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Abstract	GREENLION is a Large Scale Collaborative Project within the FP7 (GC.NMP.2011-1) leading to the manufacturing of greener and cheaper Li-Ion batteries for electric vehicle applications via the use of water soluble, fluorine-free, high thermally stable binders, which would eliminate the use of VOCs and reduce the cell assembly cost. The project has 6 key objectives: (i) development of new active and inactive battery materials viable for water processes (green chemistry); (ii) development of innovative processes (coating from aqueous slurries) capable of reducing electrode production cost and avoid environmental pollution; (iii) development of new assembly procedures (including laser cutting and high temperature pre-treatment) capable of substantially reduce the time and the cost of cell fabrication; (iv) lighter battery modules with easier disassembly through eco-designed bonding techniques; (v) waste reduction, which, by making use of the water solubility of the binder, allows the extensive recovery of the active and inactive battery materials; and (vi) development of automated process and construction of fully integrated battery module for electric vehicle applications with optimized electrodes, cells, and other ancillaries. Achievements during the first 18 months of the project, especially on materials development and water-based electrode fabrication are reported herein.
Keywords (separated by '-')	Electric vehicles - Energy storage - Batteries - Alloys anodes - Water-based binders - Innovative processing - Battery manufacturing - Automation

GREENLION Project: Advanced Manufacturing Processes for Low Cost Greener Li-Ion Batteries

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1 Introduction and State of the Art

Society's current individual mobility behavior is creating a plethora of looming problems, such as fossil carbon intensity and the concomitant consequences regarding fossil resource supply or the emissions of pollutants such as nitrogen and sulfur oxides (NO_x, SO_2) and particulate matter. While pollutant problems can be addressed by catalytic converters and filters, expectations run high that the greenhouse gas and resource problems can be addressed by substituting internal combustion engine (ICE) cars with battery powered electric cars (BEV). Most of the major car manufacturers have announced BEVs as part of their product lines in the immediate future.

Lithium ion batteries already dominate the consumer portable electronic and telecommunications market due to their higher power and energy density and they are also indicated as the option for the next generation of hybrid and electric vehicles (HEV, EV). The wide deployment of lithium ion batteries in the automotive industry would have tremendous consequences on the battery-market and it would further strengthen the central role of these systems in the field of energy

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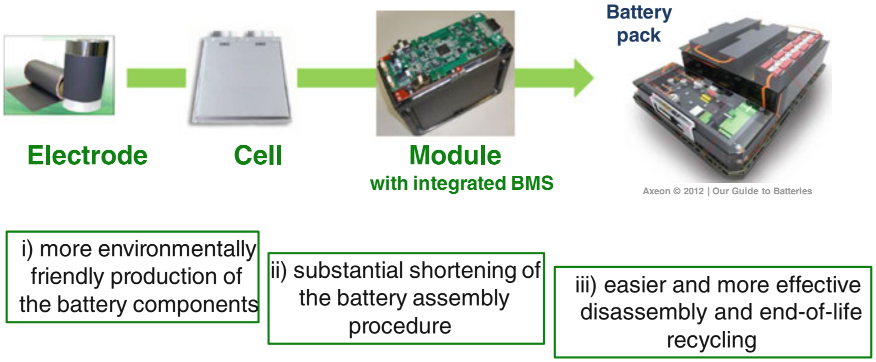


Fig. 1 Key levels of battery manufacturing value chain under development in GREENLION

storage. For that, considerable efforts are now focused on the development and realization of lithium ion batteries able to fulfill the requirement necessary for the application in HEV and EV. When the present lithium ion technology is considered, the safety and cost of batteries appear as the main drawbacks holding the introduction of this technology into the automotive market.

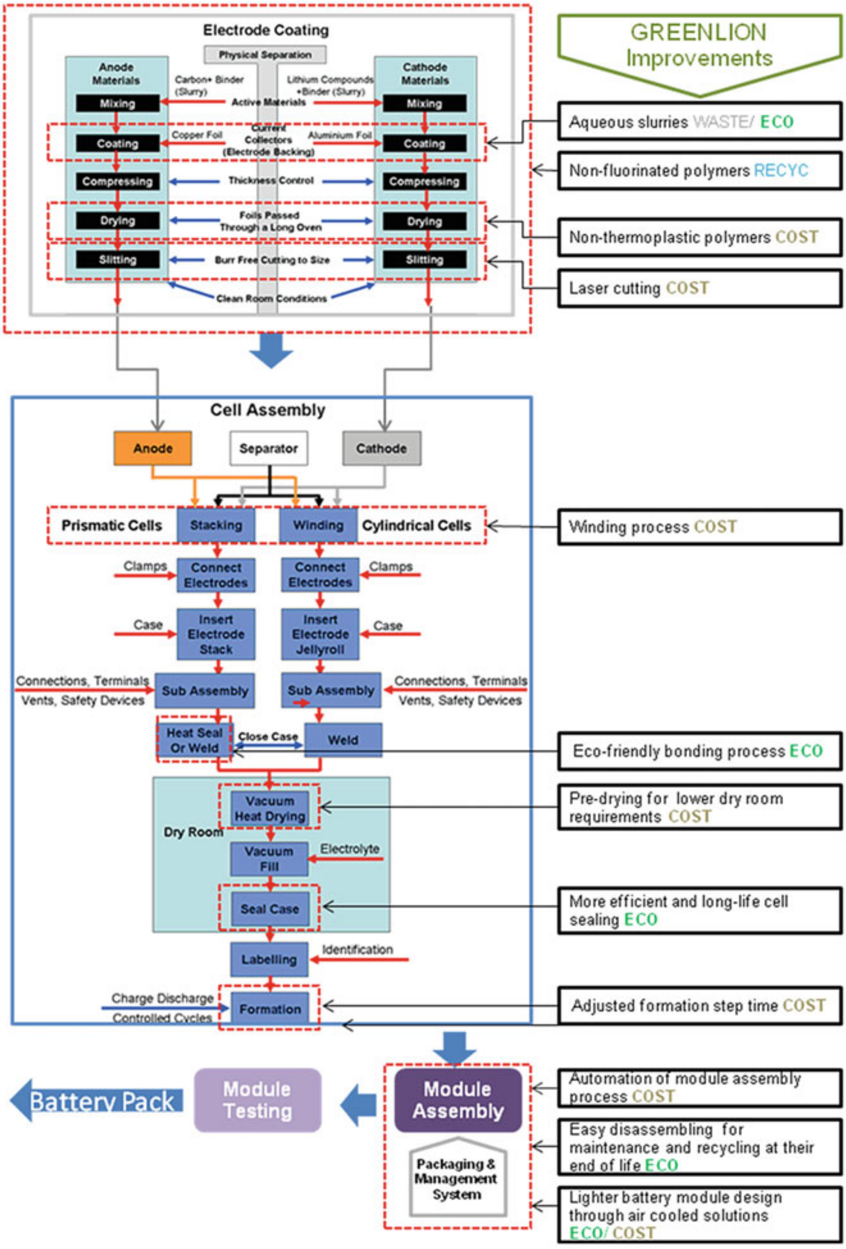
In order to tackle these issues from the manufacturing perspective before the final battery pack integration, the GREENLION consortium has identified three key levels in the value chain (Fig. 1), namely battery components, especially electrode processing, individual cells and battery modules, oriented to the battery pack for EVs.

As stated previously, the automotive industry is demanding for safe and low cost lithium ion (Li-ion) batteries to bring to the market higher range and affordable BEVs to substitute the ICE vehicles that won the battle a 100 years ago, due to Ford’s mass production line, low oil cost and insufficient battery technology of the time.

The current Li-ion battery manufacturing process has advanced greatly in the last 20 years thanks to the consumer portable electronic industry and those developments are also the basis for the production of large format cells demanded for automotive application. The Li-ion battery production comprises a sequence of steps that can be summarized as electrode preparation, cell fabrication and battery module assembly, as presented in Figs. 1 and 2.

1.1 Electrodes

The initial large scale automotive prototype lithium ion batteries use hard carbon or graphite as negative electrode materials, and nickel-substituted cobalt and/or manganese oxide (NCA, NMC), manganese spinel oxide or lithium iron phosphate as cathode active materials. Since for this first stage, the basic formulations and



ECO: Eco-friendly; **COST**: Lower cost; **WASTE**: waste reduction; **RECYC**: easier recycling

Fig. 2 Breakdown of steps for Li-ion battery manufacturing and improvements proposed in GREENLION materials from consumer batteries are being used, the costs of the electrodes still need to be decreased for the final use in automotive batteries.

Numerous groups have been studying and developing new electrode and electrolyte materials with suitable characteristics and improved performance for the realization of greener and lower cost batteries, and promising results have already been achieved [1, 2]. However, to realize batteries with such kinds of properties, not only active and electrolyte materials have to be taken into account but, in general, all the battery components and even the process to realize the batteries need to be considered and improved. Apart from the continuous research on materials with increasing energy and power density, safety, durability and cycle life (targets of at least 30 % improvement for 2020), current estimations point to a 10–15 % reduction cost from the active materials that can reach up to 35 % through electrode process optimization [3].

Several studies are now also focused on the improvement of the inactive materials as well as of the electrode production. In this context, a key role is certainly played by the binder. As a matter of fact, this component is not only responsible for the binding of the active materials and the conductive agent to the metal current collectors, but it also strongly affects the electrode processing. Consequently, the improvement of the binder must necessarily be considered as a key point for the development of new safe and greener batteries.

An interesting example of the influence of the binder is observed when the preparation of electrodes based on lithium iron phosphate ($LiFePO_4$) is considered. $LiFePO_4$ displays high stability of the capacity during prolonged cycling; it is environment-friendly, cheap, and safe [4, 5]. Because of these characteristics, it is considered as a very attractive cathodic material. So far, however, most of the research and the development in composite cathodes have been focused on the use of fluorinated binders and practically all commercial lithium-ion batteries are made using poly(vinylidene fluoride) (PVDF) as the binder. However, this polymer is costly (industrial cost in the multiton scale is around 15–18 EUR/kg); it requires the use of volatile organic compounds that are often toxic (like N-methyl pyrrolidone, NMP) in the processing, and it is not easily disposable at the end of the battery life. The introduction of alternative binders, as well as an improved preparation procedure, is necessary.

Recently, alternative binders have been introduced for the manufacture of anodes for lithium-ion batteries, like styrene butadiene rubber (SBR) that can be processed in water. Among them, one of the most interesting is certainly the sodium salt of carboxymethyl cellulose (CMC), which is a water-soluble material. This is certainly the greatest advantage of CMC because it allows processing in aqueous slurries rather than in polluting, health and environment unfriendly, volatile organic-compound-based slurries. The second great advantage of CMC resides in its easy disposability at the end of the life of the battery. Once the electrode is extracted, the active electrode material can be easily recovered by pyrolysis of the binder. Last but not least is the material cost. The CMC industrial price is about 1–2 EUR/kg, i.e., about 1 order of magnitude lower than PVDF.

1.2 Cell Assembly

Battery pricing is significantly impacted by material costs and manufacturing cost in mass production due to the multitude of operations and the precision required. The electrode thickness produced at the first step can range from 0.05 to 0.2 mm depending on the electrode type (cathode or anode), the intended application of the battery (high capacity or high power) and the cell design (cylindrical or planar).

Cylindrical cells, where components are staked and wound to be inserted into cylindrical cases, and prismatic cells, with stacked electrodes and separators, are currently the predominant designs. Pouch cells are prismatic cells with aluminum-polymer soft pack instead of metal can, so they achieve a packaging efficiency of 90–95 % and higher energy density. With high volume, any reasonable size can be produced economically. Lithium polymer pouch cells are increasingly being considered as alternatives to large prismatic cells for automotive applications; because their form is flexible they can be packaged more efficiently, and reduced cell packaging overheads result in high battery energy density. Due to large surface area and aspect ratio they have good heat dissipation. However, the cells have low mechanical stability and therefore more robust packaging is required.

1.3 Module Design and Assembly

In order to develop a battery module as a building block of a battery pack, first of all it is highly convenient to have as much information as possible about the characteristics of the vehicle to be powered by the energy stored in the battery in terms of weight, friction, aerodynamic coefficient, efficiency, voltage and current of the power train, … Besides, others features related to the vehicle performance must be defined, as the energy storage will be sized in order to cope with these requirements, such as autonomy, acceleration, maximum speed, cruise speed, etc., referred to a given driving cycle.

According to the vehicle characteristics and requirements, and once the cell has been selected, tested and modeled, all this information will be used to determine the required number of cells and modules and their series/parallel connection inside—respectively—the module and the battery pack, so that the required voltage, current, energy and power values are met. In order to define the optimum possible arrangement, the resulting module will be simulated—both electrical and thermally—out of the previously obtained models of the cells. Special consideration should be put in the lay-out of the cells since the thermal behavior of the module will strongly depend on this.

Most of the systems using batteries require a certain number of cells connected in series and parallel in order to achieve the desired voltages and current. Therefore, all the cells should be kept in the same state of charge (SOC) in such a way that the capacity of the resulting module or battery-pack is not reduced due to a weak cell that reaches the cut-off voltage sooner than the rest, or to an incomplete charge caused by a cell with a voltage higher than the others. Therefore, a cell balancing system that keeps the cells in the same SOC is required to improve the performance of the module.

Besides, special care must be taken in order to ensure that no cell is over charged or discharged, due to the electrochemical inequalities of the cells inherent to the manufacturing process or to uneven working or balancing conditions. Otherwise, the users' and cells' integrity could be compromised, as dangerous amounts of flammable gases and/or toxic chemicals can be released, and even end up in an explosion.

In order to have an optimal use of the module, it is highly convenient to have access to the information concerning the state of charge (SOC, which is the remaining charge in the cells) and state of health (SOH, which is the capacity of the cells at a given time compared to that when they were new) of the cells. For all this reasons, a Battery Management System (BMS) is required in any system using lithium-ion cells.

The operation of batteries depends on an electrochemical process for both charging and discharging, and it is widely known that these chemical reactions are significantly dependent on temperature. Nominal battery performance is usually specified for working temperatures somewhere in the +20 to +30 °C range. However, the working temperature conditions of the cells can deviate substantially from nominal values, in such a way that batteries are operated at higher or lower temperatures. As a consequence, the performance of the cells is strongly affected: in general terms, discharge time (and therefore, capacity) decreases at lower temperatures, and the number of charge and discharge cycles is reduced when working at higher temperatures.

Besides, and from a safety point of view, it is extremely important to avoid a thermal runaway (uncontrolled temperature increase) in the cells since dangerous amounts of flammable gases and/or toxic chemicals can be released, and even end up in an explosion.

Therefore, a Thermal Management Systems (TMS) is required to maintain the cells within a safe temperature range that, besides, allows optimizing the performance of the module. In order to cool-down or heat-up the cells, different systems can be used, being air or liquid cooling the most usual choices.

2 Project Description

2.1 Project Approach and Objectives

In the GREENLION project (www.greenlionproject.eu), we address the issues cited previously by the industrial development of eco-designed processes at the electrode, cell and battery module level. At the **electrode processing stage** (that will be otherwise independent of the active materials chemistry), developing and making use of:

1. aqueous slurries rather than toxic organic volatile compounds (25 % cost reduction);
2. non-thermoplastic polymers that allow for high temperature drying, which results in shorter and less expensive assembly procedure (10 % efficiency); and
3. easily disposable non-fluorinated polymers (at expected 10 times less materials cost).

At the **cell assembly level**, further improvements to the existing procedures as well as changes at some steps of the assembly process will be developed to increase energy efficiency and shorten times (and hence lower costs) during the manufacturing process, by implementing:

1. laser cutting instead of mechanical notching of the electrodes (15 % cost),
2. adjusted stack winding of components from aqueous-based electrodes and their drying process before electrolyte filling and sealing, to lower dry room requirements,
3. environmentally friendly bonding process for more effective and long-life cell sealing, and
4. adjusted formation step time (ideally for electrodes with reduced formation cycle) in cell manufacturing line (5 % time reduction).

Finally, developing a modular battery allows an easier handling of cells within a complete battery pack. At this **battery module level**, GREENLION project will design an autonomous unit including its own electrical and thermal management as a simple and reliable building block that will allow the manufacturing and maintenance of the whole battery packs easier and more inexpensively, with the lowest possible environmental impact. This will be achieved by:

1. lighter battery module designs (including electronics) with the possibility of implementing air cooled solutions instead of liquid cooling systems (expected 20 % less weight),
2. bonding process of module housing for safe operation but easy disassembling for maintenance and reuse/recycling at their end-of-life, and
3. automation of module assembly process (3 s/cell vs. manual assembly).

These developments will be scaled-up and realized in pilot lines during the project, following a continuous environmental assessment of materials and processes. A validation of the finally assembled battery module will be carried out lead by the automotive end-user who will also provide the targets and specifications for (H)EV application.

General project approach and objectives are summarized in Fig. 2. Progress beyond current State of the Art is also indicated.

2.2 *Project Consortium*

The scientific and technological cooperation in GREENLION consortium and their roles in the project are well balanced covering the complete chain from raw material, scientific comprehension, technological research and end users. As an essential part of the project, the industrial partners will commit to exploit all commercial aspects of the new manufacturing processes. To this purpose, the industrial partnership was designed to combine Li-ion cells and module manufacturers (CEGASA), processing equipment manufacturers (POLYTYPE and KEMET), material suppliers (SOLVAY and TIMCAL), automation of assembly processes providers (MONDRAGON ASSEMBLY), recycling and waste treatment services suppliers (TECNICAS REUNIDAS), and car manufacturers (SEAT and VOLKSWAGEN). The research institutions (CIDETEC, ENEA, RESCOLL, AIT) and universities (University of Muenster, Politecnico di Milano, University of Limerick) in GREENLION consortium provide complementary skills and expertise in the relevant fields of research and development that are necessary to achieve the project objectives.

3 Outcome of the Project

3.1 *Baseline for GREENLION Project and Performance Indicators*

Knowledge will be generated well beyond state of the art and the limitations of current Li-ion battery manufacturing process. In particular, Table 1 summarizes and quantifies the most significant targets.

3.2 *Expected Impact of the Project*

GREENLION will provide advances to a number of scientific and engineering challenges for battery cell and module manufacturing, and their performance thereof. The successful resolution of these will lead to breakthroughs in automotive lithium ion batteries for electric vehicles and thus to the development of a sustainable mobility and quality of life.

Greening our transport system is necessary not only to avoid the influence of oil supply ($147 per barrel peak in 2008) but also to achieve EU and international targets in emissions reductions. In the EU, 19 % of total greenhouse gas emissions and 28 % of CO_2 emissions in 2005 are linked to the transport sector. More than 90 % of the total EU transport-related emissions are due to road transport. While

Table 1 Summary of most relevant GREENLION performance indicators and targets

	Proposed innovation-performance indicators
Electrode	Development of innovative electrodes realized by water-based processes to realize electrodes characterized by: (i) high thermal stability to allow high-temperature drying (>150 °C) in order to allow assembly in less stringent dry room operating conditions and reduce post-coating treatment time); (ii) high electrochemical stability to allow the use of high voltage cathodes (at least 5 V vs. Li/Li^+); (iii) high capacity retention upon cycling (more than 80 % of initial capacity after 1,000 cycles)
	The final goal is to obtain anodes and cathodes for lithium-ion batteries with storage capacities as high as, respectively, 300 and 150 mAh/g (excluding the weight of the current collectors), and surface loadings of, at least, 5 mAh/cm^2
Cell	Implement laser cutting/slitting instead of mechanical notching of the electrodes achieving negligible degradation of active material in the cut area, reduction of burrs resulting in a safer cell, expected 15 % cost saving due to reduced maintenance and higher process efficiency
	Based on such innovative electrodes, GREENLION proposes to design and develop cells capable of delivering a specific energy of 200 Wh/kg, which is the actual target for automotive applications
Module	Lighter battery module designs (including electronics) by evaluating the implementation air cooled solutions instead of liquid cooling systems (20 % less weight)
	Automation of module assembly process with a handling time down to 3 s per cell) will enable cost reduction and quality in line with what achieved in the highly automated cell manufacturing

total EU emissions declined, transport emissions increased continuously between 1990 and 2005 due to high growth in both passenger (28 %) and freight transport (62 %).

Current and near-term (i.e. Li-ion) battery technology development is one of the key factors on the Mobility Electrification and the large scale production of these automotive batteries and reducing their costs is, in fact, critical for market entry and acceptance of Electric Vehicles. In order to achieve a break-even cost with internal combustion engines, battery costs must be reduced from the current estimated range of 675–500 € per kilowatt-hour (kWh) at high volume production (order of 100 k units) down to 350–275 €/kWh by 2020. R&D to improve power (W/kg) and energy density (Wh/kg) in order to increase driving autonomy, reductions in recharge time and achieving life cycles that approach vehicle life spans is also imperative. Increasing production rate from 10,000 to 100,000 batteries/year reduces cost by ~30–40 % [6].

GREENLION addresses further reduction costs driven not only by high volume manufacturing, but also from the components processing conditions. The use of water based binders, an order of magnitude cheaper than conventional fluorinated ones will drive down the cell manufacturing costs, besides being more environmentally friendly and eco-sustainable at the end of life of the cells. Besides the improvement in environmental, health and safety terms (including “working-condition-friendly” considerations), the initial inversion and running costs of the solvent recovery system would be avoided and water is indeed cheaper than NMP. Even though in current production plants the recovered NMP is purified and offered again at 50 % of the cost of pure solvent, distilled water is also cheaper (0.20 €/L) than 50 % of pure NMP 0.90 €/L (~1.8 €/L pure).

Expected impact in the field of new competitive processes, by means of production automation is also foreseen. Not only will the results of the project efforts enable lower cost and greener lithium battery packs production, but also equipment manufacturing and high added value processes will be developed. These new automated processes will contribute to a substantial cost reduction of lithium battery packs, and will facilitate their introduction to mass production.

Automation and new process development will improve the quality and yield of the production, while at same time reduces labor costs per kWh. This project, with the development of the specific equipments for module assembling, will enable a cycle time of 3 s for each cell. This results in a module production capacity of 880 MWh/year.

Globally, automation and equipment development in this project will enable a cost reduction of the whole battery pack of 15 %. Having in mind that only 24 % of the cost is related to the module/pack manufacturing (60 % are materials components and 16 % are transports and others), it represents a major step in the way to mass production. Market growing will also pull down the prices of the materials, and it will open the way to the mass production at competitive costs.

3.3 *Results Achieved*

GREENLION is currently at month 18 of a 4 year-long workplan. During this first stage of the project, efforts have been mainly focused on the electrode processing step, with the development and testing of active materials and binders suitable for water-based slurry formulations and electrode coating process. First selected formulations have been used for small scale GEN1 prototype pouch cell assembly while the optimized module design and assembly process is underway. These results and advances are summarized in the following sections.

3.3.1 Materials Development and Water-Based Electrode Processing

Among the main research topics of the GREENLION Project, are to be highlighted the development of ionic liquid-based electrolytes and the realization of electrodes, prepared through innovative, eco-friendly process routes, based on high-voltage cathode and large-capacity anode materials. There is growing up interest in replacing the organic solvents currently used in lithium batteries [7–9] with ionic liquids, ILs, since their non-flammability and negligible vapor pressure in conjunction with wide chemical, electrochemical and thermal stability, high ionic conductivity and heat capacity. Our basic idea is to favorably combine different IL sets in order to obtain ionic liquid mixtures with improved performance. For instance, N-methyl-N-propylpyrrolidinium bis(fluorosulfonyl)imide ($PYR_{13}FSI$) was found to exhibit moderate viscosity and low melting point, allowing fast ion conduction even at low temperatures [10]. On other hand, the much cheaper N-methyl-N-propylpyrrolidinium bis(trifluoromethanesulfonyl)imide ($PYR_{13}TFSI$) shows wider thermal and electrochemical stability [11]. In order to verify if these characteristics could be combined, $PYR_{13}FSI$-$PYR_{13}TFSI$ mixtures were prepared and investigated in terms of NMR spectroscopy, transport properties and density measurements.

Remarkable conduction values, e.g., approaching 10^{-3} Scm^{-1}, are achieved already at −20 °C for mole fraction ranging from $0.6 \le x \le 0.8$ whereas both the raw ionic liquid materials ($PYR_{13}FSI$ and $PYR_{13}TFSI$) are solid at this temperature (see Fig. 3). This highlights the synergic effect exhibited in ionic liquid mixtures, especially for low temperature applications.

NMR heteronuclear NOE correlation experiments (HOESY) experiments have been successfully used for the assessment of the intermolecular contacts between the F atoms of the anions and the H atoms of the cations in pyrrolidinium based ionic liquids, thus providing information on the local structural organization. The experiments have shown a peculiar cation-anion organization in the three investigated blends responsible of their favorable physico-chemical characteristics.

High nominal voltage cathode materials, combined with large capacity anodes are appealing issues for the realization of lithium batteries with high gravimetrical and volumetric energy. In this first stage of GREENLION, cathodes based on $LiNi_xMn_yCo_{1-x-y}O_2$ (NMC) and anodes based on carbonaceous materials (graphite, SLP) have been developed. The composite electrodes were fabricated using the fluorine-free, water-soluble, natural binder carboxymethylcellulose sodium salt (CMC) instead of the more expensive and less environmentally friendly polyvinyliden-di-fluoride (PVdF) in N-methyl-pyrrolidone (NMP). The use of CMC allows also easier recycling of the battery components. For instance, the dissolution in water of the binder allows, for example, a full recovery of the metallic current collectors [12, 13].

Commercially available NMC cathode and Timcal SLP 30® graphite anode tapes based on the aqueous CMC binders were prepared using a pre-pilot automated coating line. The cycling performance tests (Fig. 4) evidenced a time-stable capacity of 130 mA h g^{-1} for more than 40 cycles with coulombic efficiency higher than 99.0 % for the NMC cathodes. The SLP 30® anodes showed very good performance in terms of reversibility of the intercalation process. The specific capacity leveled 375 mA h g^{-1} after a few cycles. Upon 80 cycles, the SLP 30® electrodes showed still high cycling stability and columbic efficiency above 99.9 %. These results support for a further development of the aqueous CMC binder-based electrodes.

In addition, alternative water-soluble binders have been studied. Impressive electrochemical performance has recently been reported for Si nanopowder [14] and nanowire [15] anodes prepared from aqueous slurries using 15 wt% alginate as

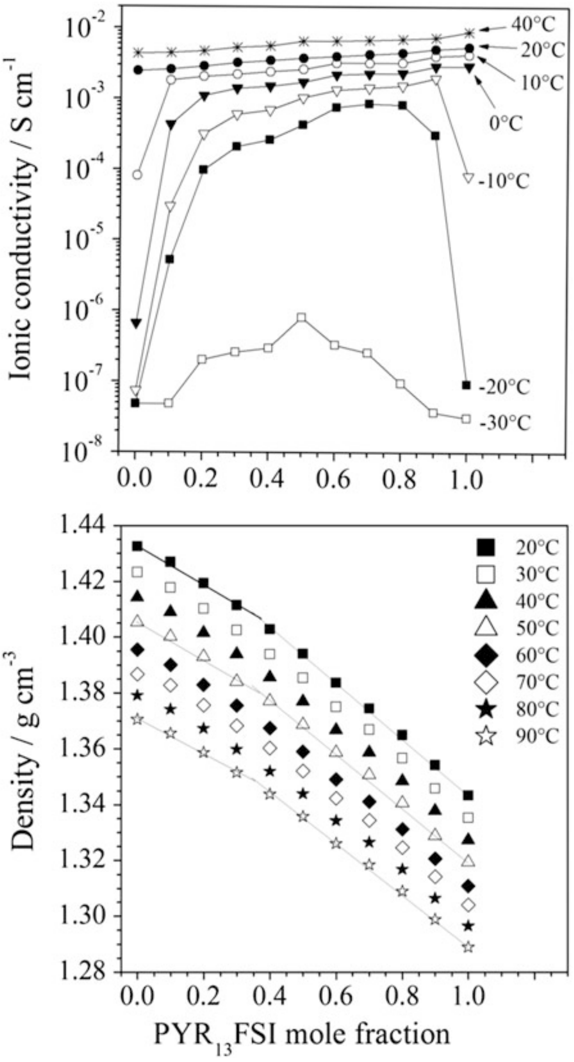


Fig. 3 Ionic conductivity (*upper panel*) and density (*lower panel*) versus PYR$_{13}$FSI mole ratio dependence for (x)PYR$_{13}$FSI/(1−x)PYR$_{13}$TFSI binary electrolyte mixtures at different temperatures

binder. To date, however, no study has been undertaken using alginates as the binder for graphitic anodes, which are almost ubiquitous in present lithium ion battery technology. It is apparent from Fig. 5 that the graphite anode with 7.5 wt% alginate outperforms that with 10 wt% PVDF (a common commercial level) over the course of the first 65 charge/discharge cycles. This result suggests that alginate may be a suitable candidate for aqueous manufacturing of anodes.

The CMC based formulations will be the first to be trialed in pilot line in order to develop optimized coating machinery and electrodes for cell assembly. The most efficient way of manufacturing battery electrodes is to simultaneously coat both

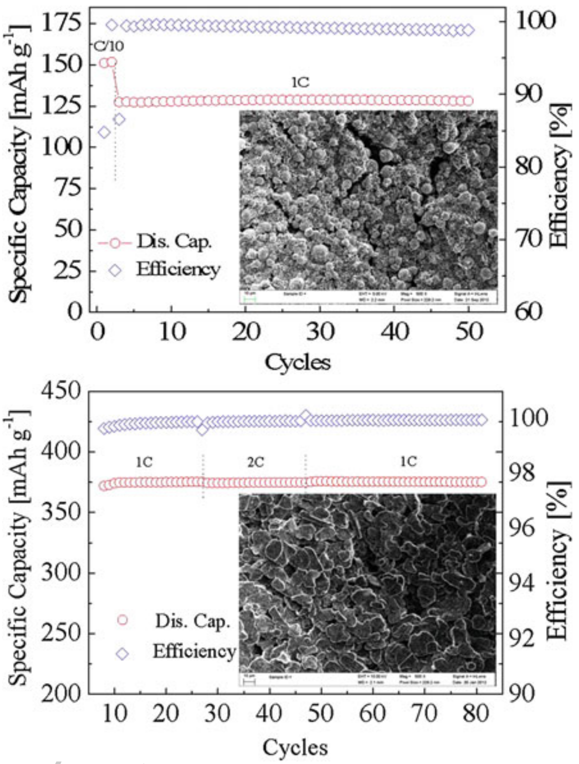


Fig. 4 Cycling performance versus Lithium and SEM image (*inset*) of NMC cathode (*upper panel*) and SLP 30® anode (*lower panel*) in (1 M) $LiPF_6$/EC:DMC (1:1 in wt/wt) electrolyte at 20 °C. Current rate: 0.1–1 C; mass loading: NMC, 3.29 mg cm^{-2}; SLP 30®, 2.45 mg cm^{-2}

sides of the substrate and to use a flotation dryer for removing the solvent. This configuration requires one of the coatings to be applied in the so called kiss coating mode as depicted in Fig. 6 for the slot coating process.

Coating trials have been carried out on a pilot machine, allowing the adjustment of parameters to achieve an excellent uniformity of the kiss-coated layer, i.e. by suppressing cross lines generated by web flutter in the flotation dryer, and by suppressing longitudinal bands generated by web deformations upstream of the slot die.

3.3.2 Cell Assembly and Module Design

During the first year, GEN0 prototype cells (10–14 Ah) were assembled as baseline for the project, from electrodes prepared with commercially available water-soluble binders and graphite/$LiFePO_4$ (C/LFP) chemistry.

The NMC and SLP 30® electrodes (around 1 m^2) prepared in a pre-pilot automated coating line were used to assemble GEN1 small pouch cells (0.5–1.5 Ah) as shown in Fig. 7, following the first large cell design (30 Ah target) proposed to fulfill the energy requirements of the end-users for an efficient automotive battery module.

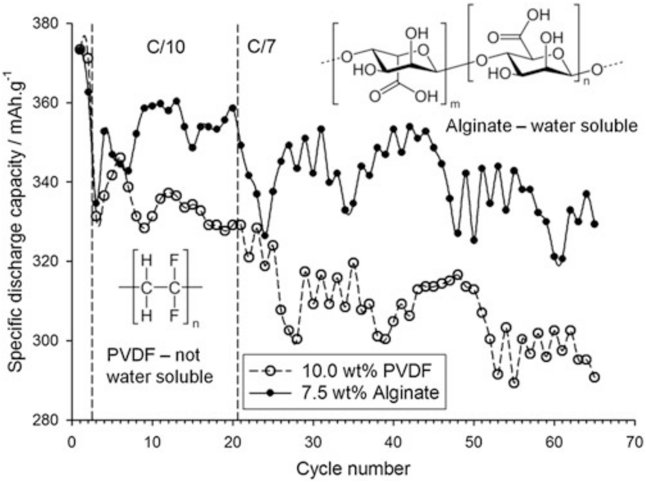


Fig. 5 Comparison of the specific discharge (delithiation) capacities of anodes prepared using polyvinylidene fluoride (PVDF) or alginate binders. The only other component of the anodes was the active graphite material—TIMREX® SLP30 by TIMCAL. The first and second charge/discharge cycles were conducted at slow rates of C/40 and C/25 respectively to facilitate the formation of a stable SEI layer. Voltage limits were between 5 mV and 1.5 V versus Li/Li$^+$. The electrolyte was 1 M (EC:DMC, 1:1 v/v) and the experiments were conducted at ambient room temperature

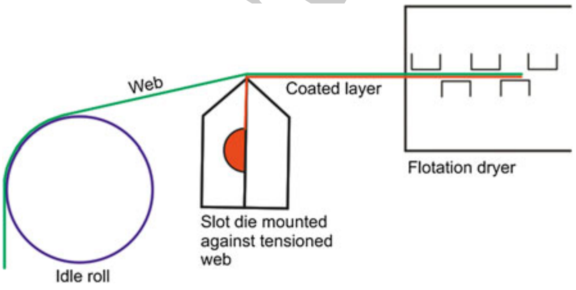


Fig. 6 Schematic view of coating the web-underside by the slot coating process operating in the kiss or tensioned-web mode

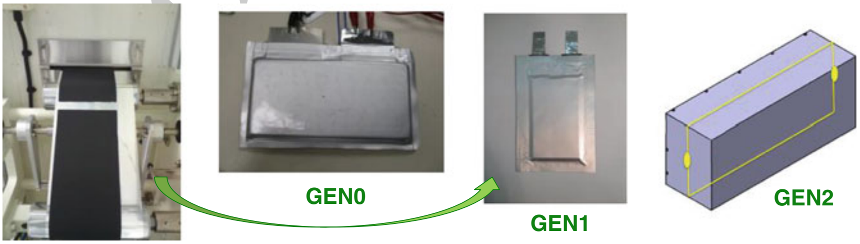


Fig. 7 From *left* to *right* CMC-based electrodes prepared in pre-pilot coating line, *GEN0* C/LFP cell, *GEN1* small pouch cell with SLP 30® and NMC electrodes and schematic *GEN2* power cell and module design

While laser notching trials of electrodes with both PVDF and water-based binders are underway, conventional cutting dies (mechanical notching) and manual stacking process were used for GEN0 and GEN1 cell assembly. Automated stacking-winding will be implemented for the GEN2 cell that has been adopted as the most efficient electrical and thermal design for high power performance.

The design of a lighter battery module suitable for automated assembly and easier disassembly is ongoing, coupled to the GEN2 power oriented cell design. Different aspects such as minimum mechanical fitting by the assembly process, modular assembly including liquid cooled cold plates, mechanical absorption of cell swelling and venting are under consideration. AQ1

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