HESCAP

NEW GENERATION, HIGH ENERGY AND POWER DENSITY SUPERCAPACITOR BASED ENERGY STORAGE SYSTEM

DELIVERABLE **D21**

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Coordinator: CEIT

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1 FINAL PUBLISHABLE SUMMARY REPORT

List of Beneficiaries

Beneficiary Number	Beneficiary name	Beneficiary short name	Country	Date enter project	Date exit project
1 (Coordinator)	Centro de Estudios e Investigaciones Técnicas de Gipuzkoa	CEIT	Spain	m1	m42
2	IMDEA Energía	IMDEA	Spain	m1	m42
3	CEA-LETI	CEA-LETI	France	m1	m42
4	Skeleton Technologies	ST	Estonia	m1	m42
5	NTUA	NTUA	Greece	m1	m42
6	APCT-Ukraine	APCT	Ukraine	m1	m42

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Executive summary

The main objective of this project is to develop a supercapacitor based energy storage system, **capable of storing ten times more energy** than the reported State of the Art technology, while keeping the high power density, long life cycle and production cost of currently available supercapacitor systems.

This will lead to a **large reduction in the overall cost** of the stored kW-h, and as a consequence, a cost-effective improvement of the **reliability**, **efficiency**, **security** and **environmental impact** of the energy networks, either for stationary or dual-use applications.

The main impact of the energy storage system (ESS), developed in the HESCAP project will be a **drastic reduction of the volume and weight** for a given energy rate, together with a **reduction of the cost** of the stored kW-h, in the five applications selected that require short-term power delivery and high duty cycle (between brackets the Industrial Advisory Panel member that is interested in each application):

- SMART GRID application
  - Voltage stabilization support (Unbalance control and Harmonics compensation) to the electric smart grids. (IAP: IBERDROLA S.A.)
  - Reduction of the variability of photovoltaic (PV) systems and small scale wind turbines in distributed generation systems and micro-grids. (IAP: IBERDROLA S.A, ELYTT)
- Uninterrupted power for critical substation loads. (IAP: , ELYTT, TRAINELEC)
- Railway energy networks, for both stationary (voltage stabilization) and on-board (autonomous traction) power systems. (IAP: TRAINELEC, ELYTT, HILTech)
- Hybrid and full-electric vehicles and their charging networks. (IAP: HILTech, JEMA)
- Safety devices in aviation (IAP: not available yet)

The specifications for every application will be established together with members of an **Industrial Advisory Panel** (IAP), made up of representatives of industrial companies that are leaders in the energy and transport sector and that have signed an agreement of collaboration with HESCAP project. Moreover, they will provide their expertise to keep the objectives focused on the European energy storage industry and will help in the dissemination of the results of the project.

By the end of the project, a 120 W-h and 10kW (50 kW during 1second with a duty cycle of 10%) HESCAP Energy Storage prototype will be developed. The energy and power of this prototype has been chosen with the aim of demonstrating its performance under the different working conditions established by the addressed applications.

The tests will be performed initially, at lab scale, in the facilities of the coordinator of the project. In addition, it will be tested and validated in the facilities of the IAP members. This will permit the evaluation of the system under real conditions in the five applications foreseen in the project. This evaluation will allow the research team to have a first real approach to the practical use of the new technology to show the advantages of the HESCAP energy storage system for stationary and for dual-use applications.

Summary of project context and objectives

WP1: Coordination and Management

All the tasks for the period from 1st April 2010 to 31st March 2012 were completed as planned. During the first review meeting some information updates were requested by the EC related with WP4 and WP6. Related with the second period of the project (from 1st April 2011 to 30th September 2012) two different technical solutions were presented during the second review meeting in order to overcome the overall technical objectives of the project.

Finally iIn December 2012 the steering committee of the HESCAP project has decided to ask the European Commission to terminate the project the 1st of January 2013 due to it is not possible to achieve at the same time and with the same product all the technical objectives fixed in the Description of Work.

WP2: Design and manufacturing of supercapacitor cells

Three types of materials were evaluated as electrode components: silica coating on carbon-based substrates, metal oxides and activated carbons. All of them were tested with different electroytes aiming at finding the best marriages between electrodes and electrolytes, according to the textural properties of the electrodes and the sizes of the ions in the electrolytes. Best results were found in the case of activated carbons in contact with aqueous gels and with ionic liquids. Particularly promising were the results obtained with some Carbide Derived Carbons (CDC) developed by Skeleton Technologies. For this purpose series of micro- and micro/mesoprous carbide-derived carbon (CDC) materials were synthesised and tested electrochemically. Additionally, the effect of physical activation to the pore size distribution and double-layer capacitance of microporous CDC was investigated. The samples with highest energy density were used to design and optimise the structure of supercapacitor cells for HESCAP prototype.

The best cell configuration was obtained using two CDC electrodes with balanced mass loading and an electrolyte made of a 50% mixture of an Ionic Liquid (PYR14TFSI) and an organic solvent (Acentonitrile). Results showed that 100% of the HESCAP power density objective was reached at 65% of the energy density objective ($P \geq 3$ kW/kg at $E \leq 26$ Wh/kg) or, in the opposite way, 100% of the HESCAP energy density objective was reached at 17% of the power density objective ($E \geq 40$ Wh/kg at $P \leq 0.5$ kW/kg).

Ultracapacitor technology initially considered for HESCAP prototype based on the soft packageing design, which indeed is suitable for the demonstration purposes (e.g. for testing electrode materials) and also for certain applications. However, for the long-life high-power supercapacitor modules, especially applying the elevated working voltage of single cells that has been included as a strategy for reaching HESCAP targets, the soft casing is not safe. Recent studies reveal that prismatic, parallelly stacked electrode packages (which also is a case of soft-packaged ultracapacitor cells) suffer significant volumetric changes due to expansion/contraction of high-capacitance electrodes during charging/discharging. The amplitude of „breathing“ is larger, the more layers are stacked in single cell. Very ambitious target parameters of HESCAP cells require the involvement of most-advanced nanoporous electrode materials and, therefore, the „breathing“ effects of ultracapacitor cells must be seriously considered; a strong metal casing is one of the requirements. On these reasons, the testing of materials, considered for HESCAP prototype, was started in strong aluminium test-cells and designing of prismatic-shaped aluminium casing was initiated.

WP3: Sensing technologies

1- Preliminary gas sensor specifications were defined (Task 3.1, deliverable D2): The target gases to detect were defined to be carbon dioxide and hydrogen. Gas sensor specifications were reported in deliverable D2 and updated in deliverable D6. According to the results on gas emission analysis and the suggestion of reviewers, the detection of carbon monoxide was added. Gas sensor will be developed by coating a gas sensitive chemical layer one kind of transducer. According to the gas concentration to detect (typically from 200 to 500 ppm), the quartz crystal microbalances (QCM) have been chosen. Bibliographic studies on chemical coatings sensitive to CO_2, H_2, CO on commercial CO_2, H_2 and CO gas sensors were also done.

2- Sensors testing (Task 3.3): in order to perform gas testing, modifications were done on LETI's gas test bench: dedicated carbon dioxide, carbon monoxide and hydrogen line were added and the software was modified. A Gas testing was performed on few CO_2, H_2 and CO commercial sensors, using LETI's gas test bench. Evaluation of gas sensors performances was done by measuring the gas sensor response for a defined range of concentrations. For each gas, one commercial sensor can be including in the HESCAP prototype.

3- A QCM apparatus (Quartz Crystal Microbalance) was set-up to test chemical coatings under gas flow. Screening of chemical coatings was completed; a large scale of layer was deposited on QCM among: Polymers: polyaniline, polyvinypyrrolidone, poly(4-vinylphenol), Ionic liquids: [C_8MIM][NTf_2], [C_6MIM][NTf_2], [C_4MIM][PF_6], [N_{4441}][NTf_2], Organic molecules : phthalocyanine and porphyrins, Silanes: APTES, FDTS, HMDS, EHTES, PFO-U-TMS, Pyralene, Hybrid organic-inorganic materials: SiOCH, Porous silica, Porous silia functionalized

Those different coatings were tested under CO_2, CO and H_2 flow. Several layers have been identified to be very sensitive to CO_2 and H_2, even at low concentrations, but unfortunately no layer was sensitive enough to CO. (Task 3.2).

For each gas, in a first time maximum 2-3 layers have been selected and tested with different thicknesses and concentrations. In a second time, gas tests were performed under a low ranges of concentrations (100-500 ppm for H_2 and 300-1200 ppm for CO_2) in order to confirm our choice. The coating robustness was then evaluated: stability, reproducibility, selectivity (gas mixtures) for each selected layer.

After all this study, it has finally been decided to incorporate one commercial sensor for the detection of CO and two layers have been selected for CO_2 (silica functionalized with HMDS) and H_2 (silica functionalized with EBTMOS).

Related to the physical design of the module, some considerations about where should be installed the gas sensors have been defined in collaboration with WP3 and WP4

Finally, a prototype have been developed: it consist of two QCM (each being sensitive to H_2 gas or CO_2) and CO sensor sensitive commercial. It was transportable and monitoring by a computer.

WP4: Assembling the stack. Testing procedures

As the <u>results of APCT performed investigations</u> have been:

1. Analysis of the results of materials and technologies testing for the stack manufacture (from IMDEA and APCT) was carried out.
2. A comparison of two stack production technologies (from IMDEA + ST and APCT) and their correspondence with the essential requirements to HESCAP technology was carried out.
3. The most probable causes of the difficulties in stack making were identified and possible solutions have been proposed.
4. ACFM technology is proposed to use for the stack manufacture in HESCAP project.
5. Optimization of the stack based on ACFM technology was carried out.
6. Identified key issues for further stack optimization and the conditions necessary for this

Finally one Ultracapacitor stack for HESCAP prototype has been designed based on the results of electrochemical evaluation of test cells under WP 2 (IMDEA + ST). Energy storage component for HESCAP prototype was proposed which parameters almost reach the targets of the project

WP5: Integration and testing supercapacitor devices

A search for simulation software has been done, particularly for power electronics, mechanical and thermal analysis. CEIT will use mainly PSIM for power electronic simulations, Creo Parametric (ProEngineer) for mechanical analysis and SolidWorks or ANSYS Fluent for thermal issues. However, MATLAB (and SIMULINK) is used as a base for any mathematical analysis. Based on the preliminary data from the HESCAP cells, an ESS model was developed in SIMULINK. It shows the advantages and disadvantages of each technology tested in HESCAP.

A prototype of the DC/DC converted that is needed in order to adequate the supercapacitor array output voltage to the application requirements have been developed. This DC/DC converter is able to work in a wide range of voltages and can work with commutation frequencies up to 100 kHz. In the same line, one high current active voltage equalization system has been developed, build and test by using commercial supercapacitor stacks. This system is based on a modified buck-boost topology.

Several simulations of the ESS system have been developed for two different applications: smart grids and transport. These simulations let's to predict the behaviour of the supercapacitor system embedded directly in the final application. They will be very interesting when the final capacitance and voltage figures are available.

Finally a testing plan for the internal stages of the HESCAP module has been presented. The final prototype is not presented yet, but similar prototype for the DC/DC converter and the voltage balancing circuit have been developed and tested in order to verify the design and testing procedure.

WP6: Ecodesign towards a green ESS

The WP6 involves the environmental analysis of the project which will lead to the ecodesign of the final output, which is the supercapacitor module.

Report D2_WP6 (m6): HESCAP Specifications - Specifications of the HESCAP eco-design requirements (Task 6.1), which involves the specifications of the HESCAP eco-design requirements, was delivered on time. The Environmental Performance and Ecodesign Parameters that have to be followed were laid out. Also the four ecodesign strategies were analyzed.

Report D6_WP6 (m14): HESCAP materials selection - Selection of materials for the HESCAP subsystems (Task 6.1) which deals with the material selection for the HESCAP subsystems has been completed. The subsystems of HESCAP have been analyzed and all the various parts involved have been laid out.

Report D9_WP6 (m18): HESCAP system simulation. Life Cycle Inventory Study -Life Cycle inventory study of the HESCAP subsystem (Task 6.2) is completed. It is based on the Deliverable D6_WP6, a Life Cycle Inventory of all the parts and materials of all the subsystems of HESCAP will be put together

Report D13 (m24): Life Cycle Assessment of the HESCAP subsystems (Task 6.2) has been completed. A complete and accurate identification and quantification of air emissions, water effluents, and other life-cycle outputs is performed for the build-up of life cycle databases.

Report D14 (m28): Selection of materials for the HESCAP system (Task 6.2) is completed with main objective to evaluate the findings of all previous reports, and mainly those of D13_WP6, in order to re-suggest on a new basis the most suitable materials for the needs of putting together a new super-capacitor. A comparative analysis takes place on a component basis and the results have been supported by relevant tables and figures.

Report D18 (m33) (Task 6.2), Environmental Impact of the production processes of the HESCAP system, has been completed. Based on the Life Cycle Assessment, the Material use, the Energy use and the Waste production, in the production of all the units are analyzed.

Their environmental Impact is performed and the report includes all the indicative diagrams of the different impacts of the whole production process

Report D20_WP6 (m36): End-of-Life management of the HESCAP system, has been completed. The end of management practices for HESCAP system were investigated and analyzed according the usage, the technological capabilities and the nature of the product itself.

WP7: Results exploitation and dissemination

Dissemination activities have been carried out according to the planning. In the first year of the project the emphasis was made on creating a dedicated webpage for the project and on publishing news and press releases, and giving interviews in general public newsletters, magazines, websites and media to promote awareness about the project. From the second year of project, the focus was placed on making presentations in national or international meetings and publishing articles in specialized research journals. As a result of this effort, 3 papers have been published in peer reviewed journals, 9 oral and poster presentations in scientific conferences have been made, and 2 general presentations about the project have been given.

An initial preliminary Market survey was made along the first six months of the project. It includes an assessment of 5 potential applications for HESCAP supercapacitorsin 3 different sectors. Later, a specific technology survey was initiated on commercial sensors for monitoring gas emission on supercapacitors and batteries.

Informal interviews with companies involved in manufacturing and commercialization of supercapacitors (KONEIKA) and batteries (SAFT, EXIDE) have provided new ideas about the characteristics that would be of interest for their respective markets. Considerable differences have been found, depending on the type of market in which they are competing at present.

With respect to exploitable results, LETI has developed gas sensors for detection of CO2 and H2 based on functionalized microporous silica and CEIT has developed one low cost and high current voltage stabilization system and one new design methodology of high frequency DC/DC converters oriented to low voltage supercapacitor ESS modules.

Finally IMDEA has designed a new electrolyte made of a blend of an Ionic Liquid (PYR14TFSI) and an organic solvent (Acetonitrile) which has been identified as a potentially exploitable result. To make this electrolyte fully useful it is necessary its marriage with activated carbon electrodes pairs, with tailored mass loadings of each electrode.

Project logo and website

HESCAP

http://www.hescap.eu/