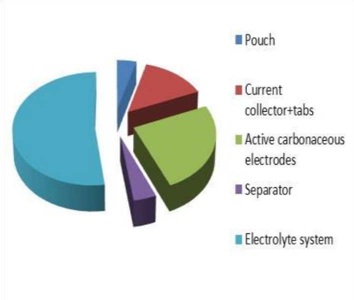
Publishable summary

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.

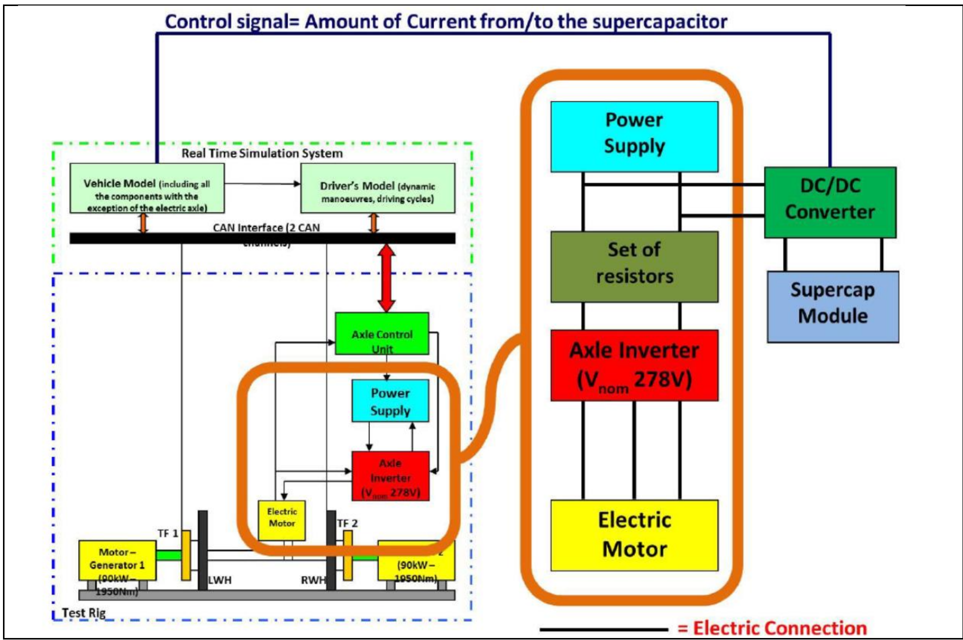
In the 2nd Reporting Period, intensive research continued in the area of different electrode materials and their combinations, including activated carbon, multiwall carbon nanotubes and graphene. Small cells were fabricated in which our novel electrodes well reached and exceeded some of our project goals, where depending on material and electrolyte, they reached maximum energy density of 25-70 Wh/kg and maximum power density of 60-10 kW/kg, respectively.



Particular electrode materials combined with organic electrolytes were selected for scaling up of electrode coating and cell fabrication to a pouch cell of pouch face of 12cmx12cm. Such scaled up pouch cells of different mass and size were fabricated and tested successfully at 10A, 50A, 300A, respectively. After intensive and extensive fabrication fine-tuning, the stated energy and power density per electrode mass of the small cells was replicated successfully in the scaled up cells. It is notable that the electrolyte system accounted for about half of the total cell mass in our large pouch cells.

Subsequently, a supercapacitor bank was constructed using our AUTOSUPERCAP large pouch cells (>300 A) and was tested successfully for consecutive start ups (without recharging) of a 12 V starter motor for a diesel engine. A supercapacitor bank was designed and validated for the specified 12 V TSS (transient start stop) application for a vehicle.

Cost analyses were carried out for the supercapacitor cells at different stages of their scaling up and it was found out that for each of the large AUTOSUPERCAP pouch cells, the estimated cost was in the range of 9.7-43 €/kW where the lower limit is within the project target of 10 €/kW, labour (range in Europe) being the prominent cost component amounting to 35% of the total cost and defining the cost range according to labour rate variations in Europe.



A commercial supercapacitor bank/DC-DC converter was installed in the hardware-in-the-loop EV test rig at the University of Surrey, connected in parallel with the simulated battery power supply, as in the diagram on the left. The system was tested successfully.

Parametric studies concluded that one of the main advantages ***derived from the coupling of a battery and a supercapacitor is the possibility of significantly reducing battery aging, in addition to marginal energy efficiency improvements when the system operates in critical climate conditions.*** The novel controllers comprised a novel Model Predictive Controller and a Dynamic Programming algorithm including a simplified battery aging model in their formulations. The simulation results of the Model Predictive Controller (MPC) and Dynamic Programming (DP) algorithm were compared with the results derived from a rule-based strategy. The rule-based (RB) controller achieves a 67% reduction of the root mean square values of battery current in the presence of supercapacitor across a selection of driving cycles in comparison with the same vehicle equipped with battery only. In the same conditions the battery peak current is reduced by 38% coupled with supercapacitor under the rule-based controller. The model predictive controller and the dynamic programming algorithm further reduce the root mean square value of battery current by a further 6% and 10% respectively in the presence of supercapacitor, whilst the peak values are additionally decreased by a further 17% and 45% respectively. Hence, it was also estimated that the presence of supercapacitor increases battery life by 400-2100%, depending on control strategy and driving cycle.

A life cycle analysis of supercapacitors and power systems in automotive applications was also carried out. Recycling protocols for the supercapacitor parts and materials were assembled in a process flow diagram and were tested.

Finally, we have identified our novel supercapacitor and materials technologies for future exploitation within the chain of material suppliers, component suppliers, system suppliers and automobile manufacturers.

http://autosupercap.eps.surrey.ac.uk/