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Final Report

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Final Report

PROJECT FINAL REPORT

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Final Report

Please note that the contents of the Final Report can be found in the attachment.

4.1 Final publishable summary report

Executive Summary

EDen project has the aim to develop a POWER-to-POWER system consisting of: (1) a new storage material with high hydrogen storage capacity, for distributed level applications, included on (2) a specifically designed storage tank, integrated with (3) an energy provision system able to match local energy sources with energy demand in form of reversible solid oxide cell.
The request for energy storage systems and power-to-power technologies is growing as fast as the energy availability from renewable sources is increasing in penetration on the energy networks. Consequently, the market is demanding for storage solutions more performing, safer and economic. It is emerged from the past EU projects that the hydrogen storage in solid state is one of the better solutions to seek. Between the materials studied for solid state hydrogen storage, Magnesium based systems represent nowadays one of the best candidates able to meet the industrial storage targets: they have proper gravimetric and energetic density (typical >7 wt.%, ≥ 100 kg H2/m3) and suitable charging and discharging time and pressure.
The main barrier to the wide use of the Magnesium based materials in hydrogen storage system is represented by two limitations: the working temperature of about 300°C and the high heat of reaction, around 10Wh/g.

Eden project up-scaled (10kg) a new Mg-Base storage material by High Energy Ball Milling technique. Its properties were improved particularly through superficial deposition of selected metal oxide catalyst by innovative vibrating sputtering probe directly on powder. This allowed faster kinetics of hydrogen absorption and desorption reaction using a minimized quantity of catalyst. Tank layout and its main parameters are designed and optimized through analytical tool that includes a deep multy-physical modelling investigations focused on heat transfer, fluid dynamic, structural mechanical analysis. Numerical simulation allowed the identification the best design/layout for hydrogen storage tank, which was finally validated through a real comparison with a small-scale (2,5 kg) and full scale (10 kg) tank systems .
Finally, system integration layout was studied, including matching analysis for flows, heat transfer and temperatures tailoring auxiliary components such as: hydrogen burner, steam generator, water removal system, compressor as well as r-SOC and hydrogen storage tank. Simulations of the whole system performances evaluated and extracted the main critical parameters for efficient system management procedure. In particular, data simulated are gathered to evaluate the connection of the storage tank with different simulated SOC behaviors, both during fuel cell mode (with hydrogen consumption) and high temperature electrolyser (with hydrogen production and storing).
The system integrated was then realized comprising an electronic control unit. The single components were tested in laboratory and real environment, by a site in Barcelona, provided by the Energy Agency of the municipality. The final net cycle efficiency of the system was 25%.
The system was operated for about 10 full cycles in reversible mode both in Trento (FBK laboratories) and Barcelona.

Summary description of project context and objectives

Project context
The wider market penetration of renewable energy systems is leveraging the problem of the grid stability and security of supply to a critical level in several countries. Intermittent and variable sources in time and in magnitude are difficult to manage and distribute, with the proper demand response. A big effort is so dedicated in developing new storage solutions able to reduce the specific problem to a sustainable level. Different technologies have indeed important limitations in density, in cycling, in security of supply and reliability, in costs, in down- and up- scalability. Hydrogen, among other solutions, has a big potential in matching the scope on a wide range of applications and through different possible storage solutions. Among these, solid-state storage is getting a level of maturity never achieved before, where the readiness level is increasing to the demonstration of the integrated

systems in real environments. Some specific developments will be illustrated on new promising materials: Mg-based metal hydrides in several nano-composites, the innovation on integration layouts proposing new solutions to manage hydrogen storage on solid state, the coupling with bidirectional solid oxide cell and the balance of plants with auxiliaries for both thermal and fuel management.
Four main themes have led to the development EDEN technology:
(i) Delivering continuous energy to buildings, small dwellings, micro-communities, by integrating intermitted thermal and electrical power sources with hydrogen storage systems;
(ii) Mitigating the problem of intermittent energy delivered to the grid. Higher storage capacity at the local level reduces the need to expand the grid;
(iii) Providing safe, reliable and high-density energy storage for domestic applications. Mg-based metal hydrides can configure as a safe material and technology, with high energy density (more than 2000 Wh/l);
(iv) Provide the market with a viable complete system for hydrogen storage that will compete with the available storage systems in terms of costs and performances.
The overall scope of EDEN is to advance the actual state of the art of hydrogen based power-to-power systems, with reversible HT technologies for the production of hydrogen from renewable sources and conversion back to electricity, integrated with a solid state storage in form of Mg-based material, reduced in costs and enhanced in thermodynamic and kinetic properties.
The novel storage material, provided of with high hydrogen storage capacity, will be manageable in real-time, included on a specifically designed storage tank. The overall EDEN system will have an integrated thermal and fuel management and it will be interlinked to an energy provision system able to match intermittent energy sources with local energy demand (buildings, small dwellings), for distributed level applications.

Main objectives
The primary objective of EDEN project is to develop a new storage material with high hydrogen storage capacity, manageable in real-time, for distributed level applications, included on a specifically designed storage tank. It will be interlinked to an energy provision system able to match intermittent energy sources with local energy demand (buildings, small dwellings). The target performance values of the system under investigation are, respectively for material, tank and overall system:
- Material: Hydrogen storage capacity: >6.0 wt.%, Hydrogen density: >80 g/l, Hydrogen desorption rate: >3 g/min, Material cost: <30€/kg;
- Tank: Hydrogen storage capacity: 4.0 wt.%, Hydrogen density: 40 g/l, Absorption heat recovery: 25%, Hydrogen stored: 600g, Desorption rate: 1,5g/min;
- TANK – SOFC/SOE system: Heat recovery, Safety, SOFC performance: >300 mW/cm2, Performance loss: <10%/year.
Secondary objectives of EDEN are the improvement of the performance of the material by addition of catalyser via PVD on powder particles; the development of a proper compaction and activation process for the material; an efficient coupling of the tank with Solid Oxide Fuel Cell with utilization of the thermal energy on both the internal system and the end-user heating; determine the possibility of use of low grade or polluted hydrogen; demonstrate the validity of the concept for small scale applications.
The system architecture will combine 5 main elements:
(1) The storage material, compacted in pellet with specific design;
(2) A safe and efficient, thermal insulated tank;
(3) The heat flow managing system, heat carrier and pumps;
(4) The heat recovery system, equipped by TES and PCM (active during hydrogen adsorption/desorption reactions);
(5) The heating system (active during hydrogen desorption) connected with the SOFC.
As reported in FCH JU objectives and technical targets in Multi-Annual Implementation Plan 2008-2013, in the Hydrogen Production and Distribution application area (AA2), the targeted cost of hydrogen delivered to retail station is 5 €/kg. Since the EDEN system is a power to power system not delivering gaseous hydrogen, this target is not directly applicable, but project's objectives are however in line with this target: with a cost of 500 €/kg, a capacity of 0.6 kg H2 and 100 cycles in system lifetime, the cost of stored H2 at each cycle (and released to produce energy) will result 5 €/kg. The Hydrogen storage system cost (CAPEX) per kg capacity @ mass production (estimate) will be around 300 €/kgH2.

Work performed
During the second project period activities have been focused on all the three main topics of the project, related to the material development, to the components improvement including the hydrogen storage tank and the overall system integration. During the second project period several tests were performed both on the validation of performances for the single components and full system integrated and the demonstration of the system in a real environment.
Development of improved material
The development of the material has been finalized, including the upscaling of the Mg-based hydride production for the EDEN prototype at the intermediate (2,5 kg) and full (10 kg) scales and the validation and upscaling of the PVD catalyst addition to the Magnesium up to the kg-scale. Three main steps were performed:
1. Identification of the Best candidate material and consolidation process
The best candidate material from HEBM production with Nb_2O_5 catalyst was selected between developed material variants, considering the best balance between the different properties resulted from the performed characterizations.
The best candidate material is a nanostructured Mg-based powder, produced with addition of 7 wt.% of graphite and 3 wt.% of Nb_2O_5 catalyst. This material fulfills project targets for storage properties: gravimetric capacity 7.1 wt.% (H_2/MH); hydrogen density 130 gH_2/l; desorption rate 1 gH_2/min (1kg of material, at storage tank working conditions).
The reproducibility of material synthesis process was verified, in view of the scale up of production and the realization of prototype.
2. PVD decoration of catalyst on Magnesium powders
A catalytic effect Nb_2O_5 was observed for both ball milled Mg-catalyst and PVD coated Mg. A comparison was made between the powder behaviors, in terms of H_2 sorption kinetics, when catalyzed either with Nb_2O_5 as milling additive or as a coating. The utilization of the catalyst on the Mg powders ranges from the ppm scale for the PVD coated powder versus few wt.% for the powder with Nb_2O_5 incorporated as HEBM additive. Tests performed demonstrated a similar reaction kinetics of the storage material in both the configurations. This represents a significant catalyst weight reduction.
3. Scaling-up of the magnesium PVD decoration with catalyst to industrial level.
In the project, three stages for upscaling were followed, producing 5 g, 40g and 400g of the material coated with catalyst. The activity was performed with external support of a supplier.

Development of the storage tank
The design of the EDEN storage tank followed several steps, starting from the modelling with a multi scale and multi physic approach. The following step moved to the definition of materials and components and the overall engineering design, lasting with prototypation and validation steps, first at the small scale, followed by an intermediate storage tank at 25% of final size. Last development was performed at the full scale, including integration and testing in the EDEN final system.
1. Numerical modelling of the storage tank
Numerical simulation was related to final optimization of internal tank components. The numerical modelling was performed considering a multi-scale and multi-physic approach. Numerical simulation has been performed to study the effect of each single component in the final complete performance of the hydrogen storage tank. This includes: thermodynamic and kinetic behavior of the material, integration between the magnesium pellet with a thermal conductive porous Expanded Natural Graphite (ENG), to increase thermal distribution inside tank, overall heat transfer during the ads/desorption reactions, thermal insulation required for the tank. A completely new concept for the heat transfer was developed. Heatpipes with custom design were engineered for the use in hydrogen tanks. The heat distribution from the heatpipes to the storage material has also been ensured. A control system and measurement of temperatures, pressure and gas flow is considered.
2. Design and engineering
FBK, MATRES and PANCO collaborated to design, engineer and finalize the development of the hydrogen storage tank, optimizing the heat transfer, the heat exchangers, the thermal management as well as the heat recovery system to increase the overall energy performance. A completely new concept for the heat transfer has been developed and was installed into the tank prototype.
3. Prototypation and testing
Two main tanks were developed, an intermediate at 2,5 kg of storage material, and a full tank with 11 total kg. The final temperature gradient on the internal volume less than 1 °C. The fuel utilization was higher than 90% between the ads/desorption reactions. The kinetics were demonstrated at

0,5g/min at the intermediate tank and at 2,0 g/min at the final tank, with 3,0 g/min as a peak performance. The designed tank gives back an H_2 storage capacity of 2% corresponding to 800g H_2 in about 11 kg of storage material, a H_2 density of about 40 g/l.

Development of the integrated system

The development of the system included initial modelling of the overall layout, design and engineering of the components, design of a control strategy and, finally, realization of the system itself. FBK, PANCO and CIDETE cooperated in the initial phase of integration performed in Germany. The integration of the system was finalized in FBK, including the testing of all the components. Optimization steps included the main following components: reversible Solid Oxide Cell, hydrogen burner, water removal system, hydrogen compressor, blower, steamer, heat exchangers, valves and components controls, the electronic control unit.

Demo activities

The demo activities were partly performed in FBK and partly performed in-field in Barcelona, by a site offered from the Barcelona Energy Agency. The activities in FBK demonstrated the behavior of each single component in a lab environment and finally the full integrated system performance and control. A dedicated electronic control unit was developed to properly monitor and control the EDEN system, storing the data of performance and monitoring the status of each component. A dedicated management of risks was included in the ECU, following the risk assessment document developed by EDEN partners. In FBK a considerable experience on the EDEN system faults was obtained.

The demo activities concluded, in the final part of the project, in Barcelona. The final step demonstrated a simplicity of installation and configuration of the overall system (< 1day for full installation, assembly and start up procedure).

Results achieved

Finally, EDEN was able to achieve improved performances on most of the initial objectives, such as:

- Mg-based powder produced by High Energy Ball Milling, with 7.1 wt.% H_2/MH storage capacity and desorption rate > 1 gH_2/min/kg at 320 °C and 1.2 bar
- Consolidation method of Mg-based powder, suitable for enhancing thermal and mechanical properties, to full exploit its storage properties in a tank
- Intermediate and full Storage Tanks realized, integrated of thermal and hydrogen management able to release more than 1,5 litres per minute;
- System integration layout comprised of all auxiliaries to properly manage hydrogen and thermal power between the hydrogen tank and the SOFC;
- Full scale POWER TO POWER system, using HT electrolyser / fuel cell and solid state integrated storage.

Description of main S & T results/foregrounds

1. DEVELOPMENT OF THE NOVEL MATERIAL

1.1 Best candidate material

The selection of best candidates from state of art and innovative processes indicated the guidelines for the development of an Mg-based hydrogen storage material suitable for EDEN project objectives.

The best candidate material from HEBM production with Nb_2O_5 catalyst was selected between developed materials variants, considering the best balance between the different properties resulted from the performed characterizations.

The best candidate material is a nanostructured Mg-based powder, produced with addition of 7 wt.% of graphite and 3 wt.% of Nb_2O_5 catalyst.

The material has a gravimetric storage capacity between 6.6 and 7.0 wt.% /(H_2/ MH) and a desorption rate between 0.11 and 0.20 wt.% / min (at 320 °C and 0.5-3 bar, similar to future tank working conditions) corresponding to a range of 10-20 gH_2/min for 10 kg of storage material.

- high energy ball milling leads to material nanostructuring, achieving an homogenous dispersion of catalysts and enhancing powders reactive surface, even introducing active lattice defects;
- Nb_2O_5 addition in bulk, in the range of 2-5 wt.%, resulted the best catalyst for magnesium based solid state hydrogen storage, gathering a transition metal effect and a surface oxide effect;
- carbon additives in the range of 1-10 wt.%, e.g. graphite powder (C), act as both ball milling process additive and co-catalyst for magnesium storage properties;
- physical deposition is a useful technique for surface modification, since the main catalyst effect is a surface effect;

- a uniform coating of powders can be achieved by employing a vibration device for their mixing during deposition process.
Particularly the evaluations of storage capacity and desorption rate were obtained by measurements independently performed by Matres and JRC, obtaining similar values for the material performances at pressure and temperature values close to working storage tank conditions.

1.2 Material characterization

The material development started from the production by HEBM of many material variants, considering different process parameters that involved different milling energy conditions. Moreover, different additives amounts have been tested, in order to select the most promising material variants. During a first stage the Nb2O5 catalyst has been introduced by HBEM, in order to include its effect during the material development process. During a second stage, the selected variants have been produced by HEBM without addition of catalyst and then processed by PVD for its deposition.
In order to select the material variants, the obtained powders have been characterized by:
- mechanical sieving, to evaluate the process yield in fine granulometric fractions, which are more active and homogenous than coarse fractions; a 45 mesh sieve (354 #m) has been selected as distinctive;
- XRPD, to evaluate crystal size by Scherrer formula, hence the nanostructure of the obtained material;
- SEM imaging: to evaluate the morphology, measure the particle size distribution and the catalyst dispersion and dimensions;
- Evaluation of the Nitrogen sorption and BET evaluation: the value obtained for the as milled material is very low (0.2 m2/g), the one measured for activated material is 15.4 m2/g for hydrogenated and 18.8 m2/g for de-hydrogenated;
- thermodynamic and kinetic properties: the selected variants powders were characterised by SolTeF laboratory of JRC Petten, employing an agreed test protocol and focusing on the achievement of thermodynamics and kinetics data:
o specific use of dedicated equipment, e.g. volumetric and gravimetric instruments;
o testing conditions: the materials testing conditions were identical to the agreed testing protocol (see deliverable D1.3) except condition for equilibrium during PCI measurements;
o materials sampling: the samples of all materials were taken from a vials “as received”, without any special treatment like sieving or grinding;
o thermodynamics: PCI curves and Van’t Hoff plots: For each set of the conditions the first measurement was PCI in order to obtain the plateau pressure. Each PCI measurement was performed using dosing volume of ~11.6 cm3; pressure step of 1 bar; max. time to equilibrium of 3 h (at 280 °C prolonged up to 10 h) with the automatic recognition of the reaction begin and equilibrium reached (test begin after 15 min.);
o kinetic curves: The Avrami method was used to calculate the kinetic constant of the reaction. The kinetic data was represented as fraction of the reacted material. The Arrhenius method was used to calculate the activation energy of the dehydrogenation reaction;
o storage properties: This confirms that the best candidate material (ED011 A3) resulted to present, as well as a good balance between thermodynamic and kinetic properties, the highest gravimetric capacity (7.1 wt.% (H2/MH)) and an intermediate desorption rate, particularly considering the data at 320 °C and 1 bar (0.11 wt.% / min), close to future tank working conditions.
Following the powder consolidation process developed, the material selected variants, particularly focusing on the best candidate, have been characterized in form of pellets. The following aspects were investigated:
- Nitrogen sorption, BET and specific surface;
- Thermal conductivity measurements;
- Sorption properties measurements.

1.3 Final results

The selection of the best candidate storage material has been performed, considering the development of material variants. This selection was driven by the characterisations performed on material variants, in form of both powder and pellets by Matres. Specific characterisations by JRC on thermodynamics and kinetics have been useful for the validation of measured hydrogen storage properties.
The best candidate material was developed in two different variants:
• The first is the bulk-catalysed variant, that was obtained by high energy ball milling (HEBM) process only, introducing the catalyst at this stage in order to obtain the amount of storage material

needed to be used for the tank prototype realization.
• The second is the surface-catalysed variant, produced by HEBM without catalyst addition, then processed by physical vapour deposition (PVD) for catalyst deposition on powder surface. This process resulted to enhance sorption rate of powder and will be tailored to achieve the targeted hydrogen storage properties, evaluating its effect on powder particles.
The bulk-catalysed best candidate material variant presents a gravimetric capacity of 7.1 wt.% (H2/MH), a hydrogen density of 130 g/l and a desorption rate of 0.1 wt.% / min, measured at future tank working conditions.
The best candidate material produced by HEBM has been tested as consolidated in form of cylindrical pellets, obtained by cold uniaxial pressing and with the consolidating fillers selected during the material development: a mixture of expanded natural graphite (ENG) and steel mesh. The obtained pellets present enhanced mechanical stability and thermal conductivity, even after 50 absorption/desorption cycles or when scaled up by size. Considering the anisotropy of thermal conductivity of pellets, due to the presence of ENG as filler, only the axial conductivity was evaluated, since it is lower than radial conductivity.
Pellets behaviour when embedded in the matrix considered for tank layer design (ENG sheets) has been evaluated. The best candidate material from HEBM production with Nb2O5 catalyst was selected between developed material variants, considering the best balance between the different properties resulted from the performed characterisations. The best candidate material is a nanostructured Mg-based powder, produced with addition of 7 wt.% of graphite and 3 wt.% of Nb2O5 catalyst. The main properties of this material are reported in the following table, specifying the relative characterisation performed and the selection criteria. Particularly the evaluations of storage capacity and desorption rate were obtained by measurements independently performed by Matres and JRC, obtaining similar values for the material performances at pressure and temperature values close to future working storage tank conditions.
Below a summary of performances, indicating (1) the specific property, (2) the measured value, (3) the characterization method, (4) the selection criteria for the specific value.
- Hydrogen Storage gravimetric capacity: 7.1 wt.% (H2/MH), Volumetric and flow-meter based Sievert analysis, Highest value;
- Desorption rate: 0.11 wt.% / min, Sievert analysis, measured at 320 °C and 1 bar, Intermediate value;
- Absorption Enthalpy, #Habs: - 75.8 kJ mol-1, PCI curves at 280, 300, 320, 340 °C and Van’t Hoff plot, Lowest absolute value;
- Desorption Enthalpy, #Hdes: 78.3 kJ mol-1, PCI curves at 280, 300, 320, 340 °C and Van’t Hoff plot, Lowest absolute value;
- Absorption Entropy, #Sabs: 136.0 J K-1 mol-1, PCI curves at 280, 300, 320, 340 °C and Van’t Hoff plot, Lowest absolute value;
- Desorption Entropy, #Sdes: 139.9 J K-1 mol-1, PCI curves at 280, 300, 320, 340 °C and Van’t Hoff plot, Lowest absolute value;
- Desorption Activation Energy, Eact,des: 230 kJ mol(H2)-1, Kinetic curves at 1 bar and 300-320-340 bar, Intermediate value
- Projected cost of material: 45 €/kg, Evaluation of raw material and process costs, Best cost-properties balance. ED005 (A1) will cost 10 €/kg more, but storage capacity is lower; ED007 (A2) will cost 5 €/kg less, but generally material storage properties are worse;
- Crystal size: 35 nm, XRPD and Scherrer formula, Not considered for selection;
- Specific surface: 15-19 m2/g, Nitrogen sorption and BET, on activated material (hydrogenated – dehydrogenated), Not considered for selection;
- Size range of dispersed catalyst particles: < 1 - 2 #m, SE,M imaging, Not considered for selection.
The best candidate material was characterised also in consolidated pellet obtained by cold uniaxial pressing at different conditions: with and without selected consolidating fillers (ENG powder and steel mesh) and in smaller and larger pellets (diameter from 18 mm to 70 mm). The material storage properties resulted to be maintained also in consolidated form, with improved mechanical stability and axial thermal conductivity, and with a good cyclability, measured up to 50th cycle. This allows to consider a pellet size for the tank layer design between the explored diameters.
Furthermore, ø18mm pellets were tested as embedded in a ENG matrix, that will be used for tank prototype layers’ realization, in order to evaluate the mechanical stability when cycling in a matrix confining and contrasting material expansion. This allowed to validate the use of the best candidate material by HEBM consolidated in pellets, embedded in a layer design similar to the one for the future storage tank.

1.4 Perspectives on the material development

The PVD process for surface-catalysed best candidate material variant production will be optimized, evaluating the effect of the catalyst deposition on material kinetics, in order to achieve targeted properties also by this kind of process. This material will be compared with the bulk-catalysed variant. For the final optimization step of PVD process the use of a more limited nano-sized particle distribution of powder from HEBM will be considered, in order to perform a further tailoring for vibrating PVD conditions, without too small or too big particles. The possibility to produce master batches by PVD will be considered too, in order to limit the amount of material to be processed, to be then diluted in higher amounts of ball milled powder. Validation of the properties of the obtained material variant will be performed by JRC, focusing on hydrogen storage wt.%, thermodynamics and kinetics.

The best candidate material in form of pellets, both bulk-catalysed and surface-catalysed, will be further characterised by thermodynamics and kinetics analysis by JRC, evaluating the effect of consolidation process on material storage properties.

The results of this work and the comparisons between surface-catalysed and bulk-catalysed best candidates will be reported in the next updated version of this document.

The best bulk-catalysed candidate material is going to be produced by HEBM and then consolidated by MBN in order to fill the storage tank prototype that will be realised and tested within WP2. The amount of ED011 powder that will be produced by MBN is around 3 kg. The addition of consolidating fillers and the consolidation process will follow, in order to produce 100 pellets for the storage tank prototype.

2. DEVELOPMENT OF THE STORAGE TANK

The design of storage tank is the activity linking the development of the best candidate material with the realization of the overall system, including all components. The design has addressed particularly the thermal management of the tank, to supply the filling storing material with the adequate level of temperature and heating/cooling power during the different operation phases (charge, discharge, start-up, transient). In EDEN project, the necessary enthalpy of desorption for the storage material should come from the exothermic heat produced during the fuel cell mode in the high temperature solid oxide cell.

2.1 Modelling of the tank

Modelling of final tank requires the model of physical phenomena during uptake/release of hydrogen on candidate material inside the tank. From the phenomena, it is possible to develop a physical model, able to properly describe the storage tank and the materials starting from initial boundary conditions, in the details relevant for the design of the final solution. They could by heat flow, temperature gradients during specific processes, fluid dynamic regimes.

Based on information available either from the EDEN partners or from the literature, an initial physical model has been developed, able to describe in an accurate way the profiles and trends of physical variables inside the tank during its predicted operation (e.g. hydrogen pressure, temperature gradient and distribution, heat flow). In addition, numerical simulation can provide feedback both on stationary and transient behaviours of the tank-system.

To achieve this goal, a simple physical model of a single pellet was realized. From the basic model of a single pellet, a more complex problem has been developed and solved, including a single layer of the tank and the behaviour of the material in 2D simulation. Finally, the overall tank-system has been simulated in 3D to obtain the complete solution. Below a more detailed description of the modelling activity performed mainly in FBK, step by step.

2.1.1 Physical model of the material

In EDEN material and tank, conjugate variables have been modelled: temperature/heat, pressure/flow and mass/reacted fraction. For any of the conjugate variables a specific physics law describes the behaviour and trend. In particular, COMSOL modules utilized for this purpose are:

- Fluid dynamics module, specifically Darcy’s module, which approximate with good accuracy fluid dynamics problem in porous media;
- Heat transfer module, specifically designed to model heat transfer between fluids and porous media;
- Mathematical module, particularly Distributed ODEs (Ordinary Differential Equations) and PDEs module (Partial Differential Equations), in order to simulate reaction kinetics of the material (the mathematic formulation of a reaction kinetic is a differential equation).

The overall approach included the following steps: initial assumptions, elaboration of the mathematical formulation, design of the mesh and the geometry of the basic model, preliminary

numerical simulation of candidate material.
The model has been validated comparing the behaviour of a possible tank-system (composed by compressed magnesium pellets and graphite discs to homogenize temperature inside an empty and closed volume) and a numerical simulation with a similar geometry. Results were in total agreement.
2.1.2 Modelling of the tank
Tank is one of the main and more important components of EDEN system. An optimal design of this component can enhance the reaction kinetics performance of the material developed in WP1 of EDEN.
For these reason, tank for solid hydrogen storage must guarantee some important features:
• An optimal control and thermostatic conditions of the temperature inside the tank,
• An optimal system and flow directions for hydrogen,
• Safety, for pressurized conditions, for high temperatures, for the presence of hydrogen.
Tank for EDEN project must achieve and guarantee two main goals:
- Total capacity, volumetric and gravimetric density of hydrogen:
o Hydrogen gravimetric capacity 4.0 wt. %
o Hydrogen volumetric density 40 g/l
o Hydrogen stored 600 g
- High kinetics of hydrogen sorption:
o Desorption rate 1.5 g/min
Parameters utilized to simulate tank are an important element of the overall modelling. They have been defined partly by characterization of material (partners MATRES and PANCO supplied parameters on reaction kinetics, thermodynamics and thermal properties of magnesium) and by scientific literature.
The modelling of the tank defined the following elements and components:
• Tank external design, in a cylindrical geometry; the benefits are the structural mechanical properties for pressurized vessels; a better distribution of temperature gradient respect other geometries; the simplicity and lower realization costs;
• Solid state material for hydrogen storage, in form a consolidated pellet, laying on several considerations: simplicity in pellet production, also in series, through cold compression methods; pellets have similar geometry respect the tank, without sharp edges; upon different need and requests, pellets can be easily designed with different sizes; pellets can be easily replaced from the tank;
• Heat pipes, for fast and concentrated heat transfer between the internal and external of the storage tank. Heat pipes are basically thermosiphons using the latent heat of evaporation, by orders of magnitude higher than the sensible heat that can be transferred by conduction/convection phenomena. To realize a compact and light system, heat pipes have been identified as the best candidate components;
• Fins and thermal conductive material: expanded natural graphite was utilized, considering it is completely chemically inert to hydrogen; it has a high thermal conductivity; it is possible to tune thermal and diffusion proprieties changing the density of material (particularly using expanded natural graphite, ENG).
An optimization process followed, identified final engineering parameters. Optimization of tank-design followed the below described method:
1. Definition of the components of the tank (length of the heat pipe, total mass of magnesium, etc.);
2. Selection of the best optimal distribution of pellets per layer, in agreement with industrial production requirements;
3. Optimization of single/multiple layer's geometry respect gas and heat diffusion;
4. Optimize final design of tank and its auxiliary necessary elements
Once the best layout for a single layer of tank has been defined, the design of complete tank has to be developed. For this purpose, last parameters to be fixed are: Height of overall tank, Height of pellet and Height of FIN.
Such parameters have to match tank's constraints reported in previous section of document. Particularly, height of tank is limited respect height of heat pipes. Indeed, only two thirds of 60 cm heat pipe's length are useful to exchange heat with the tank. Maximum value of tank's height can only be 40 cm.
The best performance of tank is achieved for the smaller pellet size (10 cm), because in this condition it guarantees a bigger number of layers and fins, as well as, a better ratio between height of pellets and fins.
The Hydrogen storage tank has been designed based on:
• Characterization parameters of selected material;

• Thermal and gas proprieties of commercial ENG;
• Thermal and gas diffusion problem on metal hydride-tank.

2.2 Engineering of the tank

Distribution of pellet has been chosen in order to make a compromise between processability and performance of pellet. Moreover, layout keeps in account the thermal diffusion problems inside tank, guaranteed both a good thermal transfer from heat pipe with porous ENG (exploiting its overall length) and a good thermal transfer to pellet with high conductive fin. Finally, considering fixed parameters of tank (e.g. height of heat pipe, volumetric density), best final layout of tank includes an elevate number of layers and fins (at least 33 with fin's thickness of about 2mm and pellet's height of about 10 mm). The developed tank design, according to the features emerged from simulations and to described considerations, has been validated by the realization of an intermediate scale tank prototype. The tests that have performed on this intermediate storage tank, particularly focusing on heat management system and on targeted storage properties achievement, confirming the project target.

2.3 Realization and Validation of the intermediate tank

The main objective related to the realization of an intermediate scale tank prototype was to validate the tank design, in order to be suitable for material sorption properties exploitation. This includes:

- Components realization and assembly;
- Material loading and packing, by an embedding of pellets in layers suitable to ensure thermal contacts of the ENG matrix with both the storage material and the heat exchange components;
- Characterisation with a measurement equipment suitable for the tank size;
- Evaluation of storage performances (i.e. capacity, sorption rate) during tank cycling, also related to targeted properties;
- Thermal management evaluation, to ensure a suitable heat exchange during both absorption and desorption steps.

The work performed led to the acquisition of further knowledge that will be employed for the realization of the full scale prototype, improving the tank design at different levels and allowing its integration with the other components of the storage system.
Starting from the tank design developed on the basis of a suitable modelling, the intermediate scale tank prototype components have been realized and tested.
The tank vessel has been constructed according to safety regulations, the heat pipes has been provided considering the required heat flows and working temperatures, a suitable commercially available lightweight thermal conductive matrix, made of ENG, has been selected. Bulk catalysed best candidate material has been produced (2.4 kg) and consolidated in pellets (95) with consolidating fillers, tailoring the pellet size according to the defined layer design. Preliminary tests have been performed, embedding small pellets on the selected ENG matrix and evaluating their mechanical and thermal behaviour, allowing a further improvement of layer design.
The components have been assembled, then the tank has been loaded by embedding pellets in the ENG matrix, according to the defined design. Particular attention was addressed to the position of controlling thermocouples and to ensure a good contact between pellets, matrix and heat pipes. Subsequently the tank has been closed and connected to the electrical heat management system and to the specifically developed characterization device, suitable for managing hydrogen flows. Once performed tests for leaks and a degassing step, the tank has been heated up, starting its activation.

2.3.1 Tank characterization

Employing the MATH2 instrument, particularly with the mass-flow control component, 28 cycles of hydrogen absorption and desorption were performed with the tank prototype, first activating the material, then evaluating the storage properties at different conditions. In order to allow a simpler comparison with the specific characterizations previously performed on the storage material, the sorption properties (i.e. gravimetric capacity, sorption rate) were referred to the amount of best candidate material in the tank. These are converted in terms of tank prototype properties at the end of this chapter.

2.3.2 Storage properties and sorption process management

Since the storage tank will be integrated in the EDEN system and particularly coupled with a reversible SOFC, the main objective of this characterization activity has been to validate the tank storage properties, which have to be suitable to sustain the flows from and to the SOE/SOFC device. In order to achieve this goal, different process parameters were tested, finding the best operating conditions for maximizing the percentage of tank capacity that can be used at future working conditions, named tank working fraction. During this activity the tank prototype was considered to be a quarter of the full scale final tank, particularly for the total amount of stored hydrogen and for the inlet and outlet flows to be sustained during absorption and desorption in the final system.

2.3.3 Desorption and Adsorption

Maintaining the temperature set point of 320°C (on the measured pellet), an absorption flow of 6 Nl/min can be maintained for about 6h, without exceeding 10 bar of pressure and allowing a tank working fraction of 94% of material capacity. Maintaining the temperature set point of 350 °C (on the ENG matrix), a desorption flow of 9.8 Nl/min can be maintained for about 3h30min, with a pressure higher than 1 bar and allowing a tank working fraction of 90% of material capacity. These can be considered validating working conditions for the future integration of full scale tank, four times bigger in material amount, with both the SOE and the SOFC modes of final EDEN system. Some improvements can be performed in order to improve thermal management during desorption, allowing a more homogeneous temperature and a lowering of temperature set point.

2.3.4 Intermediate tank performances

During the 8 cycles performed for tank activation, different sorption conditions has been tested, selecting a steady flow condition with self-regulating pressure, mimicking to future needs of the final EDEN system. Once the storage material within the tank reached the expected gravimetric capacity, corresponding to 184.6 g - 2200 Nl of H2, 20 absorption and desorption cycles has been performed, allowing the evaluation of tank sorption properties, testing different thermal management solutions. An external insulation improvement was required, increasing temperature homogeneity within the tank and lowering heat dissipation.

This tank prototype presents a storage volumetric capacity of 20 gH2/l, considering the volume of the vessel, a desorption rate of 0.029 wt.%/min at 350 °C and 0.025 wt.%/min at 320 °C, corresponding to 0.70 g/min and 0.60 g/min respectively, considering the time required to achieve the 95% of storage capacity. Since the vessel is not completely filled with layers containing pellets (at top and bottom soft ENG disks fill dead volume, but 3 more layers can be loaded), the volumetric capacity of each layer can be considered as more indicative: 37 gH2/l.

2.4 Realization and Validation of the full tank

The full scale hydrogen storage tank prototype for EDEN project has been constructed, filled with the consolidated best candidate material, powdered up and characterised.

This storage tank has been constructed by Panco on the basis of the design developed. The thermal management has been improved by using a new set of heat pipes and heat exchanger. The tank height and diameter have been increased to 400mm and 275mm. It turned out, that for the heating of this tank the heat of the SOFC – Dummy was not sufficient, thus an electrical heater (1kW power) was wound around the tank and used additionally to the heat pipes, with a suitable PID controller. Safety issues were considered too, particularly for the thickness and the material of the components. However, the weight and thickness especially of the lids could be reduced drastically using a new lid design.

The bulk-catalysed best candidate material for solid state hydrogen storage has been produced and consolidated in form of pellets by MBN. The pellets were produced with the selected consolidating fillers, for a total amount of 15 wt.%, and according to the previously defined layer design. A total number of 418 pellets, corresponding to 10.66 kg of bulk catalysed material (ED011), has been placed in 22 different layers, embedding them in a soft thermal conductive matrix of expanded natural graphite (ENG) during the tank filling operations. Each layer hosts 19 pellets and it is enclosed between two rigid graphite fins. ENG matrix and fins are in contact with heating and cooling pipes. The contact of the graphite fins to the heat pipes has been improved using a zigzag shaped cutting of the graphite.

Once closed the tank, tests for leaks were performed both at room and at working temperatures with inert gas N2, Ar and He (up to 330 °C and 10 bar (Ar and He up to 4bar)), followed by a degassing step. Then the characterizations started. Aiming to be on time for demonstration activities, the measurement system previously developed for medium to large amounts of storage materials - already used for the characterization and validation of intermediate scale prototype - was not used for full scale tank characterization. This allowed to avoid additional effort to transfer the whole instrumentation to EDEN system integration site, i.e. from Matres (Italy) to Panco (Germany). A simpler characterization set up has been implemented and used to verify material activation, consisting of 3 pressure sensors and 14 temperature sensors, with a multi-step volumetric approach. Following this approach, 5 absorption/desorption cycles have been performed for material activation, maintaining the material in hydride form after the 5th absorption and the tank in overpressure of inert gas at room temperature conditions, in order to proceed with whole system integration.

During material activation and cycling the thermal management has been tested employing different heating and cooling conditions, evaluating temperature variations by a set of specifically placed

thermocouples.
In order to fully characterize and validate the storage properties of final tank, the activation and characterization activities proceeded once installed a measurement system based on mass flow controllers. This system allowed to verify the flow of H_2 adsorbed, to be consistent with working conditions of fuel cell in SOE mode, and of H_2 desorbed, to be consistent with the gas flow required by fuel cell in SOFC mode. This latter activity has been performed in FBK.

2.5 Storage tank validation

In order to consider the final storage tank fully validated, further characterizations have to be performed, in order to:
- achieve a stable capacity, corresponding to an almost full material activation, expected higher at least than 95% of stoichiometric capacity;
- Validate the tank adsorption, to be suitable for maintaining 2 gH_2/min up to 95% of storage capacity with a maximum pressure of 10 bar, at an average temperature of 320°C;
- Validate tank desorption, to be suitable for maintaining 3.2 g H_2/min up to 90% of storage capacity with a minimum pressure of 1 bar, at a temperature range of 330-350 °C.

Once validated tank storage properties, it will be possible to connect tank and fuel cell within EDEN system, being sure that tank sorption will proceed properly.

3. SYSTEM INTEGRATION and DEMONSTRATION

3.1 EDEN system integration

The core of EDEN system is based on two main components to be integrated and operated in the most efficient way as possible: the hydrogen storage tank and the reversible solid oxide cell (SOC), which can be run in reversible mode, as an electrolyser to produce and store hydrogen in the hydrogen storage tank starting from an external electrical source; as solid oxide fuel cell to re-convert the accumulated hydrogen into electrical and thermal power.
The objective of the integration between SOC and hydrogen storage tank is to identify and optimized the physical and energy flow layout for the overall system, taking into account the auxiliaries and also with special attention to the optimization of parameters, such as the fuel utilization, management of mass flows and water content in the fuel supplied from and to the fuel cell.
Therefore, integration between SOC and hydrogen storage tank includes the identification and sizing of auxiliary components for an efficient and integrated balance of plant (BoP) able to properly manage the fuel and heat moved through the system.
The integration layout between H_2 storage tank and SOC unit has to take into account the following points.

3.1.1 Thermal management in SOFC and SOE modes

The SOFC mode is the most critical to handle, due to the elevate amount of heat power involved. Some main considerations for heat transfer and related thermal fluid dynamic regimes is summarized here below:
• Hot outlet flows:
o Heat exchanger for heat pipes. Here, heat transfer occurs between warm outlet line and a cold side at constant temperature;
o Main Heat exchanger, with heat transfer with the cold inlet flows.
• Heat exchanger at the heat pipe working at 300°C, transferring 1.4-1.6 kW, correspondent to 2.2 g/min of released hydrogen;
• Air flux is limited by temperature constraint of SOC;
• In outlet flows, it has been considered the formation of water, after reaction inside fuel cell;
• There is a constraint due to the maximum temperature of inlet and outlet flows of Solid Oxide Cell (inlet at 700°C and outlet at 800°C).
Considering the above points and an energy balance analysis, the main remarks are:
• even if the energy/power balance seems to guarantee the self-sustainability of the system from a first principle point of view (8 kW of suitable thermal power for outlet flows against almost 7.5 kW required by inlet flows), the constraint introduced by the Pitch's temperature creates a reduction of available energy/power to pre-heating inlet flows (both air and fuel);
• temperature of exhausted flows (after main heat exchanger) is about 170°C;
• Finally, energy/power balance is short of about 1.3 kW to guarantee self-sustainability of EDEN system.
Despite the presence of excess thermal power in OUTLET #ows, this is completely unusable because it is at too low temperature. So, in order to guarantee a correct heat exchange, there is the need to supply an additional thermal power, ΔQ.
Solutions for this problem are:

• Using part of produced electrical power in order to supply ΔQ by electrical heater elements;
• Coupling the system with a post-burner in order to supply the correct amount of ΔQ by burning hydrogen in fuel cell.

The First hypothesis is not very convenient, because it does affects strongly the performance of the system, reducing its net electrical production.

The Second hypothesis can be realized bypassing the hydrogen in SOC towards a burner. In fact, there is a 20 % of fuel (hydrogen) which doesn't react during SOFC mode and which can be exploit for this solution

Considering the previous condition, if the excess of hydrogen is burned (approximately 0.44 g/min of hydrogen), it could be possible to partially fill the thermal gap to achieve self-sustainability condition.

Such solution requires the application of a suitable hydrogen burner. However, adding thermal power is not sufficient to achieve the project's target.

An additional solution is to extract more hydrogen from tank and to utilize this to increase the thermal power delivered to the burner. This option implies to deliver supplementary heat power through heat pipes, in order to release more hydrogen, respect the nominal conditions. This coupled effect (more hydrogen is extracted to be burnt, more heat power is required from heat pipe) is calculated by using the Equation Engineering Solver (EES) balance of plant.

Thermal analysis for the SOE operation is less complex respect to previous one. SOC requires a constant thermal flows of about 250-300 W in order to keep the stack at constant temperature (supplied through inner electrical heater) and it is possible to exploit the heat rejected from the tank during hydrogen absorption to heat the inlet flow, or to feed the electrical heaters through thermoelectric module. This topic will be studied and analysed in task 3.2, which is about energy recover.

The SOE mass and thermal balance reported in next sections of document have been performed by considering mass and thermal flux and the presence of a bypass between outlet and inlet flow, which necessary to maintain cathode side of SOEC in reductive atmosphere. More detailed analyses, including the ones on specific components, is included in D3.1 System Integration layout

3.1.2 Hydrogen management

Hydrogen management is a crucial point for an efficient integration between tank and SOC unit, and the long term durability of the EDEN system.

Hydrogen desorbed by the tank during SOFC mode can be easily handled, because it is of high purity, and can be directly feed to the fuel cell. The presence of particulate and powders coming from tanks can be easily prevented with the application of filters, at high temperature (300-350°C) along the feed line. In SOE mode, hydrogen management is more complex. The hydrogen flow coming from SOEC has a big content of water in form of steam. Steam must be cooled, condensed and filtered from the stream of hydrogen, down to ppm level. Water entering into the tank can irreversibly react with the metallic form of magnesium material and drastically reduce its life time by generating an irreversible Magnesium oxide.

A compression step must be carried out in order to promote absorption reaction inside the tank in the range between 5-8 bar. Pressure is the driving force for conversion of magnesium into magnesium hydride. Hydrogen compressor can be based on a mechanical or chemical technology. In EDEN finally it has been selected a mechanical one.

Hydrogen flows both for SOFC and SOE mode are managed by mass flow controllers, which are placed at the inlet and outlet of the hydrogen storage tank.

Design data for the Compressor:

- Gas: Hydrogen
- Inlet temp: 20°C
- Inlet pressure: 1 bar(g)
- Outlet pressure: 9 bar(g)
- Flow rate: 0 – 1.2 Nm3/h
- Ambient temp: +5°C up to + 40°C
- Diaphragm compressor: Air-cooled
- Drive: 3-phase motor 0,55kW,

Inlet and outlet hydrogen flows have different characteristic, here below specified in pressure levels, nominal flow conditions, temperatures.

- Inlet (SOE mode): 9-10 Bar, 1.5-2 g/min, 20-40°C;
- Outlet (SOFC mode): 1 Bar, 2.5-3 g/min, 300-200°C.

3.1.3 Water management

The water management system involves the handling of water and steam flows within EDEN system, including the hydrogen dyer apparatus. This component is one of the most critical, because even a small amount of moisture in the hydrogen flow can irreversibly damage the active material inside the storage tank, and strongly affecting its kinetics performance.
In SOFC mode, the presence of steam or water doesn't require any particular processes or treatments, because it is directly carried out with the exhausted air flow after burner.
In SOE mode its management is more complex. The water flow must be purified and vaporized before being introduced in the electrolyser. Purification is performed by a softener bases on ion-exchange resin.
The main components are the Softener, the Vaporized and the Water filter.

3.1.4 Air management

Air flow plays an important role for the thermal regulation of the overall system, since the tuning of temperature in the SOC unit is achieved through this flow modulation. Moreover, air flow is used to heat and desorb hydrogen from storage tank, using the high temperature at the SOFC outlet.
Air management requires a suitable blower, mass flow meter and feedback control to retrofit air flow in the burner.
Moreover, exhausted air flow from the system, both in SOE and SOFC mode operation, is found at high temperature, and more heat can be recover for other external applications.

3.2 Evaluation of the storage tank heat recovery solution

3.2.1 Simulation of heat recovery system

From calculations, the heat pipes of the tank will extract ~1200 W heat from exothermic adsorption reactions. This large amount of wasted energy must be not only pumped for the best performance of the tank, but also recovered. By using Comsol heat transfer simulation software, we have studied different ways to recover the highest amount of heat and convert it into electricity while helping the system to cool down. Several cases were studied.

• 1st case – heat sink without TE modules. From our simulations, we conclude that 50 fins (radius 50 mm) are necessary to totally cool down the system.
• 2nd case – With TE modules on the top.

By covering the top part of the heat pipes with a flat surface and further covering it with the mild temperature TE devices, while maintaining the fins, we observe that the system is not so efficient for the electrical generation. All the heat is dissipated before allowing the TE modules as energy harvesters. Neither the solution without fins is acceptable; it would provide low power generated by the TE devices while not being a suitable option to cool down the system.

• 3rd case – TE modules re-covering the Heat Pipe.

By re-covering the heat pipes with flat surfaces so it is possible to attach the mild temperature flat TE modules and adding metallic fins to help the system to reach the most efficient point by removing the extra heat, we found that was the best option for the heat recovery solution for the hydrogen storage tank. This system accepts up to 16 modules per heat pipe.

3.2.2 Testing the heat recovery system

In order to evaluate the design proposed for the heat recovery solution of the hydrogen storage tank, the same heat pipe that will be installed into the tank have been used, transmitting 1 kW of thermal energy collected from the lower end (tank) to the upper end, where the TE system will be installed.
The metallic pieces with a square section that have to re-cover the curved faces of the heat pipes were designed. The design was optimized so that the metallic bloc fits tightly around the heat pipe and thermal loses are minimized. In addition, between the heat pipe and the metallic bloc we introduced thermal conductive grease to properly transmit the heat.
Nevertheless, to ensure the correct performance of the TE modules, it is necessary to maintain enough temperature difference between the two faces of each TE device. We decided to attach modules only in 2 faces of the 4 available per heat pipe, insulating the remaining faces, to concentrate all the heat in the 8 TE modules connected in series, so achieving the optimum working point of the TE devices. In this case, the introduction of small low-power fans, appears as indispensable due to the increase of temperature within the modules.
During in-lab testing, we have achieved a maximum temperature difference of about 95 °C, with 203 °C hot side temperature, obtaining a voltage around 18.5 V in open circuit and 1 A current, values that match with the specifications of the developed TE devices, validating the proposed heat recovery solution.

3.2.3 Integration between the heat recovery solution and Thermo Electric components with the SOFC system

The integration between the TE heat recovery system and the SOFC is mainly based on the electronic

control. The control consists of a small circuit made of relays and thermostats than can work independently from the ECU, or can be controlled by de ECU in order to change the working mode when the SOFC system changes from SOE mode to SOFC mode or the reverse.
The “Part A” consists of a relay that is controlled by the ECU to decide in which way make work the TE modules (Seebeck or Peltier mode). If the relay is closed, the power supply will give enough power to the modules to prevent the dissipation of the heat from the heat pipes and maintain the temperature inside the tank. When the relay changes the position of the contacts, the power supply will be disconnected and the system starts producing energy from the thermal gradient on the TE modules and saving or directly using it.
The “Part B” is the fans control. Fans are designed to work always automatically in both modes; in SOE mode it is needed the maximum temperature gradient between the hot and cold side of the TE module in order to obtain as much power as possible, in the SOFC mode it is needed that the cold side of the TE module (the one in contact with the heat sink) is lower than 200 #C to avoid damages. In order to have the fans always working if the heat pipes are working, we placed a thermostat in contact with the HP that will activate the fans when the temperature is higher than 100 #C.
These thermostats are fixed in the aluminium parts with screws and thermal grease in the junction to ensure the correct detection of the temperature limit.

3.3 Control EDEN technology: The Electronic Control Unit (ECU)

The EDEN power to power technology is composed by several components working together in a controlled manner: solid-state hydrogen storage tank, solid oxide bidirectional fuel cell – electrolyser, catalytic burner, water removal system, vaporiser, hydrogen compressor, heat exchangers, blower, and other components such as valves, sensors, fittings. In addition, this system is able to work in two modes: SOFC mode producing electricity from the H2 stored inside the tank or SOE mode producing H2 and storing it inside the tank.
The ECU has the objective to properly monitor and control each single parameter of the system, both at a functional and level and for safety reasons. The different sensors installed provide signals that are converted into engineering values. The ECU will manage all the electric energy produced by SOFC and consumed by SOE (in electrolyze mode) and will provide continuous and real time monitoring to achieve optimal system functioning efficiency, preventing system malfunction and operating protection mechanisms when faults occur and according to safety regulations.
ECU hardware includes:
• ELECTRONIC BOX. Core of ECU, it includes: main electronic platform (software runs over that), electronic boards for signal conditioning and power supply for the sensor transducers.
Electronic box is responsible of signal acquisition, valves control, PID tuning algorithms and sensors power supply. Electronic box is supplied only with low voltage (24 V, 12 V and 5V).
• POWER BOX. It includes, power relays for every device, SSRs (Solid State Relays) to control electrical heater, main power supply (PU) for SOE mode, UPS, Electronic control unit for valve engines and monitoring PC.
Power Box is responsible for the handling of power supply for all device in EDEN system (mainly, for the devices with high current consumption (heater, SOE, etc..)). It is externally placed respect to EDEN system box, for safety reasons, to maintain high voltage handling outside to possible explosive atmosphere.
Considering safety conditions for EDEN system, ECU implements a series of alarms making in safe side the system, for possible emergency situation and possibility of danger for things or people. Every alarm has a warming state to recover the nominal conditions.

3.4 Final summary for system integration issues of EDEN

Main design and technical consideration for the realization of EDEN system can be resumed as following:
SOFC mode:
- Two separate heat exchanger are used to recover heat form air and fuel exhaust side.
- Air exhaust from SOFC is utilized to heat the hydrogen storage tank, through heat pipes and their heat exchanger.
- A hydrogen burner is utilized to increase temperature of exhausted. Non-reacted hydrogen and an additional amount of hydrogen is burned with the exhaust air coming from the fuel cell

SOEC mode:
- Water is purified (softener) and vaporized in suitable steamer.
- Air at room temperature and steam are pre-heated by outlet flows and heat exchangers.
- Exhausted air from main heat exchanger is expelled from system, and it can be exploited for domestic using.

- Hydrogen/steam flows are purified and compressed. Compressed hydrogen is introduced in the hydrogen storage tank.

3.5 Demonstration of the EDEN components and system, in-lab (FBK)

In order to complete system integration reducing uncertainty and avoiding undesired problems during the test of the full system and the future test in real environment, different test n the single components – where reasonable – have been performed.

The tests included the following components:

- Hydrogen storage tank: The full scale hydrogen storage tank prototype for EDEN project has been constructed, filled with the consolidated best candidate material ED011, powdered up and fully characterized;
- SOFC/SOE characterization: The SOFC/SOE unit was properly integrated with the thermal management system and the corresponding auxiliary control system to guarantee the complete functionality of the overall prototype. Test and integration of the SOFC/SOE unit provided by SOLID POWER was completed following the specific operating guidelines supplied by Solid Power, which request additional architecture implementation and process evaluation for the switching phases from SOE to SOFC mode and vice versa;
- H2 Burner: Catator has designed a burner for catalytic combustion of hydrogen on the request of Bruno Kessler Foundation (FBK) to be installed in the full system architecture under development. The flow rate of hydrogen requested is 20 – 25 slpm, which corresponds to a heat output of around 4.5 kW. The hydrogen flow is mixed with a similar steam flow and the mixture enters the reactor at 800°C. Air enters the reactor at a flow rate of 400 slpm and 650°C. The device has been tested completely using Mass Flow Controllers (MFC) to control the gas flow of air and hydrogen (H2) to the burner. The temperatures after the primary catalyst and on the exhaust outlet were recorded;
- Water removal system: this component is necessary to maintain stable and cyclable properties on the storage material. The water removal system has been tested completely by FBK, verifying the pressure loss behaviour which depends on used dryer agent and the residual humidity of dried product gas. Dew point of -60°C was measured, corresponding to less than 100 ppm of water content in the gas stream, as agreed among partners;
- Hydrogen compressor: hydrogen compressor has been configured as a subsystem able to maintain the necessary pressure drops in the system, both upstream and downstream. A parallel retrofitting piping was installed and properly controlled by a modulating valve;
- Blower: the blower is an important part. Air flow is the thermal vector of system as well as the oxygen carrier for the SOFC reaction. Pressure drop of pipeline and valves in EDEN system is about 10-30 mBar, at nominal flow of 150-250 NL/min;
- Steamer: dedicated tests were performed in order to demonstrate the proper control of the steamer, following the suppliers' instructions.

The EDEN integrated system was tested on both SOE and SOFC reverse modes. FBK solved several issues emerged during the integration of the different components, particularly in the below reported elements:

- SOFC mode: automatic tuning of hydrogen mass flow;
- Pressure drop during the compressor working time;
- Procedure of start up;
- Procedure of shut down.

3.5.1 Starting up EDEN system

Starting up the EDEN system means heating the whole apparatus up to the final working temperature.

Warming of the EDEN system is an operation that takes a long time. The Solid Oxide device is the most delicate component of the system. Its inner components are susceptible to damage at quite small thermal gradients. For this reason, the heating of SOC has to take at least 8 hours.

During the warming of the system, a small amount of hydrogen has to flux in the fuel cell side. In this way, further part of hydrogen released by the tank can be burned in the burner to contribute at the heating of the whole apparatus (e.g. heat exchanger, pipes) and reduce transients.

Using a mixture of 5-95% H2-N2 (for safety reason), the warming operation takes a longer period of time (more than 20h and it also requires switching to a pure hydrogen source to achieve the final temperature), because the poor content of hydrogen doesn't contribute to the heating of system. On the contrary, using a pure hydrogen flow, the EDEN system achieves the final temperature in 8 h with a constant increasing rate of temperature.

For this reason, the start-up of the EDEN system includes the following chronological operations:

- Heating of tank (it must be charged with hydrogen) at the desorption working temperature (360°C)

by means of an electrical heater;
- A small amount of pure hydrogen is extracted from the tank (0.6 g/min) to flux in the fuel side of the system. Next, heating of the rest of apparatus (steamer, SOC, etc..) is started;
- In this way, pure hydrogen from the tank is used, and the heating operation can take a correct period of time;
- When the system is ready, SOEC mode is launched and the tank is refilled by hydrogen.

Other components of the EDEN system require less time to be ready for cycling operation (from 1- 3 h):

3.5.2 Shutdown / Switching off EDEN system

As for start-up operation, shutdown step is very slow to safeguard SOC device.
Two type of shutdown procedure are implemented in EDEN operation:

- Emergency shutdown

It is an emergency procedure used in case of critical alarm (high temperatures, presence of free hydrogen in the air, ventilation failure and manual emergency button). It includes the shutdown of all electrical devices (air blower included). All valves are closed and current operation is turned off.
In this case, an emergency valve is automatically open in order to flux the solid Oxide cells with a reducing flow (5-95% H2-N2). Emergency shutdown takes 5-8 h and it is considered complete when all temperature inside EDEN apparatus are below 100°C.

- Standard shutdown

It is a normal procedure. It is launched by suitable command on GUI (graphics Unit [o User?] Interface) of the operator. It sets a cooling temperature ramp for all devices (e.g. SOC, Steamer), at the same time it continues to supply a small amount of hydrogen to the SOFC in order to maintain a reducing atmosphere inside it. Hydrogen is fed by tank maintained at desorption temperature (360°C). When temperature of SOC goes down to 100°C, hydrogen flow is stopped, and the tank is cooled to the ambient temperature by a natural cooling process.

3.6 Demonstration of the EDEN system, in-field (Barcelona)

In EDEN project, after the integration of the different components into a single system, some demo activities were planned. These activities have the intent to extract the performance values of the EDEN technology both from in-lab and in-field test trials and solve main issues arisen from the validation process. At the end of this steps, it will be more clear for partners how to move the technology to an optimization process, to the definition of a better integration layout, including simplification measures, cost reduction, improvement in the overall efficiency. This was particularly demonstrated throughout the in-lab testing. The performance of EDEN system was also demonstrated through in-field measures. These, due to several reasons, were quite limited in time, but finally gave back really important feedback on how to handle a similar technology, from the shipping, to the installation, to the technology management, working in a realistic situation/ application.
The in-field demonstration of EDEN was held in Barcelona during June 2016. CIDETE, on behalf of the EDEN consortium, signed an agreement with the Energy Agency of Barcelona (Agència d'Energia de Barcelona – AEB) and the Barcelona City Council for the development of the demo in municipal facilities: a cleaning park equipped with a photovoltaic system. After several meetings, discussions and negotiations between public and private operators involved, the agreement was accepted and EDEN could be presented in the city of Barcelona with the support of the Municipality. This happened after several levels of discussions, including management of the technology, contractual obligations among the parties, safety precautions, duration and scope of the agreement.
During the demonstration, apart from the collection of the technical data about the performance of the system, different meetings and small events took place in the demo site to pursue the dissemination of the technology to the government and authorities and the general public.
During this period, EDEN system has performed a tens of complete cycles of charging (SOEC) and discharging (SOFC). First cycle started from a complete discharge status of tank and, for this reason, the first charging appeared so performant. Next cycles were performed in a very short time-sequence and a series of constraints in order to establish the most suitable parameters for successfully efficient operations.

3.6.1 The Demo site

The demo site of EDEN was placed at a Cleaning Park of the Barcelona City Council, at Carrer Jerez S/N, called Parc de Neteja de les Rieres d'Horta, placed on the top of a rain-water deposit and under a green area provided with photovoltaic panels.
Inside the cleaning park, and next to a big door, ensuring the ventilation of the area, there is a free space with easy adaptable connection to the grid and the water line. In addition, the park is provided

with fire alarm and anti-fire system. The available power from the PV system was 66 kW. AEB agreed on adapting a special connection to the PV system for the EDEN system.

3.6.2 EDEN BOX

EDEN box will completely embed the fuel cell, the tank and the auxiliary components (Balance of Plant – BoP). Only the heat dissipation component including the Thermo-Electric Device has to be interconnected to the external environment. The confinement box will be realized in a metallic frame. Several stainless steel plates will close the frame with related sealing materials.

To minimize the potential risks and hazards associated to a leakage of hydrogen, the system has several layers of security, in some cases in redundant configuration:

- CONFINEMENT BOX: the EDEN system is completely sealed by itself, and furthermore, to prevent the leakage on the external environment, inserted in a confinement box, sealed as well respect the external environment;
- VENTILATION SYSTEM connecting the box with the external environment (on the outside): the confinement box, when working, is provided of a ventilation system that can remove the problem of hydrogen leakages from the indoor environment. The ventilation system will work on a permanent way during the start up phase and until full commissioning of the prototypal technology.

The ventilation system will be sized upon specific requirements. Considering the volume of confinement box (approx. 1.6x1.6x1.5m = 3.84 m3), a flow of 32Nl/min will provide a concentration of 1 vol% by volume in 1’12” and of 0.4 vol% in 30”. Therefore the air within the box should be filled in a time of 30” with a flow of 7.7 m3/min. This flow must be easily achieved by a blower properly sized, installed at the exhaust of the external box. The blower will be installed on the top part of the confinement box, so that in case of a fault on the electric control, in presence of minor leakages, the hydrogen is removed by the box by natural ventilation.

Ventilation should be sufficient to dilute hydrogen leakages to 10% of the lower flammability limit (LFL) – corresponding to about 0.4% by volume.

- H2 SENSORS monitoring security levels of hydrogen within the containing box. This third level of security system will be necessary when the system will be operating in the standard mode. The ventilation system will not be operating and an intrinsic security is required.

The hydrogen detection system must be compatible with other systems such as those for fire detection and fire suppression. The detection units should not be ignition sources. Total times for detection, data summary, transmission, and display should be as short as possible. A portable hydrogen detector should be available, while a continuous automatic sampling equipment should be placed at representative points, considering possible leak rates, ventilation rates and volume of monitored space. Detection of 10% of LFL – 0.4 vol% of H2 in air – should be required for confined spaces.

The H2 sensors will be installed in redundant number: one accurate sensor and other two threshold sensors.

Other actions limiting the potential risks:

- UPS for continuous electricity provision;
- ATEX certified components;
- Water daily control ON-OFF system;
- Remote system control with alert messages (email, sms, etc.);
- Webcam with remote connection to have a visual control on the external of the system.

EDEN system has performed some complete cycle of charging (SOEC) and discharging (SOFC). In the next plots, its performances are reported for a series of complete working cycles. Results are shown respectively as:

A. Hydrogen mass flow profile, hydrogen mass production and utilization in SOEC and SOFC mode are reported. The total hydrogen mass burned or stored is shown for every cycle;

B. Electrical power productions and utilizations in SOEC and SOFC mode are reported. Total electrical energy consumed or produced is shown.

Every cycle starts and finishes under certain conditions:

- SOEC mode starts at the beginnings of every cycle, when hydrogen pressure in the tank is lower than 2 Bar(a) at 360°C;
- SOEC mode finishes when pressure of tank achieves 9 bar(a) at 320°C;
- SOFC mode starts immediately after SOEC mode;
- SOFC mode finishes when pressure inside tank goes below 2 bar(a) at 360°C.

The transient step (between SOEC and SOFC mode, and vice versa) consumes a slight amount of hydrogen which is neglected from the calculations.

3.7 Performance of the system

In order to completely describe performance of EDEN system, some of the most relevant figures of merit are reported.

3.7.1 Electrolyser Efficiency

The value of net efficiency ranges from 95% to 140% during electrolysis mode because it exclusively considers consumed the electrical power from SOEC. In high temperature electrolysis (over 700°C), a considerable amount of energy is fed from the environment as thermal power, which contributes to reduce electrical power consumption for hydrogen production. The efficiency in electrolysis mode is constant for all cycles.

3.7.2 Fuel Cell Efficiency

Efficiency of fuel cell operation is about 50-55% for the maximum electric power output (1.1-1.2 kW). Efficiency increases for low electrical power production.

3.7.3 Global Net and Gross electrical efficiency. Cogeneration efficiency.

The total electric efficiency of EDEN system can be estimated on the energy balance during both electrolysis and fuel cell mode. This value doesn't take in consideration additional electric consumption from auxiliary components of the system. As net electrical efficiency, it has been considered how many units of electrical energy it is possible to produce (recover) in SOFC mode for every unit spent in SOEC mode.

Net electrical efficiency of EDEN system is around 20-30% for every investigated cycle. Concerning first cycle, that shows the best performance, if auxiliary components are taken in consideration, the gross electrical efficiency drops to 5.1%. In the same case, considering also thermal output power in the hot exhaust air (including thermal power produced by exothermic absorption reaction of Mg based material), gross cogeneration efficiency achieves 15.3%.

Thermal power output is calculated as the heat contained in the hot exhausted air flow outlet by EDEN system, respect to ambient temperature. In SOEC mode, air flow is lower respect SOFC mode, for this reason, amount of extractable thermal power is inferior (1.65 kW respect to 2.6 kW) despite of thermal gap is approximately equal. Also in this case, efficiency is estimated by energy balance of system and taken into account operating time of working operation. More details and data are reported on the Deliverable 4.3 of EDEN project.

3.8 Final summary of demonstration

Finally, EDEN system was demonstrated through in-field tests, evidencing on one side the necessity of an additional development step. The actual technology is arrived at a TRL5, considering the EDEN technology has been tested in intended environment. Good results have been achieved considering the overall cycle efficiency and the hydrogen storage capacity. The hydrogen storage before the degradation was close to the maximum uptake demonstrated at the full scale tank size, about 800 g of hydrogen.

On the other side, some issues remain unsolved and they will be part of further tests.

The follow up of the present activities is indeed planned. To properly prepare a further initiative in form of public project or private investment, FBK has the intention to set up again the EDEN system inside a new laboratory under preparation in the institute in Trento. The new set up will allow further tests on the EDEN system, to complete pending issues such as:

- Cyclability and long term tests;
- Optimization of auxiliaries;
- Connection and utilization of the heating.

Potential impact and main dissemination activities and exploitation results

1. INTRODUCTION

The use of hydrogen as an energy carrier is relatively new and, as such, may be vulnerable to inaccurate public perception. Social acceptance is vital to the successful deployment of any technology and can be achieved by heightening awareness of the risks and benefits offered by each specific technology. For hydrogen technologies, through knowledge dissemination and education during research project duration as EDEN, providing information on safety and emphasizing the environmental advantages of hydrogen as a fuel could contribute at creating opportunities to traduce the EU investment in potential impact at economic and social level. Only with a good social acceptance and proper regulation package, a successful market deployment of innovative technologies could be addressed with consequent positive economic impact on the overall European community.

In order to contribute at this objectives, EDEN consortium have done a consistent number of dissemination initiative (more than 60 %) as public press releases, media communication events and public events to address an huge public audience - from politicians to citizens - in order to stimulate social acceptance of hydrogen technologies. In addition, the transnational cooperation prompted by EDEN consortium has managed to mobilise and promote the sharing of knowledge and capabilities (in terms of expertise, institutions and resources such as laboratories) among the whole scientific community, collaborating with other research project (like BOR4STORE, SSH2S, HYPER), participating in different FCH-JU initiatives (review days, presence at fairs, etc.). The project has produced valuable impact on the related industry and research disciplines, participating at international conferences and congress where members of the EDEN consortium presents project objectives and results. Feedback from the audience and stakeholders can be distinguished and summarized in the following main categories:

- Research: people asking for information on the project in order to complete research papers, dissertations, for use in related research prototypes or to be better informed about the project innovations and objectives;
- Industrial: people ask for information on future market deployment of the hydrogen storage technology, in order to estimate possible future market participating as a components supplier/provider or as partner in a new joint venture initiative;
- End-users: people asking for information as potential end-users willing to try out the project results;
- Working/collaborations: people and companies declaring interest for collaborating in new initiatives;
- Commercialisation: established Technology Transfer Board (TTB) evaluate how to collaborate in order to move EDEN prototype from TRL4 to TRL9 and develop a product to address preliminary market opportunities;

It is also important to note that impacts of research, capacity building and innovation projects like EDEN are also long-term in nature and the contribution to socio-economic development can not only unfold with immediate direct results, but also via indirect ones that may become visible only years after research activities have ended. Besides the obvious impact in terms of new technologies/products produced, EDEN has also helped in ensuring further knowledge sharing and capacity building projects between typically unconnected research partners established especially in South Europe - thus contributing towards the development of skills and institutional capabilities of partners. Similarly, some effort has been undertaken to generate and influence policy makers (in Spain and Italy), while promoting policy dialogue and learning in the topic of hydrogen technology and in the general energy applications towards the objectives outlined in the H2020 programs.

2. TOWARDS COMMERCIALISATION of EDEN TECHNOLOGY

MBN, as material producer, will exploit commercial opportunities related to Mg-based storage material developed inside the EDEN project, in form of powder and/or pellets, for different hydrogen storage systems. Particularly, after some improvements and optimizations of the “ED011 Nanostructured Magnesium” developed during the project, commercialization of the storage material is expected by first quarter of 2017 addressing mainly the European markets of solid state H2 storage systems. By upscaling the material production in the range of 10-20 ton/year, it is estimated that first material selling could be done in the price range of 28-30€/kg, that could be successively decreased in function of the increasing number of order for material production.

In addition to the short-time market availability of the storage material, there are several additional options to commercialize the EDEN technology, varying from selling it as a standalone product or incorporating it (or part of the tecnology developed) into existing products. These following important steps are envisaged to increase the opportunity of the market deployment, especially for the improvement and final product development of a complete integrated P2P system after the basic and applied research conducted during the project:

- Improve performances of the already available ED011 storage material;
- Scaling-up the industrial material production process (hundreds of tons/year) - in form of powder and/or pellets;
- Improve tank efficiency (control process, insulation and energy recovery) and tank weight reduction;
- Miniaturisation of ECU and safety systems;
- Involvement in the TTB of a company capable to operate as system integrator with expertise to properly address future market deployment;
- Influence policy makers for the necessity of a common national and/or international standards and regulation on solid state hydrogen storage, to facilitate the diffusion of hydrogen storage technologies and applications;
- CE marking;

In the EDEN Market Deployment Plan (MDP), a complete market analysis has been done and preliminary business cases for real deployment of EDEN P2P system have been envisaged. Here are reported, as feasible business cases, the exiting market that could be addressed in a short time:
• OFF-GRID TELECOMMUNICATION TOWER;
• HYDROGEN BALANCE FOR REFINERIES;
• GRID MITIGATION;
• HYBRID SYSTEM FOR DAILY TIME SHIFTING AND RESIDENTIAL mCHP
Three to five years is estimated as a reasonable amount of time to improve the technology as previously outlined, to decide the commercialization pathway and collect the funding for preliminary installation of the EDEN P2P system products.

3. POTENTIAL COMMERCIALISATION PATHWAYS
There are several options to commercialize the EDEN platform. Potential commercialization pathways for EDEN technology include:
1. Outright sale Simple, immediate income
2. Consulting thanks to the expertise developed during the project
3. Licensing Exclusive or not, long term income, simple
4. Joint Venture company with TTB members: agreed equity stakes, sharing in future development;
5. Independent Spin-out company: agreed equity stakes, best returns including from future R&D
The final Exploitation Plan is the result of a concertation process conducted by the project consortium in the last twenty months of the project, collected in two main documents: the Market Deployment Plan (MDP) and the Common IPR Agreement (IPR). In the following paragraph about exploitation results are briefly summarized the details included in these two important documents for future market deployment of the EDEN technology.
All the options the consortium considers viable are described in the IPR Agreement. Since today, EDEN project has assessed not only the technological development, but also the aspects related to the regulatory frameworks and standards which allows customisation of the final prototype to match the requirements for the development of a marketable product. These may include:
• Safety related standards;
• Maintenance procedure standardisation: instructions related to the maintenance procedure for the system (definition of lifetime of each spare component and/or system, definition of terms of use for the system);
• Regulatory framework assessment.
At the moment it is deemed that the commercialisation pathways best suited for the EDEN results are primarily the spin-out route and the licence route, with the opportunity of outright pending IP applications for the single components or process.

4. DISSEMINATION ACTIVITIES
During the whole duration of the project (October 2012 – June 2016) more than 35 dissemination actions (average value of 0.8 event/month) have been taken by the project consortium under the WP5, following a common agreed dissemination plan - with at least one event each three months - in order to maintain a constant attention on project advancement and activities. As reported in the following figure, the dissemination actions have been distributed using different media channels to address a huge audience, from the scientific community, to industrial sectors and policy makers, until the possible final users (citizens, companies, etc.). In parallel, the EDEN official websites published in February 2013 (M5) have been constantly updated and completely restyled at the end of 2014 (M26). Additional dissemination material (a new brochure with detailed information about the system applications, postcards, rollup, etc.) have been developed in order to better address the interest of energy sector actors and stakeholder and diffused in trade fairs, conferences, exhibitions and face to face meetings.
A consistent number of dissemination activities have been done in 2015, seventeen, due to the fact that preliminary results on the whole system architecture was available only during the first quarter of 2015 and that the project end was initially planned at September 2015, with the Final Dissemination Event in Trento already organized and publicized. Due to the technological and shipment delay occurred at the end of 2015, two additional dissemination events in Barcelona during project extension in 2016 have been organized as EDEN closing events after the test campaign in real environment.

EXPLOITATION RESULTS

5. EXPLOITABLE FOREGROUND

Exploitable foreground and relative applications, as a non-exhaustive list, are here summarized:

- Modelling, simulation and design of hydrogen systems for complex production - storage - usage of hydrogen;
- Modelling and simulation of hydrogen storage in solid state materials with multi-scale models and multiphysics phenomena analysis of hydrogen storage in solid state material for R&D activities, industrial innovation, new product productions, educational and academic courses;
- Improved knowledge on Mg-based hydrogen storage material characterization - in powder and particularly as consolidated pellets - as services for material industrial production, for measurements of storage performance (gravimetric capacity, sorption rate) and for solid state hydrogen storage material development;
- Development of synthesis route by high energy ball milling for nanostructured Mg-based powder for hydrogen storage;
- Plasma deposition of ultrathin films onto powders for catalysis in energy sector application (photocatalysis for H2 production), sintered powder consolidation in electrodes for fuel cells or for electrodes in OLEDs applications;
- Catalyst application by physical vapor deposition onto Mg for H2 sorption kinetics improvement for catalysis in energy sector application (photocatalysis for H2 production), sintered powder consolidation in electrodes for fuel cells or for electrodes in OLEDs applications;
- Production procedures of consolidated pellets including consolidating fillers enhancing thermal conductivity and mechanical stability, specifically developed for tank used in hgh temperature hydrogen storage systems;
- Testing equipment and procedures for medium to large amounts of solid state hydrogen storage materials;
- Development of safe and cost effective procedures for material production in inert atmosphere and correlated procedures for transportation and commercialization;
- Hydrogen tank design with proper heat pipes geometry for solid state hydrogen storage systems;
- Measurement instrumentation and characterization procedures for hydrogen storage tanks;
- Design, development, assembly and control of a heat recovery solution for industrial applications;
- Expertise in power-to-power (P2P) system development for energy storage applications, grid management, residential and industrial scalable solutions based on hydrogen;
- Safety requirements and procedures for hydrogen storage system installation in industrial and residential applications;

6. FOREGROUND TO BE PROTECTED AND EXPLOITED COMMERCIALLY

The list below illustrates the major innovative developments achieved:

- Catalyst application by physical vapor deposition onto Mg for H2 sorption kinetics improvement
- Hydrogen storage tank for integration in P2P system
- Complete P2P system architecture based on solid-state hydrogen storage solution

Patent application is under evaluation by the consortium, as outlined in details in the IPR Agreement.

7. SETTING UP of TECHNOLOGY TRANSFER BOARD

The Technology Transfer Board is a horizontal structure defined at the beginning of the project between the Project Coordinator, the project partners and external industrial parties interested in exploitation of the project results and in developments after the project closure. The TTB's task is to ensure full exploitation of the project results. Today, the actual TTB is participated by 14 European and international entities with more than 70% representing European SME.

As a first results of the collaboration, SOLID POWER and FBK are preparing a collaboration agreement specific to the topic of HT Electrolysers and reversible Solid Oxide technologies.

Based on updated expression of interest of the TTB members to exploit the EDEN technology, partners involved for deployment of the technology will meet again to evaluate future collaboration pathways.

8. COMMERCIALIZATION REQUEST & EXPRESSION OF INTEREST

Commercialisation requests and further funding opportunities collected are here summarized:

- Request to collaborate with the SOLID POWER company in the field of HT electrolyzes and reversible Solid Oxide systems;
- Request to collaborate with the HZG company in research and development of new hydrogen

storage materials and systems;
• Interest of local municipality of Isera in Italy for the installation of a prototype unit in the municipality renewable energy station, based on solar PV and hydrogen generation system;
• EDEN was requested to provide information at local municipality of Borgo Valsugana (Italy) to better understand advantages, environmental and social impact of the EDEN technology;
• EDEN was requested to provide information at Barcelona Energy Agency (BEA) in Barcelona, Spain to better understand advantages and applications of the EDEN technology in big smart cities;
• EDEN was requested to provide a feasibility study and a full prototype for a potential installation by a private user in a rural family building requiring 3Kw of power;
• EDEN was requested to provide collaboration in teaching courses at industrial and technological schools in Italy (progetto Alta Formazione).

Address of project public website and relevant contact details

Project Website: http://www.h2eden.eu/

Relevant contact Details:
Mr. Luigi CREMA
Fondazione Bruno Kessler - FBK (Italy)
CMM – Centre for Materials and Microsystems
ARES – Applied Research on Energy Systems

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4.2 Use and dissemination of foreground

Section A (public)

Publications

LIST OF SCIENTIFIC PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES										
No.	Title / DOI	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Date of publication	Relevant pages	Is open access provided to this publication ?	Type
	DEVELOPMENT OF A EXPERIME NTALLY VALIDATED MODEL FOR SOLID STATE HYDROGEN STORAGE DESIGN OF MATERIAL AND TANK	M.Testi, F .Alberti and L.Crema	EFC 2013 - 5th European Fuel Cell Piero Lunghi Conference		ENEA - ITALIAN NATIONAL A GENCY FOR NEW TECHNOLOGIES , ENERGY AND S USTAINABLE ECONOMIC DEVEL OPMENT	Lungotevere Thaon di Revel, 76 00196 RO ME	15/12/2013		Yes	Conference
	EDEN: NOVEL POWER-TO-POWER SYSTEM FOR ENHANCED HYD ROGEN STORAGE IN SOLID STATE	L. Crema, M. Testi, and F. Alberti	EFC2015, European Fuel Cell Technology & Applications Conference - Piero Lunghi Conference		ENEA - ITALIAN NATIONAL A GENCY FOR NEW TECHNOLOGIES , ENERGY AND S USTAINABLE ECONOMIC DEVEL OPMENT	Lungotevere Thaon di Revel, 76 00196 RO ME	18/12/2015	217 - 218	Yes	Conference
	DIFFERENTIAL PRESSURE APP ARATUS: AN ENHANCEMENT OF CLASSIC SIEVERT INSTRUMENT	Matteo Testi, Luigi Crema	EFC2015, European Fuel Cell Technology & Applications Conference - Piero Lunghi Conference		ENEA - ITALIAN NATIONAL A GENCY FOR NEW TECHNOLOGIES , ENERGY AND S USTAINABLE ECONOMIC DEVEL OPMENT	Lungotevere Thaon di Revel, 76 00196 RO ME	18/12/2015	293 - 294	Yes	Conference
	New concept for thermal management in a	D. Platzek, H.	9th Int. Symposium Hydrogen & Energy		EPFL		31/01/2015	33	Yes	Conference

	hydrogen tank	Platzek, A. Bianchin, E. Forlin, M. Testi, F. Alberti, N. Laidani, R.Bartali, L. Crema, P. Matteazzi, S. Ortega, G. Noriega, M. Bielewski, J. C. Ruiz-Morales								

LIST OF DISSEMINATION ACTIVITIES								
No.	Type of activities	Main Leader	Title	Date	Place	Type of audience	Size of audience	Countries addressed
1	Posters	FONDAZIONE BRUNO KESSLER	Nb2O5 deposition on Mg by plasma te chnique for hyd rogen storage applic ations	31/08/2015	Manchester, United Kingdom	Scientific comm unity (higher educat ion, Research) - Ind ustry - Policy makers	100	EC countries, USA, China
2	Press releases	FONDAZIONE BRUNO KESSLER	Kick off meeting of EDEN project	12/10/2012	Italy	Civil society	1000	National/internation al
3	Press releases	FONDAZIONE BRUNO KESSLER	PROVIDING HYDROGEN E NERGY TO H OMES	15/10/2012	Italy	Civil society - Medi as	50000	National/internation al
4	TV clips	FONDAZIONE BRUNO KESSLER	TV show “Dedalo” on Ada Channel	24/10/2012	https://www.you tube.com/watch? v=TdLuMaMxEtE	Civil society - Medi as	2000	National/internation al
5	Articles published in the popular press	FONDAZIONE BRUNO KESSLER	“La casa pulita è a idrogeno e sta nasce ndo a Trento”, Weekly press insert on scientific dissem ination "Le Scienze" , La Stampa	07/11/2012	Italy	Civil society - Medi as	30000	National
6	Posters	FONDAZIONE BRUNO KESSLER	IPHE Workshop - Hydrogen Storage	15/11/2002	Seville	Scientific comm unity (higher educat ion, Research) - Ind ustry - Policy makers	200	International
7	Organisation of Conference	MATRES SCRL	National Congress on Energy and Hyd rogen European program – H2IT Association	02/12/2012	Milano	Scientific comm unity (higher educat ion, Research) - Ind ustry - Policy makers	100	National
8	TV clips	FONDAZIONE BRUNO KESSLER	National TV – RAI – TG2 (Radio Tele visione Italiana) – news programme - EDEN project prese ntation	14/12/2012	Italy	Civil society	50000	National

9	Press releases	MBN NANOMA TERIALIA SPA	"Nanotecnologie, l'I talia è sul treno", newspaper AVVEN IRE	12/01/2013	Italy	Civil society	5000	National
10	Web sites/Appli cations	FONDAZIONE BRUNO KESSLER	EDEN website on line	24/02/2013	Web	Scientific comm unity (higher educat ion, Research) - Ind ustry - Civil society - Policy makers - Medias	2000	International
11	Articles published in the popular press	FONDAZIONE BRUNO KESSLER	Più idrogeno per dar e energia alle abita zioni	25/02/2013	Italy	Civil society	5000	National
12	Posters	CIDETE ING ENIEROS SL	International Congre ss on Materials and Renewable Energy (MRE) http://www.e nergy-conferenc e.co.uk	02/07/2013	Athene, Greece	Scientific comm unity (higher educat ion, Research) - Ind ustry	500	Greece, Interna tional
13	Posters	MBN NANOMA TERIALIA SPA	Euro PM2013 Con gress & Exhibition – European Powder Metallurgy Associa tion http://www .epma.com/euro-pm2013	15/08/2013	Gothenburg, Swe den	Scientific comm unity (higher educat ion, Research) - Ind ustry	800	Sweden, Interna tional
14	Articles published in the popular press	MBN NANOMA TERIALIA SPA	Milano Finanza – Economical ne wspaper - Article en titled "Micropolveri, grandi numeri"	18/09/2013	Italy	Civil society	8000	National
15	Organisation of Workshops	UNIVERSIDAD DE LA LAGUNA	FCH JU Joint Wo rkshop participation to the workshop is restricted to partners of EDEN, HYPER, SSH2S and BOR4S TORE projects http:/ /ares.fbk.eu/events/ fch-ju-joint-worksho p	02/10/2013	Tenerife, Spain	Scientific comm unity (higher educat ion, Research)	100	Spain, European
16	Posters	FONDAZIONE BRUNO KESSLER	FCH-JU review d ays 2013	11/11/2013	Brussels, Belgium	Scientific comm unity (higher educat	200	Europe / Internation al

						ion, Research) - Industry - Policy makers		
17	Oral presentation to a scientific event	FONDAZIONE BRUNO KESSLER	Development of a experimentally validated model for solid state hydrogen storage design of material and tank	11/12/2013	Rome, Italy	Scientific community (higher education, Research) - Industry - Policy makers	500	National/international
18	Press releases	UNIVERSIDAD DE LA LAGUNA	Mid term results of the EDEN project presented at Brussels	10/06/2014	Spain	Civil society - Medias	1000	Spain, International
19	Organisation of Conference	MBN NANOMATERIALIA SPA	Euro PM2014 Congress & Exhibition, – European Powder Metallurgy Association http://pm2014.epma.com/	21/09/2014	Salzburg, Austria	Scientific community (higher education, Research) - Industry	800	Austria, International
20	Oral presentation to a wider public	FONDAZIONE BRUNO KESSLER	1° Summit Energetico "Europa Domani" - Quale Energia per il futuro?	06/11/2014	Castelfranco Veneto, Italy	Industry - Policy makers - Medias	50	Italy
21	Oral presentation to a scientific event	PANCO - PHYSIKALISCHE TECHNIK ANLAGENENTWICKLUNG & CONSULTING GMBH	NEW CONCEPT FOR THERMAL MANAGEMENT IN A HYDROGEN TANK	25/01/2015	9th International Symposium Hydrogen & Energy, Emmetten - Switzerland	Scientific community (higher education, Research) - Industry	50	International
22	Flyers	FONDAZIONE BRUNO KESSLER	FBK-CMM NEWSLETTER	01/04/2015	Trento, Italy	Scientific community (higher education, Research) - Industry	1000	International
23	Exhibitions	FONDAZIONE BRUNO KESSLER	Hannower Messe – FCH-JU stand	13/04/2015	Hannover, Germany	Scientific community (higher education, Research) - Industry - Civil society - Policy makers - Medias	5000	International
24	Posters	FONDAZIONE BRUNO KESSLER	NANOENERGY 2015 - International	01/06/2015	Manchester, United Kingdom	Scientific community (higher educat	200	International

			Conference on Nano technology, Nan omaterials & Thin Films for Energy Applications			ion, Research) - Ind ustry - Policy makers		
25	Flyers	FONDAZIONE BRUNO KESSLER	EDEN FINAL DISS EMINATION EVENT – Invitation letter to event	16/06/2015	Trento, Italy	Scientific comm unity (higher educat ion, Research) - Ind ustry - Civil society - Policy makers - Medias	1000	National/internation al
26	Oral presentation to a scientific event	FONDAZIONE BRUNO KESSLER	HYCELTEC 2015 - Iberian Symposium on Hydrogen, Fuel Cells and advanced Batteries	05/07/2015	Tenerife, Spain	Scientific comm unity (higher educat ion, Research)	100	Spain, International
27	Press releases	FONDAZIONE BRUNO KESSLER	EDEN FINAL DISS EMINATION EVENT	14/09/2015	Italy	Civil society - Medi as	50000	Italy, International
28	Press releases	FONDAZIONE BRUNO KESSLER	HYDROGEN TO SUPPLY POWER FOR HOMES AND PUBLIC SPACES	14/09/2015	Italy	Civil society - Medi as	1000	National/internation al
29	TV clips	FONDAZIONE BRUNO KESSLER	Regional TVs se rvices (RTTR and RAI TGR Trentino Alto Adige) – news programme	23/09/2015	Trento, Italy	Civil society	5000	Region Trentino Alto Adige, Italy
30	Media briefings	FONDAZIONE BRUNO KESSLER	EDEN FINAL DISS EMINATION EVENT	24/09/2015	Trento, Italy	Medias	12	Italy
31	Interviews	FONDAZIONE BRUNO KESSLER	Radio Trentino InBLU ? Interview to Luigi Crema on EDEN	24/09/2015	Trento, Italy	Civil society	5000	Region Trentino Alto Adige, Italy
32	Organisation of Workshops	FONDAZIONE BRUNO KESSLER	EDEN FINAL DISS EMINATION EVENT	24/09/2015	Trento, Italy	Scientific comm unity (higher educat ion, Research) - Ind ustry - Policy makers	70	International
33	Oral presentation to	FONDAZIONE	European Resear	25/09/2015	Trento, Italy	Civil society	4000	Region Trentino

	a wider public	BRUNO KESSLER	chers' Night 2015					Alto Adige, Italy
34	Oral presentation to a scientific event	FONDAZIONE BRUNO KESSLER	BOR4STORE Final Event	28/09/2015	Hamburg, Germany	Scientific comm unity (higher educat ion, Research) - Ind ustry	50	Europe
35	Oral presentation to a scientific event	FONDAZIONE BRUNO KESSLER	3rd DRESDEN CONFERENCE "E NERGY IN F UTURE"– Materials for Energy	11/11/2015	Dresden, Germany	Scientific comm unity (higher educat ion, Research) - Ind ustry - Policy makers	500	Germany, Europe
36	Oral presentation to a scientific event	FONDAZIONE BRUNO KESSLER	FCH-JU review d ays 2015	17/11/2015	Brussels, Belgium	Scientific comm unity (higher educat ion, Research) - Ind ustry - Policy makers	200	International
37	Oral presentation to a scientific event	FONDAZIONE BRUNO KESSLER	EFC 2015 – Euro pean Fuell Cell - Pi ero Lunghi Conf erence http://w ww.europeanfuel cell.it/	16/12/2015	Napoli, Italy	Scientific comm unity (higher educat ion, Research) - Ind ustry - Policy makers	500	Italy, International
38	Organisation of Workshops	CIDETE ING ENIEROS SL	EDEN system pre sentation to Barcelo na policy makers	21/06/2016	Barcelona, Spain	Policy makers	15	Spain
39	Organisation of Workshops	CIDETE ING ENIEROS SL	EDEN demo final event	28/06/2016	Barcelona, Spain	Policy makers - Medias	30	Spain

Section B (Confidential or public: confidential information marked clearly)

LIST OF APPLICATIONS FOR PATENTS, TRADEMARKS, REGISTERED DESIGNS,UTILITY MODELS, ETC.					
Type of IP Rights	Confidential	Foreseen embargo date dd/mm/yyyy	Application reference(s) (e.g. EP123456)	Subject or title of application	Applicant(s) (as on the application)
Patents	Yes	19/12/2013	WO2013186417	ELECTRICAL GENERATOR FOR EXPLOITING HEAT RESERVOIRS USING A RING-BASED THEMOELEC TRIC SYSTEM	CIDETE

OVERVIEW TABLE WITH EXPLOITABLE FOREGROUND								
Type of Exploitable Foreground	Description of Exploitable Foreground	Confidential	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable for commercial use or any other use	Patents or other IPR exploitation (licences)	Owner and Other Beneficiary(s) involved
Commercial expl oitation of R&D results	Plasma deposition of ultrathin catalyst coating on Mg p owders	No		Coated powders by dry processes and characterization	Powders for cat alysis in energy sec tor application and for OLEDs elect rodes.	Already available	No	FBK
Commercial expl oitation of R&D results	Catalyst application by physical vapor d eposition onto Mg for H2 sorption k inetics improve ment	No		Specific deposition technology for H2 sorption kinetics improvement	Catalysis in energy sector, electrodes for fuel cells , el ectrodes for OLEDs	N/A	Patent application i s under evaluation	FBK, Matres, MBN
Commercial expl oitation of R&D results	Modelling, simu lation and design of hydrogen systems	No		Expertise and tools for R&D activities and industrial p roduction	System engineering for the design of production - storage - usage of hydrogen	Already available	No	FBK
Commercial expl oitation of R&D results	Power-to-power system design and development	No		Expertise and tools in the development of control archi tectures of power to power systems based on hydrogen	Energy storage solutions, Grid management, Re sidential and Indust rial applications ba sed on hydrogen	Already available	No	FBK
Commercial expl oitation of R&D results	Modelling and s imulation of hy drogen storage in solid state materials	No		Expertise and tools for the development of multi-scale models and mult iphysics phenom ena of hydrogen storage in solid st ate	R&D activities, Industrial innovati on, Educational and Academic progra mmes	Already available	No	FBK
Commercial expl oitation of R&D results	Hydrogen tank d esign with proper heat pipes geometry	No		Operation principle of heat exchange in tank. The design with the heat pipes is the preferred s olution with the hig hest efficiency and dissemination o utput instead of co	Solid state hyd rogen storage s ystems	N/A	Patent application i s under evaluation	PANCO

				nventional tube design or plate heat exchangers				
General advancement of knowledge	Improved knowledge on Mg-based hydrogen storage material characterization, in powder and particularly as consolidated	Yes		Service for measurements of storage performance (gravimetric capacity, sorption rate) validated by JRC	Solid state hydrogen storage material development	Already available	Product not patentable	MATRES
Commercial exploitation of R&D results	Testing equipment and procedures for medium to large amounts of solid state hydrogen storage material	Yes		Measurement instrument and characterization procedures "MATH2" specifically developed for activation and testing of medium to large amounts of storage material and for characterization of storage tanks	Solid state hydrogen storage systems	6 months after project end	not patentable	MATRES
Commercial exploitation of R&D results	Development of synthesis route by high energy ball milling for nanostructured Mg-based powder for hydrogen storage and cost effective production procedures in inert atmosphere	Yes		ED011 – Nanostructured Magnesium, powder specifically catalyzed for hydrogen storage applications	High temperature hydrogen storage systems	6 months after project end	Background knowledge on ball milling and equipment mechanosysntesis principles are already protecte	MBN
Commercial exploitation of R&D results	Production procedures of consolidated pellets made by nanostructured powder for hydrogen storage including consolidating fillers enhancing thermal conductivity and mechanical stability, within an inert atmosphere chain	Yes		Bulk nanostructured magnesium pellets specifically developed for tank for hydrogen storage	High temperature hydrogen storage systems	12 months after project end	Patent protection is under evaluation depending on results coming for pilot scale experimentation.	MBN

Exploitation of R&D results via sta ndards	Safety requirements for a hydrogen insta llation	No		Knowledge for a further H2 installa tion.	Industrial, resident ial applications	N/A	N/A	CIDETE, FBK, PA NCO
Exploitation of resu lts through (social) innovation	Relation and pr ocedures with the administration	No		Contacts in the Barcelona admi nistration. Kno wledge on how to proceed and approa ch.	Public bodies	N/A	N/A	CIDETE
Commercial expl oitation of R&D results	Heat recovery	No	01/08/2016	Design, develop ment, assembly and control of a heat rec overy solution.	Electronics, power electronics, mac hinery, automobile	Already available in CIDETE portfol io	No	CIDETE

ADDITIONAL TEMPLATE B2: OVERVIEW TABLE WITH EXPLOITABLE FOREGROUND	
Description of Exploitable Foreground	Explain of the Exploitable Foreground
Plasma deposition of ultrathin cata lyst coating on Mg powders	It has been engineered a process to deposit ultrathin coatings of metals, metal-organic and other compounds by a physical vapour deposition process directl y onto powders, such as Magnesium or other compounds. This deposition allows the realization of few nanometer coating able to functionalize the target material minimizing the use of catalysts or precious metal by order of magnitudes. The process has been validated using a own developed coating equip ment. The process can be transferred to other applications in the energy domain, such as electrodes, catalyst layers in fuel cells, supercapacitors and batterie s, and outside the specific sector of energy, such as in OLED electrodes.
Catalyst application by physical va por deposition onto Mg for H2 sorption kinetics improvement	Different tests for the optimization of the production process toward cost reduction has been conducted, and also the recovery of fraction of powders not s uitable for the subsequent processes that is between 90 and 500µm.?The routes explored for smallest particle recovery allows to individuate the solution of re-process with other batches of material and the agglomeration of particles with Spray Dryer which allows to have particles that are more suitable for the catalyst PVD deposition with more homogeneous particle size distribution. From an economical point of view resulted more effective to re-work the finest fraction in other fresh material batches, the drawback of introducing more oxygen trough these smallest particles is compensated by the recovery of a waste that would be difficult to treat.?
Modelling, simulation and design of hydrogen systems	Competences and expertise acquired by personnel in modelling, simulation and design of hydrogen system could be used in further research project and R &D activities – as expert consultant in collaboration with industrial partners- in the development of new processes and products. Specific for the modelling of hydrogen systems is the lumped and dynamic analyses, looking for the more efficient configuration.
Power-to-power system design and development	Competences and expertise acquired by personnel in design and development of complete P2P system architecture is the results of a long trainee and pra ctice period of the personal during the project. The setting up of a complete P2P solution is a complex process which may take into account not only the te chnological aspects solved during the R&D activities, but also the selection of the right components off-the-shelf available on the market, the electronic and user interfaces for the management and control of the system, the safety regulation for the installation and maintenance of the system, etc.?This expertise could be an added value in future EU research project where system integration and demo activities in real environment is required, but also as consultancy activities for company that face the market of different energy storage solution (hydrogen, flow batteries, etc..) as support for prototype and product develop ment.?
Modelling and simulation of hy drogen storage in solid state mater	Competences and expertise acquired by personnel in modelling and simulation of hydrogen storage, especially in the case of solid state materials, could be used in further research project and R&D activities – as expert consultant in collaboration with industrial partners- in the development of new procedure a

ials	nd products. The modelling was performed on the concept of multi-scale (not just an application of commercial tools) and multi-physic (contemporary an alysis of different physical environments).
Hydrogen tank design with proper heat pipes geometry	Competences and expertise acquired by personnel in the design of tank with heat pipes is suitable for a proper management of the thermal energy during the charge and discharge of the tank, which is fundamental to guarantee the required performances in hydrogen storage solution independently by the dimens ion of the tank.This expertise is the results of a long trainee and practice period of the personal during the project. This could be an added value when R&D activities are requested for the development of new products in the specific field of highly efficient heat transfer.
Improved knowledge on Mg-based hydrogen storage material characte rization, in powder and particularly as consolidated	Expertise in testing and validation of the storage materials. Along the upscaling of the mateirial, several characterization at different scales of the Mg-based hydride were performed. There is a full know how developed on techniques to test the material's physical properties, including thermodynamics and kinetic behavior. A new differential insturment was diveloped alongside the project by FBK. Intermediate storage tank was validated in lab environment by MATR ES at 25% of he final volume for storage material.
Testing equipment and procedures for medium to large amounts of s olid state hydrogen storage material	Expertise in management of instrumentation and in the definition of characterization procedures for hydrogen storage materials could create commercial opportunities for storage materials design and testing and for storage tanks activation and testing. These competences could be applied and extended at the whole hydrogen storage market.
Development of synthesis route by high energy ball milling for nanostr uctured Mg-based powder for hy drogen storage and cost effective production procedures in inert atmo sphere	MBN, as material producer, will exploit commercial opportunities of Mg-based storage materials, in form of powder and/or pellets, for different hydrogen storage systems. Particularly, MBN will commercialize “ED011 Nanostructured Magnesium” product after some improvements and optimizations beyond the EDen project purposes, addressing mainly European markets of solid state H2 storage systems.?A new process are capable to uniform the particle d imension and increase performances of the storage material. The biggest particle are reduced by a second milling process at milder condition. The optimizat ion of the process has been realized by designing and realizing a special milling chamber for tumbling process, in which were possible to perform in the sa me time, dispersion of Expanded Natural Graphite and big particle reduction. This chamber were designed to have a fast link with vials for Mg-material transportation in order to be easily filled and discharger.?These industrial improvements allowed to estimate a reliable material price at industrial level pro duction (corresponding to 28-30 €/kg for productions bigger than 10-20 tons/year) and allowed to define a business plan for the exploitation of the results on material development.
Production procedures of conso lidated pellets made by nanostructu red powder for hydrogen storage in cluding consolidating fillers enha ncing thermal conductivity and mechanical stability, within an inert atmosphere chain	Expertise in consolidation of the Mg hydride in form of a pellet, able to maintain the form and the aggregated layout after several (tens) tests and cycles. This has been validated along the project.
Safety requirements for a hydrogen installation	Actually there is different regulation for each member state regarding the installation of hydrogen based system in real environments. The expertise achiev ed in defining the requirements (safety control system, ventilation, power supply, etc.) and implement the safety procedure wil be a valuable support in the definition of EU standard for safety and in the realization of new products and rptotype compliant with the actual regulation.
Relation and procedures with the administration	Expertise in relationship with public administration and territorial security services. Identification of procedures to agree on risk assessment, contractual fo rms, agreement on testing procedures and phase.
Heat recovery	In order to recover the biggest amount of wasted heat during the charge/discharge of the tank, a heat recovery system based on thermoelectric (TE) devices have been realized. TE modules in between aluminum efficient heat sinks and metallic flat surfaces. More specifically, the heat pipes (HP) efficiently tran sport the heat inside or outside the tank. During the charging phase of the tank, an exothermic reaction takes place and it is necessary to dissipate such amount of heat as efficiently as possible. Recovering part of this heat and transform it in electrical power by means of thermoelectric (TE) devices allows to contribute at the electrical balance of plant (BoP) of the entire P2P system. During the discharging phase (desorption, SOFC mode), the TE modules were are able to maintain the high temperature inside the tank to guarantee the proper hydrogen velocity. .?Finally, the heat recovery solution will contribute at t he overall electrical balance of plant (BoP) of the entire P2P system, increasing the overall system performances and reducing the power consumption n ecessary to manage the system?

4.3 Report on societal implications

B. Ethics

1. Did your project undergo an Ethics Review (and/or Screening)?	No
If Yes: have you described the progress of compliance with the relevant Ethics Review/Screening Requirements in the frame of the periodic/final reports?	

2. Please indicate whether your project involved any of the following issues :

RESEARCH ON HUMANS	
Did the project involve children?	No
Did the project involve patients?	No
Did the project involve persons not able to 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 (hESCs)?	No
Did the project on human Embryonic Stem Cells involve cells in culture?	No
Did the project on human Embryonic Stem Cells involve the derivation of cells from Embryos?	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	No
Research having potential for terrorist abuse	No

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	1
Work package leaders	0	6
Experienced researchers (i.e. PhD holders)	2	7
PhD student	1	1
Other	2	7

4. How many additional researchers (in companies and universities) were recruited specifically for this project?	2
Of which, indicate the number of men:	1

D. Gender Aspects

5. Did you carry out specific Gender Equality Actions under the project ?	Yes

6. Which of the following actions did you carry out and how effective were they?	
Design and implement an equal opportunity policy	Almost effective
Set targets to achieve a gender balance in the workforce	Not effective
Organise conferences and workshops on gender	Not Applicable
Actions to improve work-life balance	Very effective
Other:	FBK has developed an internal policy on Gender aspects through the project FP7 -FESTA (nr. 287526). Women involved in the projects have been assigned of responsibility in tasks and activities. This action involved: - FBK: Nadhira Laidani as responsible of research for FBK in WP1, Gloria Gottardi as researcher in the material development - CIDETE: Silvia Ortega as responsible for technical activities performed by the partner and contacts with local authorities of Barcelona Municipality. Almudena Marquina as responsible for reporting activities and management activities - JRC: Patra Karagounis, main contact for management activities

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?	No
If yes, please specify:	

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)?	Yes
If yes, please specify:	Collaboration with students involved also in activities under the Graphene Flagship, Dissemination event at Researcher Night 2015, collaboration with local technical 2nd schools with seminar and presentation of the EDEN technology, included the visit at FBK laboratories used in the project. EDEN technology was icluded in a thesis of a local secondary school as well.

9. Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?	No
If yes, please specify:	

F. Interdisciplinarity

10. Which disciplines (see list below) are involved in your project?	
Main discipline:	1.2 Physical sciences (astronomy and space sciences, physics and other allied subjects)
Associated discipline:	
Associated discipline:	1.3 Chemical sciences (chemistry, other allied subjects)

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)	Yes
11b. If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)?	Yes - in determining what research should be performed
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)?	No

12. Did you engage with government / public bodies or policy makers (including international organisations)	Yes - in implementing the research agenda

13a. Will the project generate outputs (expertise or scientific advice) which could be used by policy makers?	Yes - as a secondary objective (please indicate areas below - multiple answer possible)
13b. If Yes, in which fields?	
Agriculture	No
Audiovisual and Media	No
Budget	No
Competition	No
Consumers	No
Culture	No
Customs	No
Development Economic and Monetary Affairs	No
Education, Training, Youth	No
Employment and Social Affairs	No

Energy	Yes
Enlargement	No
Enterprise	No
Environment	No
External Relations	No
External Trade	No
Fisheries and Maritime Affairs	No
Food Safety	No
Foreign and Security Policy	Yes
Fraud	No
Humanitarian aid	No
Human rightsd	No
Information Society	No
Institutional affairs	No
Internal Market	No
Justice, freedom and security	No
Public Health	No
Regional Policy	Yes
Research and Innovation	Yes
Space	No
Taxation	No
Transport	No
13c. If Yes, at which level?	European level

H. Use and dissemination

14. How many Articles were published/accepted for publication in peer-reviewed journals?	4
To how many of these is open access provided?	4
How many of these are published in open access journals?	3
How many of these are published in open repositories?	1
To how many of these is open access not provided?	0
Please check all applicable reasons for not providing open access:	
publisher's licensing agreement would not permit publishing in a repository	No

no suitable repository available	No
no suitable open access journal available	No
no funds available to publish in an open access journal	Yes
lack of time and resources	No
lack of information on open access	No
If other - please specify	
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).	1

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?	0
Indicate the approximate number of additional jobs in these companies:	0

18. Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:	Safeguard employment, In small and medium-sized enterprises

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:	4Difficult 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

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

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	Yes
Media briefing	Yes
TV coverage / report	Yes
Radio coverage / report	Yes
Brochures /posters / flyers	Yes
DVD /Film /Multimedia	No
Coverage in specialist press	Yes
Coverage in general (non-specialist) press	Yes
Coverage in national press	Yes
Coverage in international press	Yes
Website for the general public / internet	Yes
Event targeting general public (festival, conference, exhibition, science café)	Yes

23. In which languages are the information products for the general public produced?	
Language of the coordinator	Yes
Other language(s)	Yes
English	Yes

Attachments	EDEN publishable summary_add ons.pdf
Grant Agreement number:	303472
Project acronym:	EDEN
Project title:	High energy density Mg-Based metal hydrides storage system
Funding Scheme:	FP7-JTI-CP-FCH
Project starting date:	01/10/2012
Project end date:	30/06/2016
Name of the scientific representative of the project's coordinator and organisation:	Dr. Luigi Crema FONDAZIONE BRUNO KESSLER
Name	
Date	
Signature	