4.1 Final publishable summary report

a - Executive summary:

OPERA4FEV Project aims to manufacture electrical vehicle cheaper and lighter by using thermoplastic solutions for battery racks. OPERA4FEV is acronym of "OPerating Energy RAck For Full Electric Vehicle"

This project involves a consortium of 9 partners from 6 European countries and has a total budget of €7 millions. Initiated in July 2010, submitted in December 2010 and awarded in February 2011, the project started in September 2011 for a total period of 60 months.

The call targeted was FP7-2011-GC-ELECTROCHEMICAL-STORAGE GC.SST.2011-7.7: Advanced eco-design and manufacturing processes for batteries and electrical components.

A demonstrator of a thermoplastic rack has been built and tested in an IVECO Daily.

The OPERA4FEV rack has proven to be a viable solution for replacement of metallic material battery racks for electrical vehicles. Then, any actual, existing or future rack can be designed in plastic depending of customer request.

Customer are aimed to be car manufacturers or even light trucks manufacturers. Can also be interested manufacturers of any other vehicles of even stationary power storage manufacturers.

The lightweight design of the rack will have a positive influence on CO_2 emissions: OPERA4FEV housing (all in plastic) is 30% lighter than a classical (metallic) one. Price of these plastic parts is 5 time lower that metallic parts.

The versatile design possibilities of plastic material can be adapted for complicated vehicle shape and configuration, therefore enabling to get more batteries and energy onboard of the vehicle. The adaptability of plastic design allows integration of functions – for example fixation of bosses or ribs with adaptable thickness to ensure crash resistance – thus decreasing by 15% the number of components. It also allows the design of interfaces that can simplify the assembly.

b - Project context and objectives

Context

The OPERA4FEV project aimed to develop thermoplastic battery racks on one functional demonstrator for a large scale vehicle from FIAT. To improve deployment of electrical vehicles in Europe, large scale production processes for rack and electrical components need to be developed.

The innovative solutions proposed by OPERA4FEV will integrate electrical connexions, cooling and component housing in a thermoplastic approach to reduce cost, weight and assembly time.

In order to show the relevance of the solution and meet strong industrial benefits, thermoplastic racks will be manufactured and assembled with industrial means.

The whole value chain will be addressed, including the eco-design (dismantling and recycling of critical materials), assembly and integration of cells and electrical components.

As safety of the on-board battery in electric, hybrid, and plug-in vehicles is of paramount importance to the international automakers, OPERA4FEV will pay particular attention to evaluate the effects of the rack characteristics regarding vehicle crash safety, and will focus on the potential risks for the vehicle and its occupants in case of failure of one or more batteries.

Objectives

To sum up, the main objectives are:

- the integration of cells into the thermoplastic rack
- an easier mounting and fast connexions of cells
- the reduction of assembly time
- 25% cost reduction on components (cells excluded) compared to existing rack
- the improvement of dismantling for better maintenance
- 50% reduction of number of components
- the eco-design of the racks and easier end of life (materials, dismantling) based on life cycle assessment
- the plastics parts design to improve thermal regulation, guaranty safety/crash behavior and deal with large dimensions
- the use of recycled polymers (70% in weight)
- 30% weight reduction on components (cells excluded)
- a concept proposal adaptable to automotive industry and evaluated with a representative tool and assembly line (able to reach 20 vehicle/day).

c – Results / foregrounds

c.1. Design, material and simplification

The basis assumption we do not use a modular conception to avoid the box-in-a-box concept and its higher weight was rejected as a result of the choice of the cells. In fact, the cell was chosen due to its stability and energy density, but it was too low to ensure the optimal filling of the cocoon in one layer. This fact leads us toward a multi-layer concept, and from there to a modular concept. Nonetheless, an optimization was possible due to the ease to integrate function on plastic part, whether it is a principal function (as the creation of 2 holes to fix a component), or it is a constraint function (for example the additions of ribs to pass a crash calculation). Plus, the module has been designed to be a functional brick with management capacity of the modular level and independent cooling, allowing intermediate control prior to the full assembly of the pack.

The use of plastic parts ensure natural electric insulation. This propriety, coupled with the RADSOK concept that allows plugging between cells without the need for a screwing and the access linked to it, permit the casing of live components prior to the building-up of the voltage. This allows easier and

Figure 1:Pre-assembly of TMD between the two module covers ensure an insulating plastic casing before the build-up of the tension

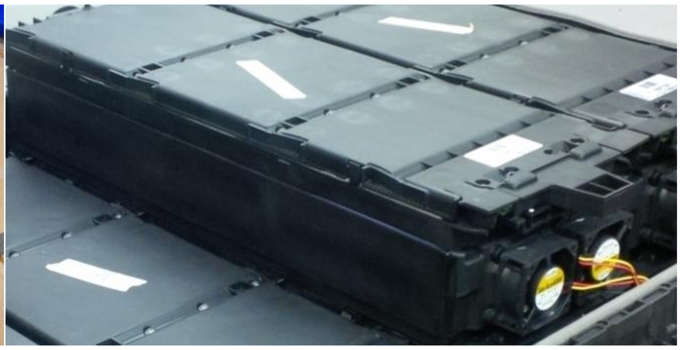


Figure 2: Radsock design allows plugging of the cells without the need of screwing access to cell pins. The tension build up to mean voltage (45V), but the live components are protected.

safer operations during the assembly of the pack.

The exact calculation for the weight reduction is difficult, as this calculation would need a metallic pack with the same energy and the same integrations. Nonetheless, an estimation has been made : a 18kWh metallic pack has been calculated from an existing 16.5kWh pack with almost the same service integration by a proportional calculation, and addition of estimated weight for the cooling function that is not included in the metallic pack.

Weight (kg)	Components class:	Pack design:		
		16,5kWh metallic pack	Pseudo 18kWh metallic pack	OPERA4FEV 18kWh plastic pack
Weight for as many modules as in one full pack {	Module bodies	17,0	18,6	13,2
	Module electric components (W/O cells)	1,8	2,0	14,0
	Body	27,3	29,8	27,1
	Electric components	44,7	48,8	13,6
	Total, for 1 pack	90,8	99,1	67,8

This calculation lead to a 32% gain on the pack weight.

As for the weight reduction, the difficulty is to dispose of a metallic equivalent to be able to compare fruitfully. The same 16.5kWh metallic pack has been used as a model, with a proportional calculation on the sole number of components linked to the number of modules in the pack.

# parts (-)	Components class:	Pack design: 16,5kWh metallic	Pseudo 18kWh metallic	OPERA4FEV 18kWh plastic
As many modules as in one full pack {	Module bodies	396	432	240
	Module electric components (W/O cells)	6	7	48
	Body	83	83	91
	Electric components	20	20	81
	Total, for 1 pack	505	**542**	**460**

This leads to a 15% reduction of the number of components. This number is far from the 50% objective, partially due to the modular conception. Anyway, other leverages effects has to be used to reduce cost, mainly the ease to assemble following natural electric insulation and suitable functional geometries, fully using the design versatility of plastic parts.

Figure 3: The 2-layer concept, required to ensure the 18kWh energy storage in the bulking with the size of the chosen cells, leads to a modular conception

Figure 4 :High-level integration means the set-up under the vehicle is ensured with the fastening on the frame and the plugging of 4 connectors.

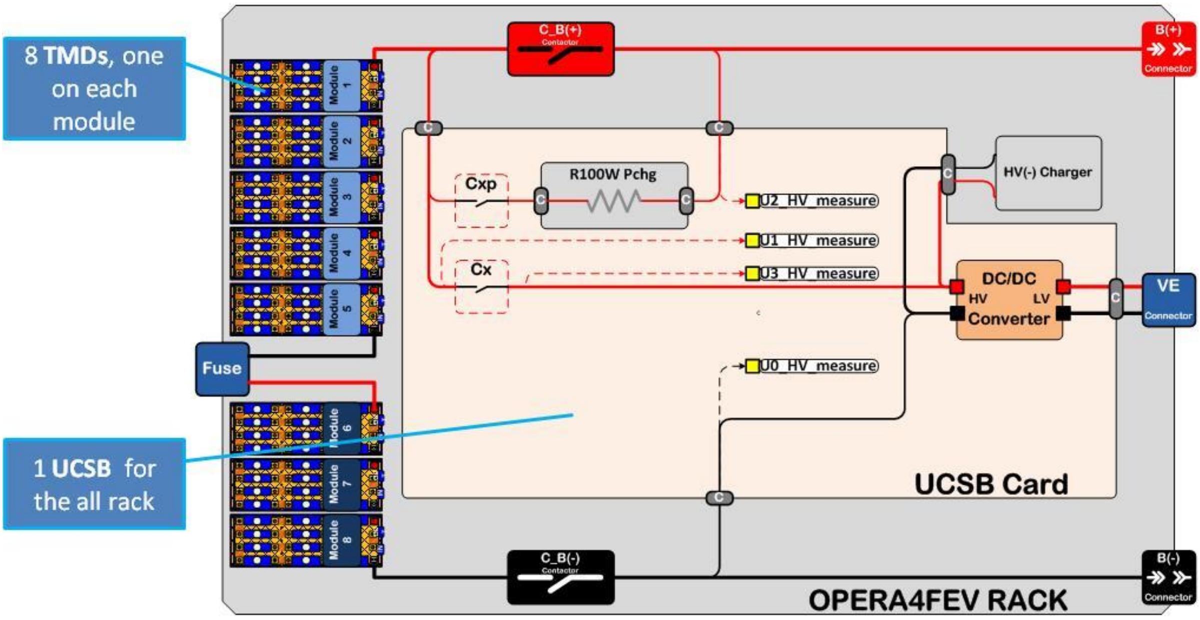
c.2 Electronic design and management

The electric architecture developed for the OPERA4FEV project was based on the drastic reduction of quantity of parts.

To achieve this, two actions have been undertaken:

- development of a “all –in-one BMS” (called UCSB) for both signal and power management inside the rack

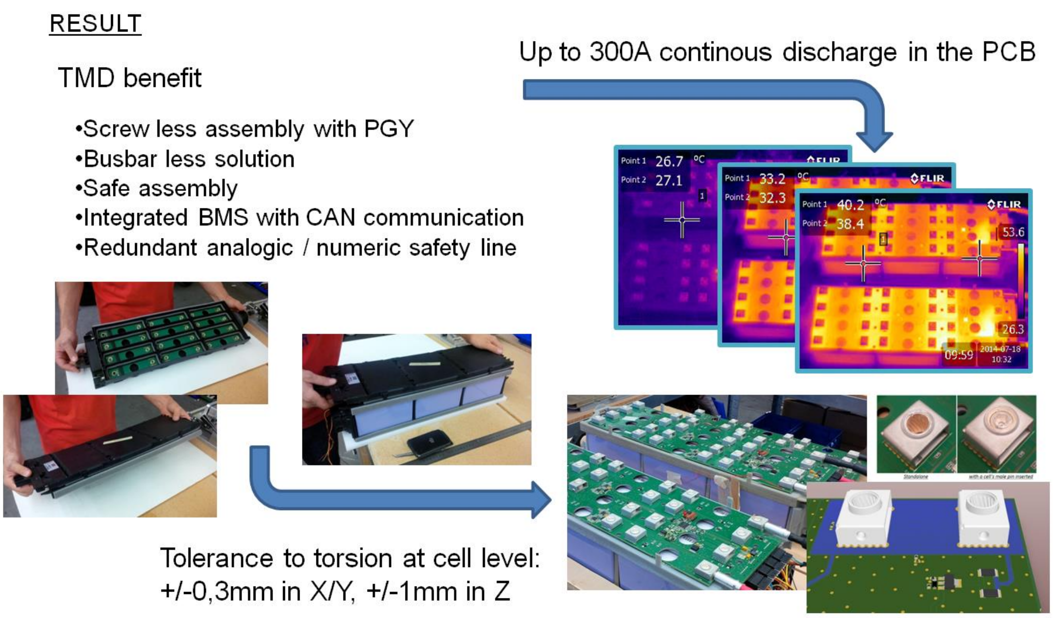
- development of busbarless and screw less solution (called TMD) for the cell assembly inside the modules



For the “all-in-one BMS”, we managed to include inside this electronic card UCSB the following functions:-

- BMS: management of the modules, interface with client
- DC/DC: converts the 400Vdc into 12Vdc for the vehicle, with 2000W max power
- Precharge contactors
- Control of contactors
- Thermal management of module
- Charger control
- Heater for the cells

For the module TMD, we had to cope with the flexibility of plastic parts. A soft connexion between cells and TMD has been developed to allow mechanical tolerance in every direction, but keeping 300A current carrying capability. The TMD is carrying the current without busbar, without screws.



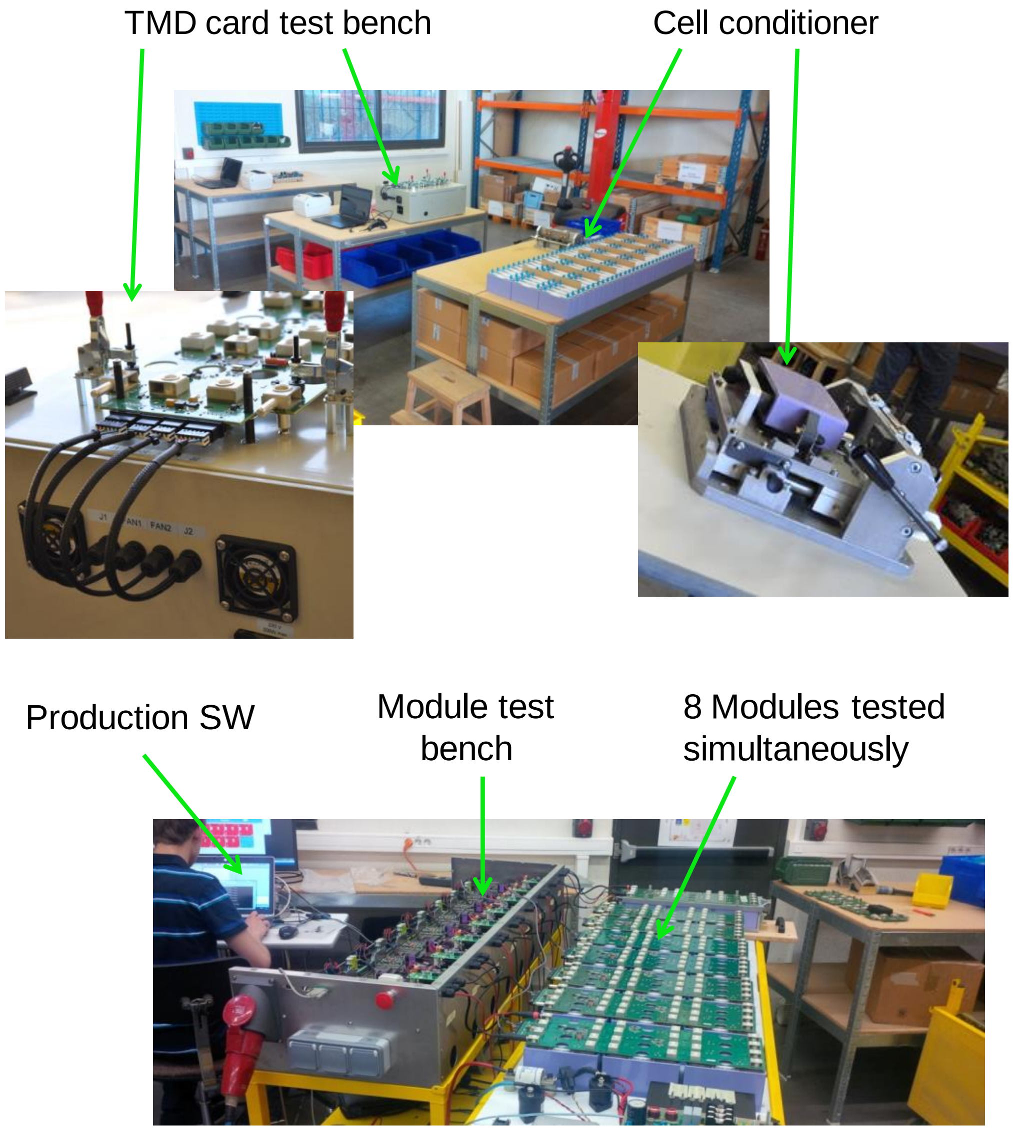
Results of this combined architecture with UCSB and TMD are relevant:

- Time to assembly the complete rack passes from 10,7 down to 4,8 man.hour
- Quantity of parts involved passes from 500 down to 228 parts in the OPERA4FEV rack

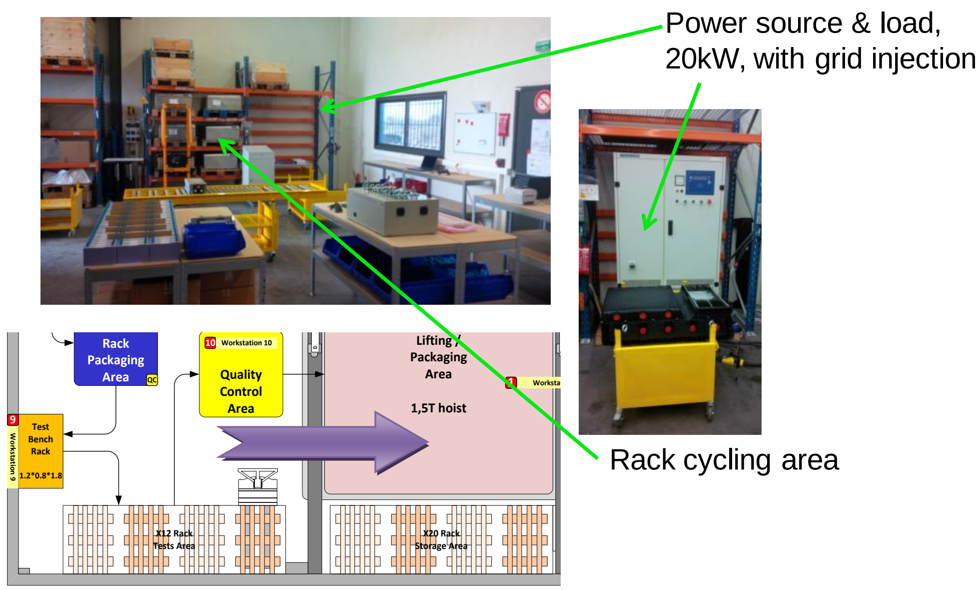
Some rank 2 interesting results can also be noticed:

- Time to disassembly the complete rack is 2 man.hour, making the recycling much cheaper
- During assembly / Disassembly process, IP2X is respected at every stage, making the recycling and maintenance cheaper and safer
- The harness (all wires and connectors) is twice less than standard integration, making it quick and cheap.

Set up module production line



Setup of Rack production line



Compared to a classical BUSBAR and SCREW solution, the OPERA4FEV rack with TMD + PGY concept price is 6% higher. But we can assume in case the automotive indutriy really look into developping this connector, the price shall become equivalent or even better.

TMD is the main electronic card that is set on the 12 cells of each module, that takes care of the lithium cells and inlcudes the BUSBAR path for main current. The TMD is a Printed Circuit Board (PCB), with 6 layers of 105µm copper.

On standard application with steel battery racks, the TMD can be directly screwed on the cells. But this requires the battery module and battery rack has no risk of deformation or torsion during all life. This is not the case in the OPERA4FEV project as the plastic rack and modules allow some torsion.

In OPERA4FEV rack, the power connexion between the cells and the TMD requires the accept some mechnanical movement and misallignement: the PGY has been developped for this. It is composed of two parts: One part is a 10,3mm pin on the cell polarity, and the second part is the PGY itself that is welded on the PCB, and drains the current from the pin via Radsok contact to every of the 6 layers of copper inside the PCB.

One of the main advantage of the OPERA4FEV rack are:

- High modularity in case of multiple rack: nothing more in the vehicle
- Easy integration: only motor / inverter remains in the vehicle

c.3 Crash resistance

Guarantee the crash resistance of a large battery pack manufactured completely in plastic material is a challenge. To achieve this, crash performances of the rack has been designed using finite element (FE) models and verified with full-scale crash tests. The FE models have been aided during the design process of the OPERA4FEV rack. Subsequently, prototypes (with accurate geometry) were dynamically tested for assess the crash performance and validate the design.

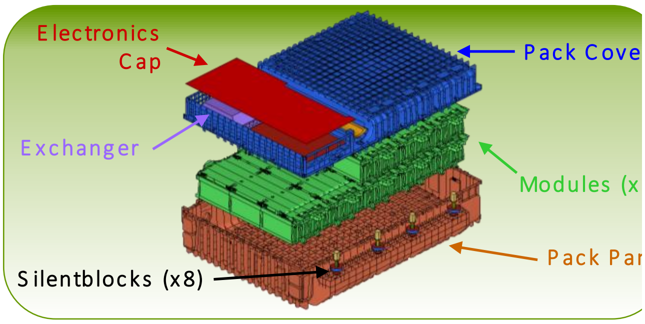
For the **FE models**, several R&D activities have been developed in order to achieve the requirements taking into account the following key aspects:

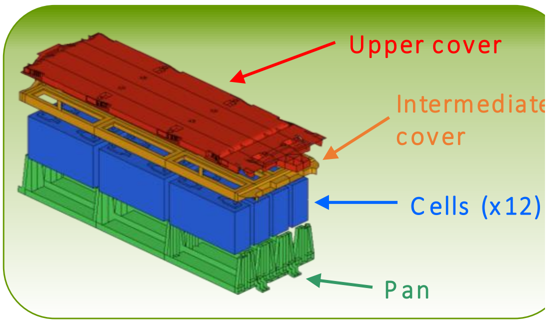
- Material mechanical properties. The OPERA4FEV rack is manufactured in thermoplastic material. Besides, some of the requirements for the material (flame retardant, good injectability, cost, recyclability, etc) have downgraded its mechanical properties

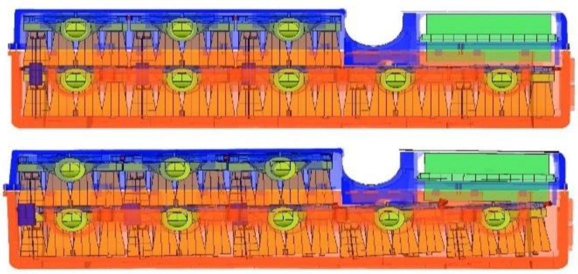
- Inertial loads. To ensure crash safety Five crash directions with three different levels have been simulated. The inertial loads are generated by the cells that represent the 70% of the rack mass, being the 17% of the mass the resistant and isolating parts made on plastic.

- Asymmetric loads. Due to the attachment fixation of each module, the characteristics for cooling and electrical connexions, the effects of the inertial loads are not symmetrical. Furthermore, all the modules need to be manufactured with the same geometry to reduce costs. Therefore, it is necessary to developed solutions for asymmetric loads using the same geometry that difficult the compliance of the crash requirements.

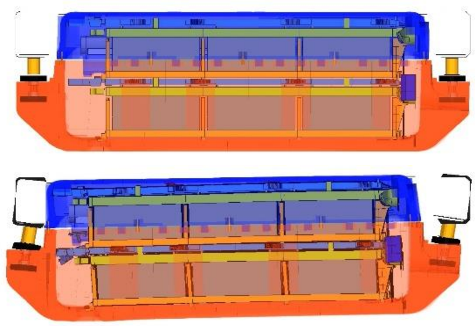
A detailed FE of the OPERA4FEV rack was developed (more than 600.000 nodes/elements) to assess the crash behaviour of the rack at the worst configuration (at +60ºC because the material has the lower mechanical properties from the crash standpoint). Several specific crash solutions have been developed to enhanced the performance of the rack among which are the following: male-female interactions, inter-modules wedges, additional ribs in external casings, controlled fracture areas, stopper for enhanced lateral crashes, etc. The following figure shows an overview of the FE model, as well as snapshots for longitudinal and transversal crashes (the first image shows rack at its original position and the lower image shows the movements of the rack and its internal components during the crash).







LONGITUDINAL ACCELERATION



LATERAL ACCELERATION

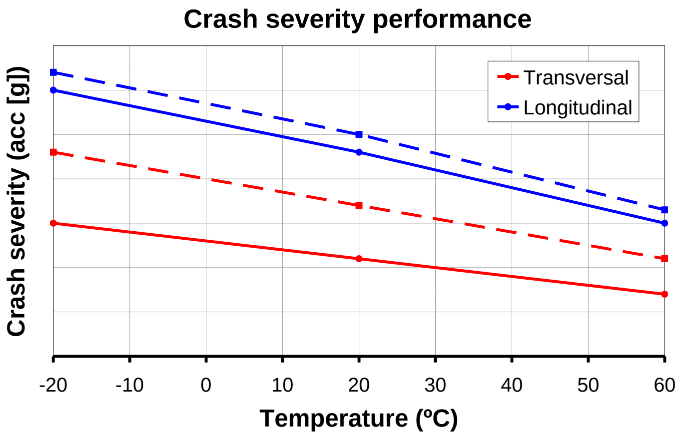
The **FE model has been able to demonstrate** that:

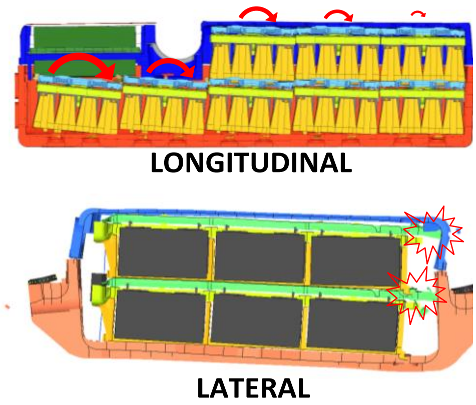
- At final status of the FE model, there is NO rupture of the external layer (crash requirement). It is possible to withstand the crash loads using thermoplastic material as structural component (not only used as cover).
- The FE model has improved the rack design. With respect to the original design, the final design of the rack is able to withstand more than 5 times crash energies with an increment of less than 2% of the total mass.
- With the restriction of the material (very frangible due to other requirements), R&D activities have been developed to obtain crash energy absorption extended features with controlled fracture zones in order to absorb the crash energy using internal fractures with progressive leveling.

The **FE models** were subsequently used in the **exploitation phase**. The material solution adopted for the OPERA4FEV project due to the high content in fibreglass presents a brittle behaviour at all temperature ranges. The design of the rack has been validated for a maximum temperature objective of 60ºC. Nevertheless this temperature is too high to perform the real crash tests. The FE models in exploitation phase have the following main objectives (chronological order):

- To provide support for carrying out the mechanical tests. Some of the mechanical tests are conducted at laboratory temperature (typically at +20ºC). The mechanical properties of the thermoplastic material are influenced with the temperature, therefore the FE models have been used for taking into account this mechanical variations imposed by the change of temperature.
- To verify the FEM models predictions with the results of the real tests (model validation).
- To obtain the maximum crash safety performance of the battery rack depending on different criteria: mainly the impact direction and temperature.

The following figure shows the crash severity performance of the OPERA4FEV rack depending on the temperature of the plastic materials. The solid lines represents the critical severity for the rack, when the probability of external breakages is increased up to reach the dash line that represents the catastrophic rupture of the rack (when the rack loses its integrity). Furthermore, next figure shown some of the analysis executed to understand the crash mechanisms in order to enhance the crash behaviour.



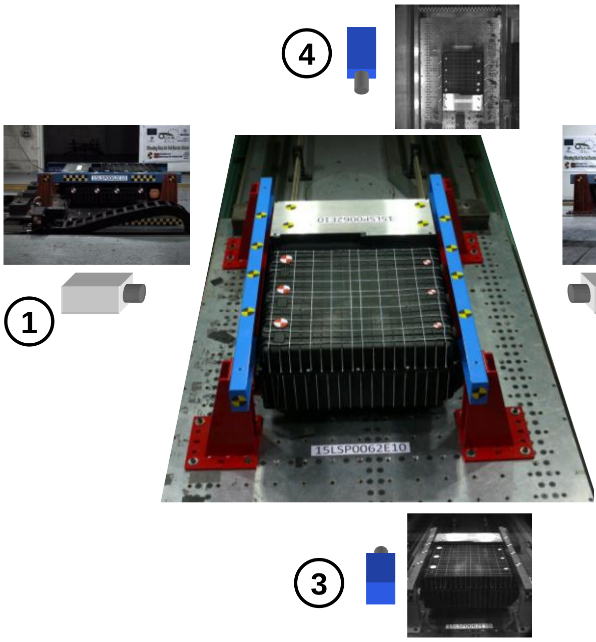


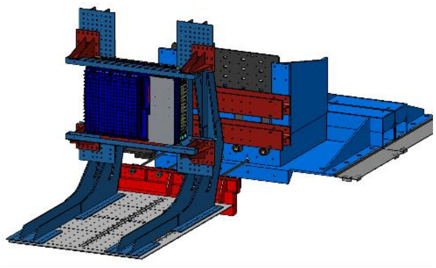
Regarding the exploitation of the FE models the following conclusions have been obtained:

- The FE model has been validated against full-scale crash tests (see below the crash test assessment). The model used for the design process was good enough and the initial predictions have shown less resistant behaviour than reality. Minor changes have been neccesary to adjust the FE model during the exploitation phase.
- The validated model has predicted that the OPERA4FEV rack (at +20ºC) is able to fulfil the crash requirements for the 100R02 regulation for vehicle category N1 (this fact has been confirmed by dynamic tests).
- The maximum safety performance have been calculated at three temperatures (-20ºC, +20ºC and +60ºC). Due to the fragility of the plastic material used in the OPERA4FEV rack, the maximum performance is highly influenced by the maximum acceleration (and is less influenced by the energy involved in the crash).

The **OPERA4FEV rack** has been dynamically tested to assess the crash performance (**13 full scale crash tests with an Iveco Daily chassis replacement**). The tests have been designed with a dual purpose: obtain data for validate the FE models (showed previously) and assess the performance of the full-functional rack with the requirements of the UNECE regulation 100 (regarding the approval of vehicles with regard to specific requirements for the electric power train, that include a REESS – Rechargeable Electrical Energy Storage System). The dynamic tests were performed at five different directions: longitudinal (frontal and rear), lateral (left and right sides) and one vertical.

The left image of the next figure shows the overall configuration of the crash test and the high speed cameras location (4 units were used to assess the kinematics of impact, each camera was operated at 1000 fps). At the right part, it is shown the vertical verification of the rack (CAD model during the design of specific tools manufactured for the crash assessment and real picture during the test performance).





The main conclusions obtained from the crash tests are:

- Valuable information has been obtained from the tests in order to validate the FE model and later be able to take advantage of the simulations in other crash scenarios.
- The plastic material has demonstrated that is able to withstand the crash loads defined by the regulation 100R02. With the FE model simulations the rack withstands the N2 profile pulse (design criteria at +60ºC). At +20ºC (standard laboratory conditions) the rack is able to withstand the N1 acceleration profiles, i.e. more than two times the energy absorption of the N2 requirements.
- The functional racks have been tested following the requirements of the regulation 100R02 for N1 type vehicles (at +20ºC). The same set of cells and electronics have been tested (five times) and the rack is still functional after these tests.

c.4 Thermal Management

The work performed in this project is to develop a methodology to characterize the thermal behavior of the battery cells and to investigate, based on the cell characteristics, experimentally and by theoretical modeling the thermal behavior of the rack and optimize the heat exchanges in the rack in order to achieve the goals of thermal management. In this framework, the work achieved during the project is the following:

- Needs on thermal management have been defined with MECAPLAST and EVE.
- Cooling requirements have been calculated and the corresponding heat exchanger has been sized. The design has provided important information for manufacturing the rack prototypes
- Thermal characterization of the cells (heat generation):
  - a special bench was developed with MECAPLAST and EVE (MECAPLAST manufactured a mock-up module, EVE produced a cell control system with charging and discharging and CETHIL/INSA instrumented a testing cell/module with thermo-couples);
  - The EVE cell control system allowed measurements of cell voltage and positive terminal temperature with imposed current for different cycles (NEDC for example). This enabled

an electro-thermal model of a cell with different load profiles: The thermo-electrical model, chosen, identified and improved is able to provide the heat source generated within the cell in any operating conditions. The models obtained for heat generation have been validated against temperature measurements for the module for European Driving Cycles. Based on the modeling:

  - heat generation model was used for one cell CFD model
  - heat generation model was also for one module CFD model
  - modeling heat generation of a module enabled thermal recommendations for the rack

- Cell surface temperature has been observed with infrared camera and measured with thermocouples: Infrared camera detected that cell surface was not heated uniformly and indicated that the most heated cell zone was around the positive terminal; thermocouples provided more accurate results and allowed comparison with simplified model and CFD results.

- Measurement of thermal conductivity on a specific bench has been subcontracted and revealed that thermal conductivity tensor was not isotropic. For example, disposing a cell with the terminals up, the vertical direction is denoted z axis, y axis is parallel with the long vertical surface and x axis with the short vertical surface, thermal conductivity tensor measured at 25 °C is: (k_x,k_y,k_z) = (1.29, 1.68, 2.42) W/(m K) and it was used in numerical simulations.

- The 12-cells mock-up module has been investigated with PIV measurement. PIV studies, performed in both vertical and horizontal plan, showed that channel width (gap between cells or between cell and wall) and position of air inlet have important influence on the flow rate and flow structure. In order to obtain a better thermal management, it is important to guarantee the same channel width in a module. PIV measurements of velocity have been used to validate the air flow modeling and the heat control in the rack.

- Numerical simulations of thermal and flow behavior of one cell and a module have been performed: A 3D CFD model is proposed to predict the temperature evolution in a module, under current cycling inspired from real operating conditions.

- After reading and summarizing the documents and data provided by the cell supplier, some battery abuse test have been selected, subcontracted, followed up and analyzed. These abuse conditions are referenced in international regulations and standards. 3 types of hazardous conditions are concerned:
  - Electrical overload: overcharge, short circuit …
  - Mechanical load: crush, penetration, shock, fall …
  - Thermal loads: thermal shock cycle …

A full report on the abuse tests has been realized and provided to the project consortium. The LEV50N cells should be integrated by considering the following most hazardous conditions:

  - With regard to electrical overload, forced charge test revealed h<u>igh temperature increase</u> (550°C) and <u>venting</u> which can be observed after 15 minutes of overcharge (125A) or 38 minutes of overcharge at 50A;
  - Concerning mechanical load, crush test showed fire, strong venting and cell temperature of 650°C;
  - In terms of the thermal loads, thermal stability test showed major gas venting of the cell as well as a strong temperature increase (up to 450°C).

c.5 LCA and recycling

The Life Cycle Assessment (LCA) compares the environmental performance of the Opera4FEV rack in an electric van with other van technologies: diesel, gasoline, LPG (Liquefied Petroleum Gas) and CNG (Compressed Natural Gas). The life cycle stages of the studied system are manufacturing, use (Well-To-Wheel) and end-of-life (recycling). The functional unit is 1 km driven under European average conditions. In order to perform the LCA study a detailed manufacturing inventory of the Opera4FEV rack has been developed, together with detail model of the use stage and the EoL in a recycling plant. To have a full overview of the environmental impacts, 12 impact categories are assessed: Global Warming Potential (GWP), Particulate Matter (PM), Photochemical Ozone Formation (POF), Human Toxicity (HT), Acidification (ACD), Ecotoxicity for Aquatic Fresh Water (EAF), Freshwater Eutrophication (FE), Ionising Radiation (IR), Marine Eutrophication (ME), Ozone Depletion (OD), Resource Depletion (RD) and Terrestrial Eutrophication (TE). The results show that the manufacturing and the Well-To-Tank stage play an important role in the environmental impacts. During the manufacturing stage, it has been identified that the content of metals contributes significantly to the impacts, due to the emissions generated when extracting and processing metals, especially copper and steel. In that sense, the Opera4FEV rack improves the environmental performance of the electric van, since the rack is manufactured with thermoplastic materials instead of aluminium. The fact of using plastic also reduces the weight of the electric van, which reduces the amount of energy required to move the van and hence less electricity is demanded in the use stage. On the other hand, the content of metals in a battery pack is inevitable, due to their electrical properties. The sensitivity analysis has shown that, reducing the amount of copper improves the environmental performance of the manufacturing of the battery pack. This influences especially in the manufacturing of the LMO battery cells, where the copper is used as current collector in the anode. Nevertheless, reducing the amount of copper in the anode is not an easy task, as it defines the electrochemical properties in the cells, therefore when varying this parameter the properties of the cells will be modified as well. Regarding the use stage the environmental impact generated in the WTT of the electric van, which includes the production and distribution of the electricity, is highly influenced by the electricity mix used. In this study a European mix has been implemented to represent European average conditions, making the impacts from the WTT stage of the electric van an important contribution during the life cycle, especially in the impact categories GWP, POF, ACD, ME, OD and TE.

Furthermore, a recycling and aging study is conducted on the thermoplastic battery rack. The mechanical properties do not show a high influence by the different reprocessing runs, and the presence of antioxidants do not improve the mechanical properties of the material. The melt flow index increases after the reprocessing runs, due to the breakdown in the polymer chain. The antioxidants reduce the increment of MFI due to the reprocessing process. The heat deflection temperature decreases after reprocessing process. The results also show that the polymer retains its flammability properties. The aging of the thermoplastic battery rack is tested in an oven. The mechanical properties do not show a high influence after the aging process. Moreover, the battery rack material resists temperature until 100ºC during 1500h. Finally, the presence of antioxidants slightly improves the mechanical properties of the material, meanly strength and impact resistance. The environmental impacts of the recyclability are calculated with a LCA study. The recovery of the materials in the hydrometallurgical recycling plant avoids emissions during manufacturing and processing of materials, and therefore the generation of environmental impacts. This is thanks to the substitution approach taken in the study, which in general improves the overall impact of the battery pack. The results presented in this study show that the Opera4FEV rack performs better in the majority of the impact categories assessed, when compared with an aluminium rack. The results also show that even in a pessimistic scenario where the plastics are not recovered in the recycling plant, the Opera4FEV rack will have an overall environmental performance lower than the aluminium rack.

A literature study of the most promising reuse and recycling technologies for Li-ion batteries is performed, with a particular focus on metal fraction valorisation and on external case. Several battery recycling technologies are available today and discussed in detail in the reporting. To meet the strict targets of the ELV Directive 2000/53/CE (85% of reuse and recycling by weight from 2015 and 95% of reuse and recovery by weight from 2015). It will be needed to create a well-defined system of dismantling, collection and recycling / recovery of components. The recycling process includes the disassembly of each cell in the battery and safely extracting the precious metals, chemicals and other byproducts, which are sold on the commodities market, if profitable to do so, or re-introduced into a battery manufacturing process. However, recycling does not need to be reached after the first use of the battery pack in an EV. Circular thinking should include remanufacturing and repurposing concepts. For instance, after the first life, the traction battery can be remanufactured for the reuse in vehicles or repurposed to be used in a non-vehicle, stationary storage application. Recycling is and will be the last stage of the life cycle of a battery pack, due to the incentive of governments for a circular economy, aiming at reducing as much as possible waste generation.

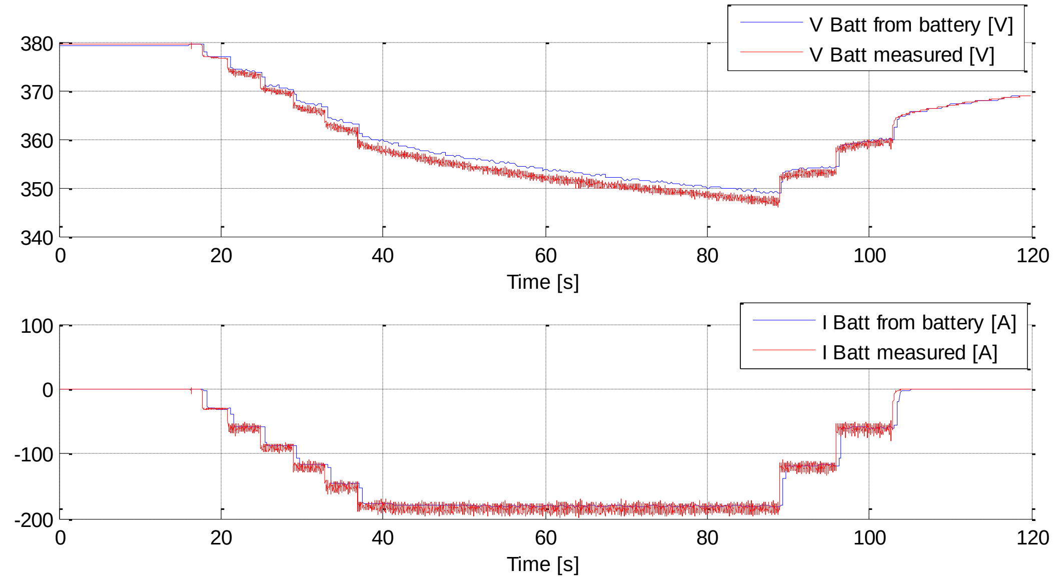
Furthermore, **it has been proven than it is possible to use recycled polymer in the rack, but only up to 20-30%.**

c.6 Performance

Total measured weight: 225kg
Plastic + Fixations + gaskets : 40 kg →

Cells	157,44	kg
Rack mecanical	27,05	kg
Rack electrical	13,56	kg
8 Modules mecanical	13,22	kg
8 Modules electrical	14,00	kg
Complete IVECO RACK	**225**	**kg**
Cells Wh/kg	*114*	*Wh/kg*
Modules Wh/kg	*97*	*Wh/kg*
Complete rack Wh/kg	*80*	*Wh/kg*

The system was tested at different level in order to validate the system from battery level to vehicle level. The battery was connected to the test bench in CRF in order to validate the preliminary function, the CAN communication and the power and energy capability. Some pictures below show some performance results from the test bench, the battery is fully compliant with the required performances at vehicle level



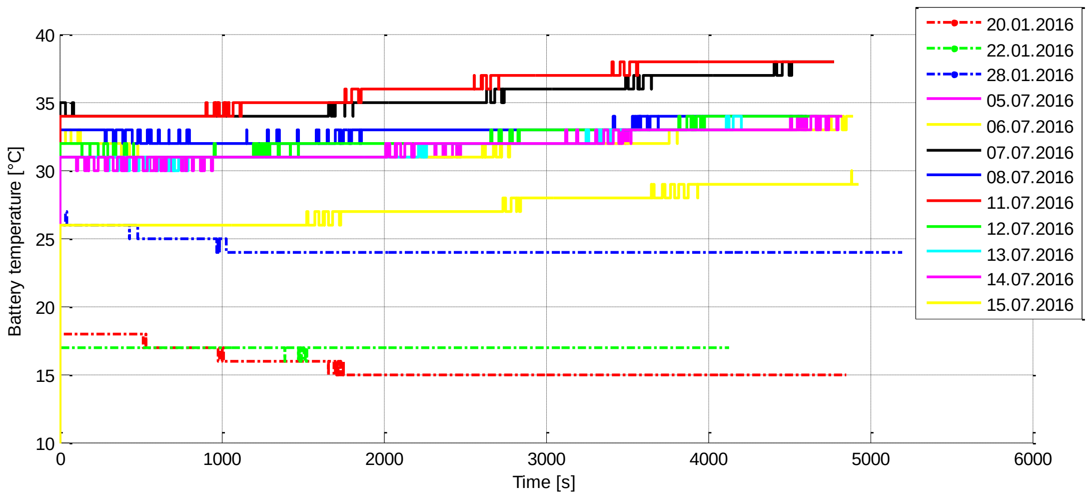
After the performances testing, the battery was mounted on the vehicle and testing activity was performed in order to verify that the vehicle performances will not decrease with the new 400V battery. In particular, attention was paid regarding the maximum speed, acceleration and energy consumption. Preliminary testing was performed inside the CRF testing facility, in order to validate the vehicle behaviour in a safe area. Here the vehicle was tested in the flat track circuit and in the slope track area.

Parameter			8 % Slope		12 % Slope		16 % Slope		20 %
			↗	↙	↗	↙	↗	↙	↗
Acceleration	Max Mean	m/s²	1,5 0,58	0,3 0	1,6 0,9	0,7 0	1,8 0,9	0,6 0	2,3 0,7
Speed	Max Mean	km/h	27,8 24	12,1 11,2	24 23	18,8 15	21 20	22 15	21 20
PWT Torque	Max	Nm	93	-35	100	-35	106	-36,5	115
PWT Current	Max	A	91	-13	93	-20	94	-24	95
PWT Power	Max Mean	kW	33 30	-5 -2,5	34 32,5	-7,8 -6	34,5 32	-9 -6,5	35 34
Est. Consumption	Mean	kWh/km	1,24	-0,135	1,42	-0,32	1,58	-0,32	1,68

Parameter			Value
Acceleration	Max Mean	m/s²	3,4 0,5
Speed	Max	km/h	85
Time 0 to Max Speed	Mean	s	53
PWT Torque	Max	Nm	193
PWT Current	Max	A	120
PWT Power	Max	kW	42
Acceleration Energy	Mean	kWh	0,54

Finally the vehicle was tested in real condition with traffic condition inside Turin. A road path was defined with the objective to cover both urban both extra-urban driving. The result is shown in the below figure.

The track length is about 30km and the testing was performed during cold season on January and hot season on July in order to validate also the cooling circuit at different temperatures



During the road testing activity, visual inspection on the mechanical fixing and mechanical rack was done in order to verify any problem.

c.6 Cost

The lightweight design of the rack will have a positive influence on CO_2 emissions: OPERA4FEV housing (all in plastic) is 30% lighter than a classical (metallic) one. Price of these plastic parts is 5 time lower that metallic parts.

d – The potential impact

Already deeply involved into the automotive industry, each partner of the project wants to acquire new knowledge, methods, and competitiveness in the field of electric vehicles.

MECAPLAST : to build new skills, methods and network to propose integrated solutions to OEMs.

EVE SYSTEM : to set-up a pilot production line dedicated to niche markets and to develop modular electronic solutions

INSA/CETHIL : is expecting to get more experience on electrical vehicles, creating knowledge on heat transfer problems, and improving design of battery racks using thermoplastic materials.

UPM-INSIA wants to develop and apply to electrical vehicles a new approach in crash safety activities, accidentology, crash modelling and testing. Obtain justification for the development of current and future regulations.

CRF : interest for a new, reliable, safe and cheaper Li-ion battery racks dedicated to automotive.

VUB is expecting extension of existing data base on inventory of BEV and battery racks, and an international exposure as LCA-leader in the field of electric vehicles.

Olesa will acquire knowledge in design, development and manufacturing of large molds for automotive battery racks using thermoplastic and composite materials.

REPOL : Optimization of extrusion and injection parameters with the final goal to obtain best and homogeneous mechanical and thermal properties with the smallest possible amount of virgin polymer

Dissemination activities have occurred all along the project.

- Presentation have been performed by academic partners at various events: SETAC Europe 18th LCA Case Study Symposium in 2012 in Copenhagen, EEVC in Brussels in 2015, International Conference on Ecological Vehicle and Renewable Energy EVER in 2015, 4th EU Electromobility Stakeholder Forum in Brussels in 2016.
  Other are forecasted in 2016: Electrical vehicle Symposium in Montreal, where VUB will present OPERA4FEV results.
- Scientific work have been performed by 2 PhD students:
  - Javi San Feli in VUB: A chapter of a book has been written (Lightweight and integrated plastic solutions for power battery racks in electric vehicles)
  - A student from UPM: Análisis del Comportamiento Mecánico de un Rack de Baterías frente a Eventos de Choque
- Industrial partners have shown results to the automotive industry through several events:
  - Automotive Techdays in Lyon: both in 2012 and in November 2016
  - Renault Techdays in Paris in 2015
  - Toyota Techdays in Brussels in 2016

Industrial partners will be able to exploit results of the project:

- MECAPLAST may sell plastic rack to OEM
- EVE has already started to use its knowledge on the rack architecture, to propose innovative solution to its clients. Real battery racks using the TMD technology have been delivered to clients since October 2015. Mid of 2016, 1MWh has already been produced.
- REPOL has developed a new material, that could be used either in automotive industry or electronic industry