development/adaptation (Involved partners: POLITO, CPERI, DBI; duration: months 7-18)

This activity is under the responsibility of CPERI and is being carried out together with Task 2.4 without any delay.

2.2.7. T 2.7 WGS reactor development (Involved partners: IRCE, DBI, JM; duration: months 7-18)

This activity is running according to the project schedule. As showed in the Task 2.2, JM is providing input for the recommended operating conditions for the current generation of water gas shift catalysts and expected performance in the BioRobur^{plus} system. DBI is performing the testing activities at a prototype scale.

2.2.8. T 2.8 Detailed design of catalytic reactors series (Inv. partners: DBI, SUPSI; duration: months 13-18)

This activity has started earlier than planned:

- DBI is performing the detailed design of the OSR and WGS components in the existing ATR-reactor.
- Based on the WGS catalyst screening, the WGS reactor are being designed.

2.2.9. T 2.9 Catalytic reactors assembly and pre-certification (Involved partners: DBI, CPERI; duration: months 16-24)

The activities involved in this task have been also anticipated.

- Main equipment design has already started.
- Activities of interconnecting and final design of the plant here are linked with the WP5.

2.3. WP3 - Advance integrated hydrogen purification (HST)

Within this WP, the most promising process options for hydrogen purification through concept design are identified. Moreover, the performance of mass-produced adsorbing materials (PSA) and absorption fluids (CHEM and PHYS) under relevant process conditions are identified and deeply characterised. Other objectives that this WP includes are:

- Conceive and validate models for the design of process sorption and desorption units as well as their operation procedures.
- Continuously assess the development of alternative purification routes to consider their integration in case of significant technological breakthroughs are attained
- Selection of the most appropriate H_2 purification process
- Design and manufacturing of related process units
- Assembly pre-certification of the H_2 purification line

This WP is split in 6 tasks as follow:

2.3.1. T 3.1 Purification system concept design (Involved partners: HST, POLITO; duration: months 1-6)

- The BioRobur^{plus} scheme has been modified in order to meet the BioRobur^{plus} objectives (delivery 50 Nm^3/h of 99,9% H_2; overall plant efficiency ≥ 80% based on HHV).
- The main criticisms to the Proposed Scheme of purification were the high investment and operative costs of proposed purification unit and limitation of the functionality of PSA unit due to N_2 adsorption.
- An alternative MEA-free scheme was proposed as the final scheme of the Fuel Processing System to meet both the Unit and Plant objectives.
- The decision to remove the MEA-based sorption unit was taken based in different point of view: separation efficiency, power and energy consumptions, CAPEX costs.
- The final concept has lower environmental impact compared to the original one.

2.3.2. T 3.2 Sorption materials and fluids selection, characterisation & optimization (Involved partners: POLITO, HST; duration: months 1-12)

This activity leads to the realization of physical chemical characterization and performance tests of sorption materials and fluids. In the case of PSA, zeolites and activated carbons will be the reference materials.

- The test-rig for the material characterization is being designed.
- Materials will be performed using single gas and the syngas mixture
- This activity is delayed with respect to the project schedule due to longer test rig procurement.

2.3.3. T 3.3 Detailed modelling & quantification of regeneration strategies (Involved partners: POLITO, KIT, HST; duration: months 4-18)

- An extended literature research is being performed for the final purification unit design.
- Calculation for the proper design will be performed.
- Regeneration strategies will be studied.
- A multicomponent model will be proposed in order to validate the results obtained from the experiments performed in Task 3.2.

2.3.4. T 3.4 Evaluation of possible integration with alternative purification routes (Involved partners: POLITO, KIT, DBI, HST; duration: months 1-12)

Membrane separation technology has been studied as an alternative option for the hydrogen purification. The conclusions of the study are:

- The H_2 purification cost depend strongly on the first stage pressure and the necessary membrane area.
- High pressures at the inlet reduces the cost for the membrane process.
- The literature review shows generally, the membrane and module costs predominate with 50 – 60 % the CAPEX of a membrane process. The OPEX are determine by the compression costs.
- Technically, there are available only two types of membranes, polymeric membranes and Pd-based Membranes. Inorganic membranes/ carbon membranes are currently the subject of research. Nevertheless, published results show a good performance concerning hydrogen purity (99.8%) as well as a good suitability in respect to the BioRobur^{plus} process conditions (temperature, pressure).
- Hydrogen losses are in the range of 2 and 10%. The H_2 losses decreases with the technical effort (one, two or three membrane stages).
- An additional compressor is essential.
- A hydrogen purity of 99.9% is not applicable with such systems. A hydrogen content > 70% in the feed is necessary for purities up to 99.9% when one module of membrane is used. So, if a

purity of ≥ 99.5 % is desired, a second gas treatment is unavoidable, e. g. a smaller pressure swing adsorption for fine purification. Summarized, a stand-alone system based on polymer is not applicable for current thermal interconnection with given targets.

- Concerning the Palladium/metallic membranes: If only the hydrogen purity is considered, palladium-based system would be the first option due to achievable purities > 99.9999%. Furthermore, such systems are commercially available. However, typical operating temperatures for optimal working are contrary to the current thermal design. Also, the cost of the Pd is very high, for this that solution is economically challenging.

2.4. WP4 - Off-gas burner enthalpy valorisation (KIT)

The main objective of this WP is to develop the off-gas burner and heat transfer systems, which are required for utilizing enthalpy of the off-gases in the biogas reformer process.

The detailed objectives of this WP are:

- Concept design of an off-gas burner, which ensures a safe operation with the low/varying caloric value gases and exhibits an efficient combustion and low pollutant emissions.
- Development of enhanced structured (ceramic) components for heat exchanger/burner.
- Combustion modelling of sophisticated burner and further development of burner design and burner control strategy.
- Evaluation of the operating range and emission performance by prototype burner experiments.
- Detailed design of final system including the off-gas burner and complete heat transfer system for the thermal integration in the biogas reformer.
- Construction and pre-certification of final components.

According to the objectives of WP4, the burner concept should promote a safe operation with varying off-gas composition as well as low pollutant emissions. This work package is divided in six tasks.

2.4.1. T 4.1 Off-gas burner concept design (Inv. partners: KIT, SUPSI, ENGICER, HST; duration: months 1-6)

Within this task, KIT has been developed the burner concept, which ensures a safe operation with the varying composition range and has low pollutant emissions. The development of the new burner design is based on already developed burner concepts.
The burner concept was study for both cases, for the plant scheme from the conceptual status and for the alternative MEA-free scheme.

- T 4.2 Development of burner structured components (Involved partners: SUPSI, ENGICER, KIT; duration: months 1-24)
- T 4.3 Detailed combustion modelling & conception of burner operation/control strategies (Involved partner: KIT; duration: months 3-24)

- T 4.4 Prototype burner assembly and testing (Involved partners: KIT, SUPSI, ENGICER; duration: months 7-24)

Tasks 4.2-4.3 have been started and the Deliverable 4.1 has been submitted in time.

2.5. WP5 - Complete biogas-to-hydrogen fuel processor (HST)

The general specifications of the system must be defined primarily. Other objectives comprised in this WP are:

- To perform conceptual, basic and detailed design
- To define the final control system
- To define and execute the indoor testing and certification procedures
- To define and execute the final testing and operation procedures in real environment.

This work package is divided in seven tasks:

2.5.1. T 5.1 Fuel processor specifications (Involved partners: HST, DBI, KIT; duration: months 1-6)

In this task specifications for the overall fuel processing system were issued. Process requirement for feeding flexibility and product quality specification were issued accordingly to market consideration and biogas typical availability. As far as industrial services are concerned, the specification of type and quantity were defined and adjusted to the availability of already present services, like cooling water, electric power, etc. Further specifications of plant dimensions, noise, emissions, communication interfaces between the specific control boards respectively sensors and the master control have been defined, as well.

- A Block Flow Diagram of the Fuel Processing System has been performed. The scheme shows the interconnections between the different sub-units of the plant and the battery limits (Air, Biogas, Water, H_2 and Offgas).
- General specification of the final plant has been defined: The connection to the battery limits is composed of two terminal connections (for example, flanges, fittings, clamps, etc.). One of the terminals is located within the battery limits of the Biorobur^{plus} fuel processing system ("Plant Side"), the other is located outside the battery limits of the fuel processing system ("Site Side"). The Site Side is the biogas generation plant of ACEA, where the system will be installed and tested.

The plant has the following types of Connections:

- "Process Connections":
  - "Inlet Flows" as defined below;
  - "Outlet Flows" as defined below.
- "Services Connections" as defined below.

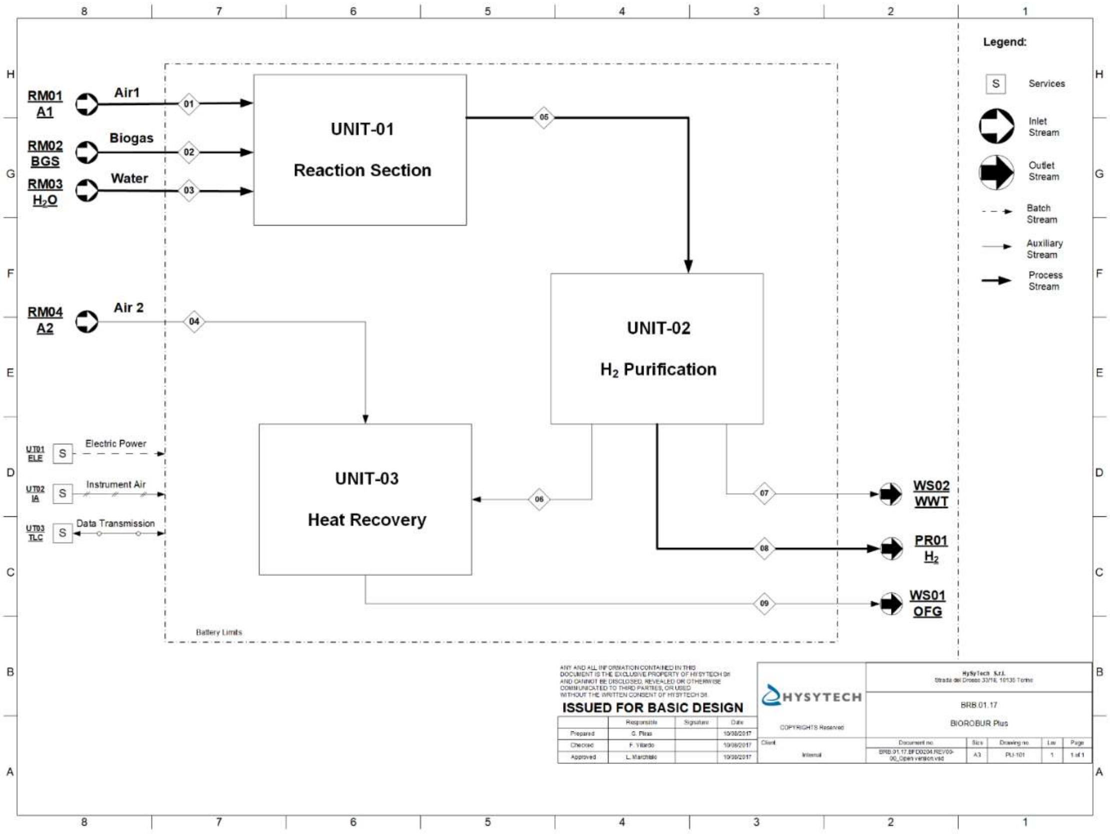


Figure 1. BioRobur^plus MEA-fee BFD.

Inlet Specifications

The inlet flows for the fuel processing system are below specified:

1. *Biogas*

Biogas is a gaseous mixture consisting primarily of Methane (CH_4) and Carbon Dioxide (CO_2) as can be seen in the Table 2. It also includes other impurities. Biogas is mainly obtained from a fermentation process and from the landfill gas collection. The source of the biogas influences its normal compositions (on dry basis):

Table 2. Normal composition of Biogas from different sources

	Fermentation	Landfill
Methane (CH_4)	58,2%	55,0%
Carbon Dioxide (CO_2)	41,2%	38,9%
Nitrogen (N_2)	0,5%	5,0%
Oxygen (O_2)	0,1%	1,0%

Depending from the sources, the biogas contains not negligible quantities of compounds, as impurities, that must be taken into account during the design of the pre-treatment unit of the fuel processing system. In the Biorobur^Plus project the fuel processing system will be installed into the Acea site where the biogas is obtained via fermentation. The maximum levels of impurities present on the Acea biogas are:

(i) Hydrogen Sulphide (H_2S): 1.000 mg/Sm^3 (Maximum);

(ii) Liquid Water (H_2O): Dew Point @ 40°C & 0 barg;

(iii) Aromatic Hydrocarbons: 200 mg/Sm^3;

(iv) Solid Particles Content (< 5 µm): less than 1% (Maximum);

Some of them can quickly poison the catalyst (H_2S) or compromise seriously the system capacity. A pre-treament unit is needed to reduce them to quantity that can be bear by the system. These quantities will be defined accordingly with the partners directly involved into the design of the system equipment.

The main characteristics of the Biogas stream are:

Flowrate (Min / Nor / Max):	ns / 37,5 / 56,3 kg/h
Temperature (Min / Nor / Max):	15 / 35 / 50 °C
Pressure (Min / Nor / Max):	0,01 / 0,02 / 0,03 barg

The normal low biogas feeding pressure is not an issue for the Biorobur^{plus} system because using the ejector, driven by the steam used for the reforming reactions, the biogas is sucked inside the plant.

2. *Water*

Water is here intended as demineralised water. It is used by the ATR Reactor as a reactant for the steam reforming reaction. The water is feeded to the reactor as steam which is produced trough evaporation, using the heat exchangers that recover thermal energy from the whole system.

The main characteristics of the Water stream are:

Flowrate (Min / Nor / Max):	ns / 45 / 67,5 kg/h
Temperature (Min / Nor / Max):	10 / 20 / 30 °C
Pressure (Min / Nor / Max):	0,5 / 1 / 2 barg

3. *Air (Process Air)*

Process Air is here intended as the atmospheric air used as reactant inside the ATR Reactor to generate the thermal energy to sustain the endothermic reforming reactions. Process Air need to be filtered (maximum dust 0,01 µm).

Flow (Min / Nor / Max):	ns / 95 / 142,5 kg/h
Temperature (Min / Nor / Max):	-5 / 20 / 35 °C
Pressure (Min / Nor / Max):	atm.

4. Air2 (Combustion Air)

Combustion Air is here intended as the atmospheric air used as oxidant inside the Off-gas Burner to generate the thermal energy needed by the system.

Combustion Air does not need any particular pre-treatment. Only a standard particulate filter shall be installed on the suction of the Combustion Air Blower.

Flow (Min / Nor / Max):	ns / 43 / 64,5 kg/h
Temperature (Min / Nor / Max):	-5 / 20 / 35 °C
Pressure (Min / Nor / Max):	atm.

Outlet Specifications

The outlet flows for the fuel processing system are below specified:

1. H_2 (Hydrogen)

Hydrogen is here intended as the product of the fuel processing system. The Biorobur^{plus} Project requires the following objectives for the Hydrogen:

Characteristic:	3.0 Grade (99,9% purity by volume)
Flow (Min / Nor / Max):	ns / 50,4 / ns Nm3/h
	ns / 107,5 / ns kg/day
Temperature (Min / Nor / Max):	15 / 40 / 50 °C
Pressure (Min / Nor / Max):	10 / 12 / 15 barg

The Hydrogen produced by the Biorobur^{plus} system does not need any further purification and can be directly fed to the storage system or to final users.

2. Plant Offgas

Plant Offgas is here intended as the product of the combustion between the Combustion Air and the Process Offgas (produced by the H_2 Purification Unit) into the Heat recovery unit. The Plant Offgas is the only continuous gaseous waste produced by the fuel processing system. The Plant Offgas has the following characteristic:

Flow (Min / Nor / Max):	ns / 72,6 / 108,9 Nm^3/h
	ns / 107,2 / 160,8 kg/h
Temperature (Min / Nor / Max):	120 / 150 / ns °C
Pressure (Min / Nor / Max):	0,01 / 0,02 / ns barg

Molar Composition (Normal):

Table 3. Normal composition of Plant Off-gas

CO_2	42,4%
CH_4	0,0 %
O_2	2,5 %
N_2	36,8 %
H_2O	18,3 %
H_2	0,0 %
CO	0,0 %

Utilities Specification

The services required for the installation, operation, start-up and shut-down of the fuel processing system have been also identified.

Noise

This plant will be designed to minimize the noise level in order to keep it below the allowed limits. The operation of the system will do not require the presence of operators and the use of specific hearing protection (noise level < 80 dB). Very specific requirements, related to the noise protection, will be eventually issued after the detailed engineering design. The fact that the plant will be containerized will reduces the magnitude of the consequences for the peoples and the environment.

Control Systems Philosophy and General Architecture

The following figure shows the Control System Architecture of the control system:

- Network Interfaces: the system shall maintain full communication in case any of the interfaces/COM is down. Interface shall allow communication with third parties PLC's or with the remote-control station placed at Hysytech Headquarter.
- PLC: Executes both DCS functions and logics as well as Safety functions. Additional I/Os modules will be needed to manage the additional signals of the new plant.
- DeltaV Workstation: is the PC where is installed the software and where are connected the license keys that allows the system to be programmed and operated. Datalog files are automatically generated by the control software and can be read from the PC.
- UPS: shall feed the control system for the time necessary at PLC to take the system in Emergency Shut-Down: PLC's, Workstation, communication devices and Field instrumentation and valves (Motors Excluded) are under UPS line.
- Main Control Panel: is the HMI of the plant. The control panel is conceived to monitor all the process variables, their setpoints are shown and can be read and written both from local and

remote using different level passwords. The measured variables trends are shown into dedicated charts updated with a chosen frequency.

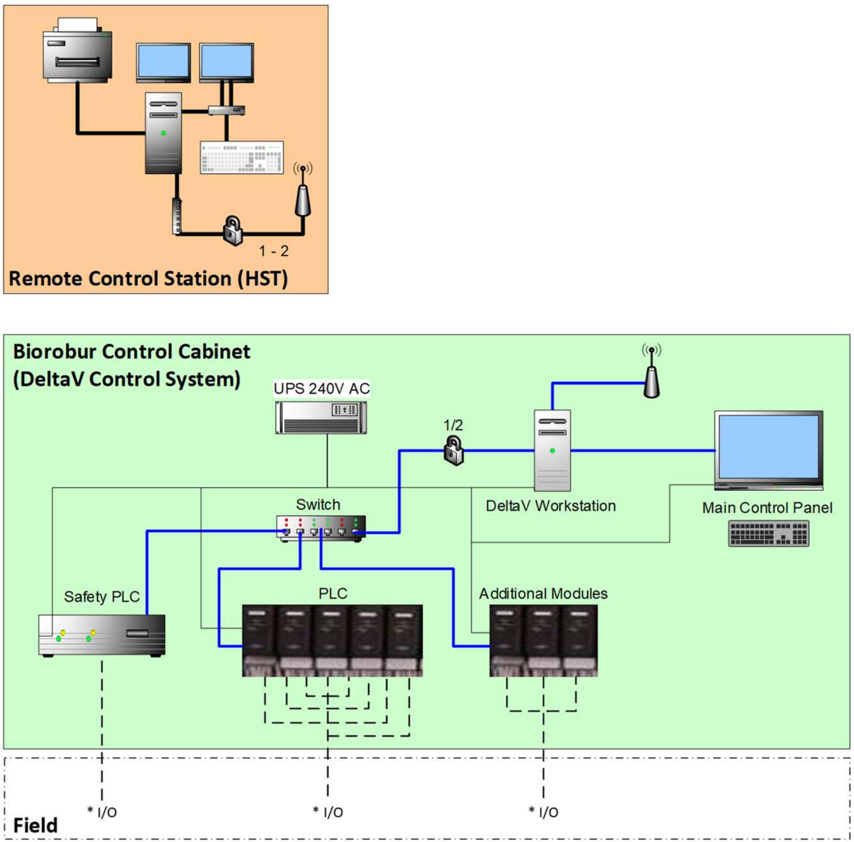


Figure 2. Control System Architecture.

<u>Preliminary layout</u>

The Biorobur^{plus} Plant will be installed in containers because of the following advantages:

- Prefabrications: all the equipment, valves and instrument can be pre-assembled and wired inside the container. Supplier can run preliminary Factory Acceptance Tests to do preliminary tests and decrease installation and start-up times;
- Transportability: the ISO container has standard sizes worldwide accepted handled by truck and ship;
- Quick Installation: only the set-up of the battery limit connections (mechanical and electrical) are needed;
- Lower surface consumption related to standard plant;
- Removability: in case of dismantlement or moving of the plant it is facilized because of the use of containers.

2.5.2. T 5.2 System modelling and concept design (Involved partners: HST, POLITO, KIT, ACEA, JM; duration: months 7-24)

The scope of this task is to finalize the Conceptual and execute the Basic Design (BD), based on the available design and experimental data from previous BioRobur project plant. The BD allow to confirm and better structure the design phases, the schedule and the risk allocation planning.
The knowledge of the individual components constitutes the base for the dynamic simulation of the plant. Currently, at POLITO, all the block diagram has been simulated in dynamic conditions (D5.2), based on the actual knowledge on the equipment (existing and still to be fully designed). Start-up protocols were also simulated.

2.6. WP6 - Prenormative, LCA, safety and market studies (POLITO)

The main objective of the WP6 is to develop the tools that will ensure critical assessment of all issues that relate to the acceptance by the mass market for the BioRobur^{plus} system and particularly:

- Assess component and system sustainability.
- Develop decision-making schemes for various stakeholders based on technical-economic-environmental criteria.
- Propose business models for different European regions and associated market plan.
- Demonstrate the overall energy performance of the new BioRobur^{plus} system for decentralised biogas conversion into H_2.
- Identification of exploitation channels for the BioRobur^{plus} system.

This work package is divided in the following three tasks:

2.6.1. T 6.1 LCA & prenormative studies (Involved partners: POLITO, HST, KIT, JM; duration: months 7-42)

The task involves a Life Cycle Analysis (LCA) of the BioRobur^{plus} process. POLITO and the partners involved in this task, will combine the LCA and the multi-criteria assessment method to evaluate and supporting the selection of each component and the entire BioRobur^{plus} system. The BioRobur^{plus} project will demonstrate the capacity of bio-hydrogen production from biogas in a cost competitive and sustainable manner thereby replacing traditional industrial routes with a novel approach by exploiting all possible energy integration means, as well as innovative structured catalysts and control means to achieve not only cost-competitiveness but also durability and environmental viability.

In order to gather the necessary information for LCI, each component of the BioRobur^{plus} process has to be analyzed.

In order to realize the LCA assessment, the following information is necessary:

- Resources consumption (raw materials, catalyst, inlet and outlet flows)

- Energy consumption
- Equipment used
- Disposal products
- Process emissions

In order to gather the necessary information for the LCI, a questionnaire has been created and sent to all partners. Each component of the BioRobur^{plus} process has to be described in the respective file. With the collaboration of all partners, primary data of the BioRobur^{plus} process will be collected and based on that POLITO will perform a first version of the LCA analysis within M18 to support the related critical decisions.

2.6.2. T 6.2 REACH and safety analyses (Involved partners: POLITO, HST, KIT, JM; duration: months 7-42)

This task involves a REACH evaluation of all new chemical formulations of the BioRobur^{plus} process. REACH is a regulation of the European Union, adopted to improve the protection of human health and the environment from the risks that can be posed by chemicals, while enhancing the competitiveness of the EU chemicals industry.

REACH establishes procedures for collecting and assessing information on the properties and hazards of substances. To start, POLITO has performed a questionnaire to be completed with information (N° CAS, Hazard identification, exposure time, quantity, ecc) about each substance that are being used within the BioRobur^{plus} project.

2.6.3. T 6.3 Scale-up/marketing analysis and exploitation plan (Involved partners: HST, ENGICER, ACEA; KIT, JM; duration: months 7-42)

The BioRobur^{plus} concept configurations and implementation contexts is recently started with special emphasis on the comparison with competitive technologies and systems for renewable hydrogen production (direct bio hydrogen production from fermentation, electrolysis and power-to-gas concepts). The relevant impact concerning the application of the BioRobur^{plus} technological innovations will be quantified and expressed in measurable financial terms with the support of all technology providers.

2.7. WP7 - Dissemination & training (POLITO)

The work package 7 guarantees the dissemination of knowledge generated, to organize training activities in the BioRobur^{plus} project.

2.7.1. Task 7.1. Dissemination (Involved partners: POLITO, all partners; duration: months 3-42)

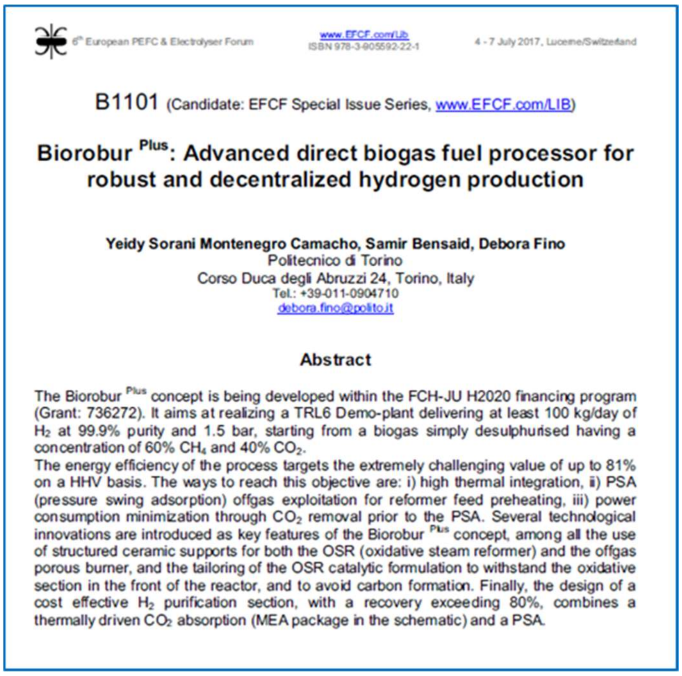
The plan for exploitation and dissemination of the results of BioRobur^{plus} project, which will be updated during the project’s lifecycle and beyond has been presented in the Deliverable 7.1.
At the beginning of the project, a dedicated website has been set up: http://www.bioroburplus.org
The public section of the BioRobur^{plus} website will be kept updated with the consortium activities both for internal exchange of information (private area) and for the dissemination of the project aims and results (public area). Information on participants and links to their own websites and contact addresses are also provided. The Coordinator will establish and maintain the BioRobur^{plus} website with support of all Partners.

Within the first 12 months, the project has been presented in different conferences and posted on social networks:

a. BioRobur^{plus} concept has been published on the Polito's website.

Figure 3. Polito's website.

b. Oral presentation and paper publication in the conference proceeding of the of 6th European PEFC & Electrolyser Forum 2017:
   - Yeidy Sorani Montenegro Camacho, Samir Bensaid, Debora Fino, Biorobur Plus: Advanced direct biogas fuel processor for robust and decentralized hydrogen production, Chapter 08, Session B11 (Fuel processing, purification & compression), 4-7 July 2017, Lucerne, Switzerland, ISBN 978-3-905592-22-1.



6th European PEFC & Electrolyser Forum | www.EFCF.com/Lib ISBN 978-3-905592-22-1 | 4 - 7 July 2017, Lucerne/Switzerland

B1101 (Candidate: EFCF Special Issue Series, www.EFCF.com/LIB)

Biorobur Plus: Advanced direct biogas fuel processor for robust and decentralized hydrogen production

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Abstract

The Biorobur Plus concept is being developed within the FCH-JU H2020 financing program (Grant: 736272). It aims at realizing a TRL6 Demo-plant delivering at least 100 kg/day of H_2 at 99.9% purity and 1.5 bar, starting from a biogas simply desulphurised having a concentration of 60% CH_4 and 40% CO_2.
The energy efficiency of the process targets the extremely challenging value of up to 81% on a HHV basis. The ways to reach this objective are: i) high thermal integration, ii) PSA (pressure swing adsorption) offgas exploitation for reformer feed preheating, iii) power consumption minimization through CO_2 removal prior to the PSA. Several technological innovations are introduced as key features of the Biorobur Plus concept, among all the use of structured ceramic supports for both the OSR (oxidative steam reformer) and the offgas porous burner, and the tailoring of the OSR catalytic formulation to withstand the oxidative section in the front of the reactor, and to avoid carbon formation. Finally, the design of a cost effective H_2 purification section, with a recovery exceeding 80%, combines a thermally driven CO_2 absorption (MEA package in the schematic) and a PSA.

Figure 4. Conference participation with oral presentation.

c. Poster presentation at the 10th World Congress of Chemical Engineering (WCCE10), 1st-5th october 2017, Barcelona, Spain

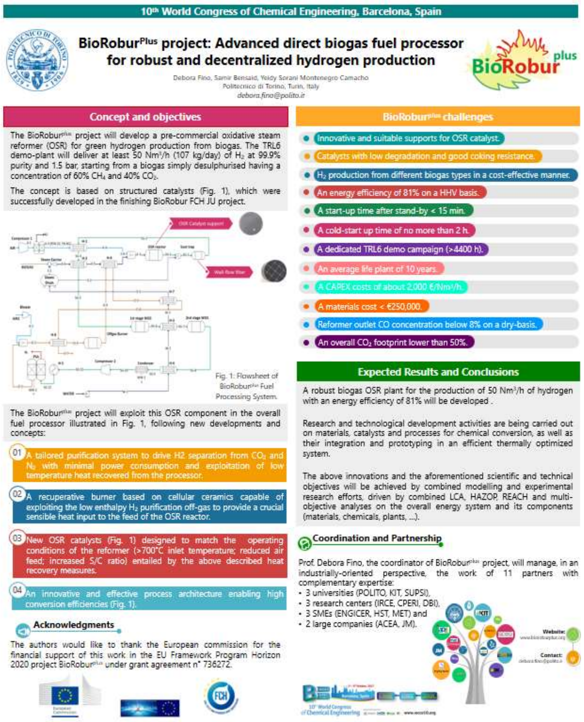

Figure 5. Poster for WCCE10 conference.

The project is going to be presented by Prof. Fino in a workshop in Turin on the 8th February.

Social networking will be continuously updated with the results of the project.