PROJECT PERIODIC REPORT

Grant Agreement number: **266097**

Project acronym: **AUTOSUPERCAP**

Project title: **DEVELOPMENT OF HIGH ENERGY / HIGH POWER DENSITY SUPERCAPACITORS FOR AUTOMOTIVE APPLICATIONS**

Funding scheme: **Collaborative Project (CP) – STREP**

Periodic report: 1st

Period covered: **from 1 January 2011 to 30 June 2012 (18 months)**

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List of participants:

Participant no.	**Participant Short Name**	**Participant organisation name**	**Country**
1 (Coordinator)	SURREY	The University of Surrey	UK
2	MAST-Carbon	MAST Carbon International	UK
3	NCSR-Demokritos	NCSR Demokritos	Greece
4	BTS	Bayer Technology Services GmbH	Germany
5	CRF	Centro Ricerche Fiat (CRF)	Italy
6	IMCB-CNR	Institute of Composite and Biomedical Materials – National Research Council	Italy
7	Oerlikon-Graziano	Oerlikon Graziano	Italy
8	KIT-G	Karlsruhe Institute of Technology (KIT) Institute for Technology Assessment and Systems Analysis G	Germany
9	AGM	AGM Batteries Limited	UK

Publishable summary

The aim of AUTOSUPERCAP is to develop supercapacitors of both high power and high energy density at affordable levels by the automotive industry, and of higher sustainability than many current electrochemical storage devices. There are several issues to achieve a high performance/low weight power system that not only need to be addressed by various groups of scientists and engineers but those issues need to be analysed and processed in an integrated framework. In this project, we have assembled a multidisciplinary Consortium of leading researchers, research organisations, highly experienced industrialists, and highly active SMEs to tackle the problems. Supercapacitors are essential in electric vehicles for delivering power in the acceleration phase, which is a considerable proportion of a driving cycle, as well as to recover energy during braking which is also recommended for a sustainable energy and power system of a modern vehicle. High power and sufficient energy density (per kilogram) are required for both the performance of the power system but also to reduce the requested weight of supercapacitors. Some target performance levels have been given in the FP7-GC Workprogramme including 20 kW/kg power density and 10 Wh/kg energy density for supercapacitors while there is also a cost target of 10E/kW.

The **objectives** of this project are:
(a) Develop different types of carbon materials and structures as electrodes for supercapacitors in combination with different electrolytes and separating membranes, with the aim of a tenfold increase of current maximum energy density while maintaining high power density at least at 25 kW/kg. More specifically, binary carbon structure electrodes are targeted to have an energy density of more than 25 Wh/hr and a power density of 25 kW/kg.
(b) In selecting the best supercapacitor cells for further scale up and fabrication of one or more supercapacitor banks, cost in terms of Euro/kW is also amongst the selection criteria apart from the power and energy density performance.
(c) Perform power system simulations and parametric studies to investigate the effects of a high energy density/high power density supercapacitor on an efficient and sustainable automotive power system, and design a supercapacitor bank to optimise the performance of the power system.
(d) Perform a cost and life-cycle-analysis of the proposed supercapacitors for their applications in electric vehicles to assess the business case, economic and environmental sustainability.
(e) Identify supercapacitor and materials technologies for future exploitation within the chain of material suppliers, component suppliers, system suppliers and automobile manufacturers.
(f) Investigate and develop recycling methodologies and routes for all carbon materials of the proposed supercapacitors.

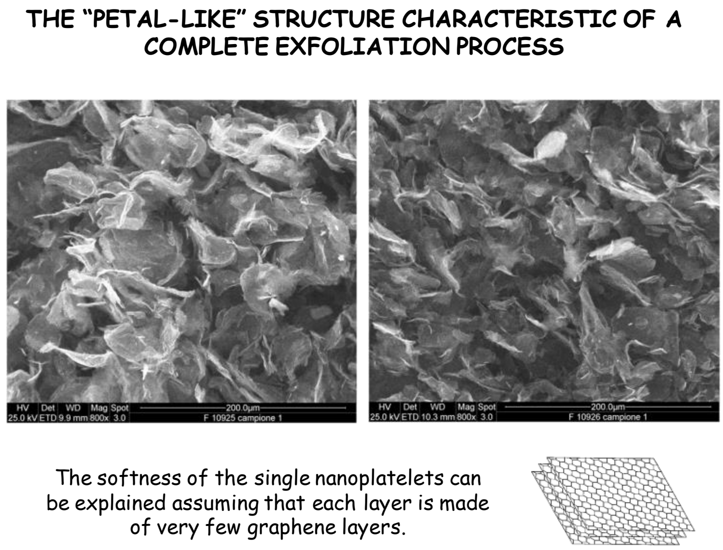
First of all, a set of applications were identified including start-stop vehicle applications of 12 V and 42 V. A set of specifications was assembled for the supercapacitor for each of these applications as well as for a full EV application. Organic electrolytes have been selected due to their high voltage suitable for automotive applications. An integrated computer model was developed in Matlab/Simulink linking the automotive power system with a battery-supercapacitor energy storage unit, where comprehensive battery and supercapacitor models were implemented and validated successfully against experimental data. In preliminary parametric studies, the supercapacitor reduced the pulse load on the battery which proved enormously beneficial at battery cell level reducing both max current and min voltage, and RMS values, extending the battery life. Computer simulations are going to be performed in further parametric case-studies for each type of supercapacitor material, in order to be able to design a supercapacitor bank to operate at the optimum point for both the supercapacitor materials and the automotive power system.

The emphasis in the first period of the project has been on the development of novel materials and material combinations for supercapacitors, testing them in the fabrication and testing of small supercapacitor cells, 2-5 cm^2. Materials considered for the porous electrodes were different types of

activated carbon powder, activated carbon fabrics, multi-wall carbon nanotubes, and graphene. Carbon materials of various origins were tried and innovative treatments were developed in the project to reach a tested maximum power density of 18 kW/kg, whereas the energy density varies, depending on material, from 10-18 Wh/kg to 24-28 Wh/kg. The addition of only a very small amount of MWNTs raises the tested power density to 40 kW/kg and the energy density to 20-26 Wh/kg.

Another development has been in fabricating high performance supercapacitor cells with activated carbon fabrics reaching a maximum energy density of 43 Wh/kg while their tested maximum power density was 10 kW/kg. Such high energy density is significant for supercapacitors, as one could think that they may be used to replace a part of the energy storage system. The advantage of the supercapacitor replacing a substantial part of the energy storage is that supercapacitors can be cycled $5x10^5$-10^6 times and, hence, have much longer life than batteries. This is particularly important for the EV and HEV car users as they will not need to replace an aged energy storage system during the vehicle lifetime.

Graphene nanoplatelets were produced in different forms and were also functionalised: Although their production and treatment did not always yield graphene of the same consistent quality and BET, some samples resulted in higher performance supercapacitor cells with organic electrolyte as is shown in Fig.1.



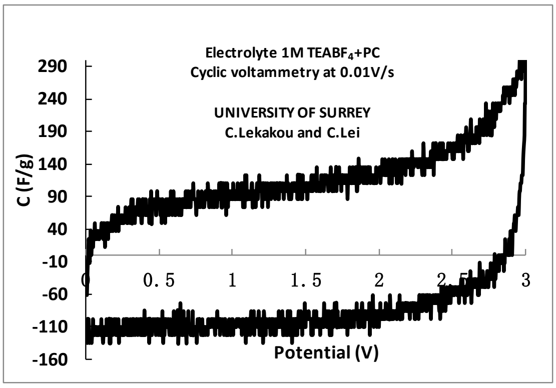


Fig.1. Graphene was produced by IMCB-CNR and NCSR-Demokritos. University of Surrey processed and used it in the fabrication of supercapacitor cells.

Apart from small area supercapacitor cells (see Fig.2), larger area cells of about 1 A4 page have also been made and tested, as well as stacks of such cells of 18 V maximum voltage (Fig.3). We have started with a detailed cost analysis for each type of supercapacitor to assess them cost-wise and identify the cost bottlenecks in the life cycle analysis. At this stage, a preliminary energy demand analysis has been carried out for each electrode material and a preliminary cost analysis has also been carried out for each type of supercapacitor cell. First of all, it has been confirmed that all electrode materials considered in this project are at the lower end of energy demand. However, costs are generally high, mainly due to the fact that many of our prices originate from laboratory suppliers used to sell small quantities: although we have some large-sale prices for some materials (e.g. aluminium foil), for other critical materials we still have prices for only small scale, laboratory-like quantities, which leads to high prices. Hence, we have not obtained prices for large-scale production cells yet.

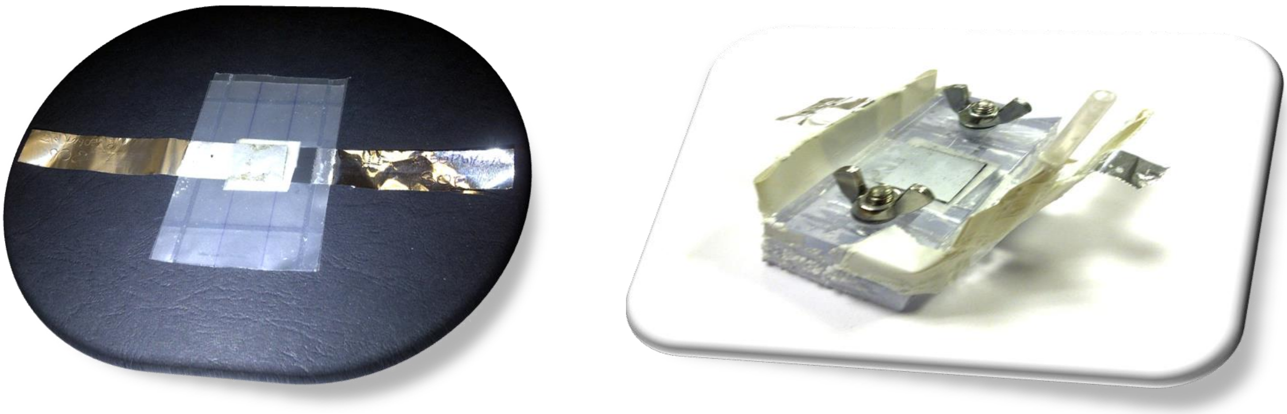


Fig.2. Small supercapacitor cells (a) after fabrication and (b) in the test frame

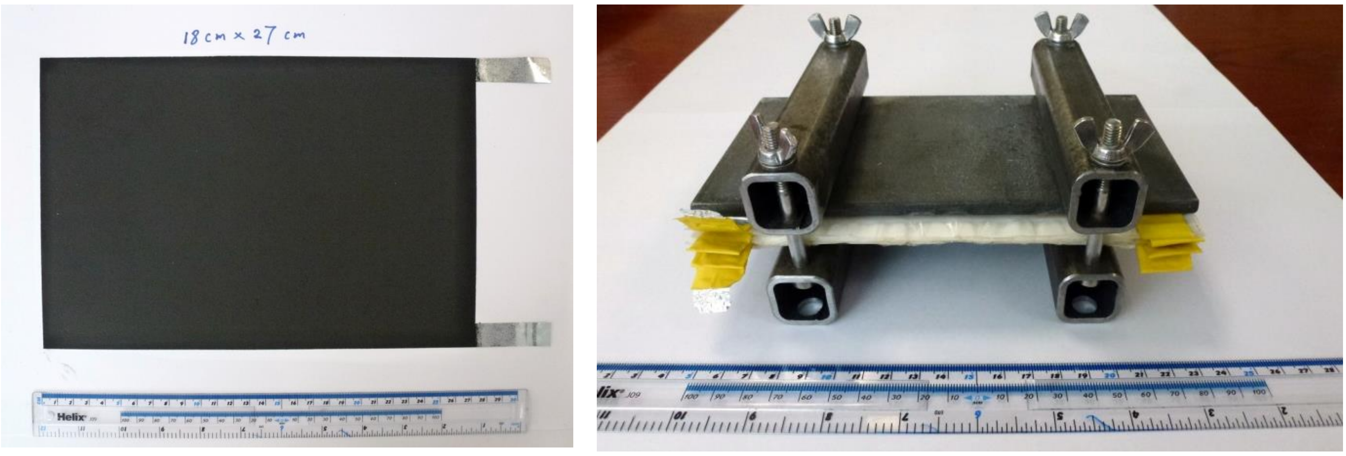


Fig.3. Fabrication of supercapacitor stack with 6 cells, each cell 18x27 cm^2

Work on recycling has focused on the development of innovative methodologies for the dismantling of the supercapacitor case and packaging, and later separation of electrode particles by electrophoresis. Current electrochemical storage technologies are based on rare and expensive metal electrodes, e.g. Li in Li-ion batteries with a cathode containing a large amount of Li. In this project, we consider carbonaceous type of electrodes which have more than one avenue of recycling.

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