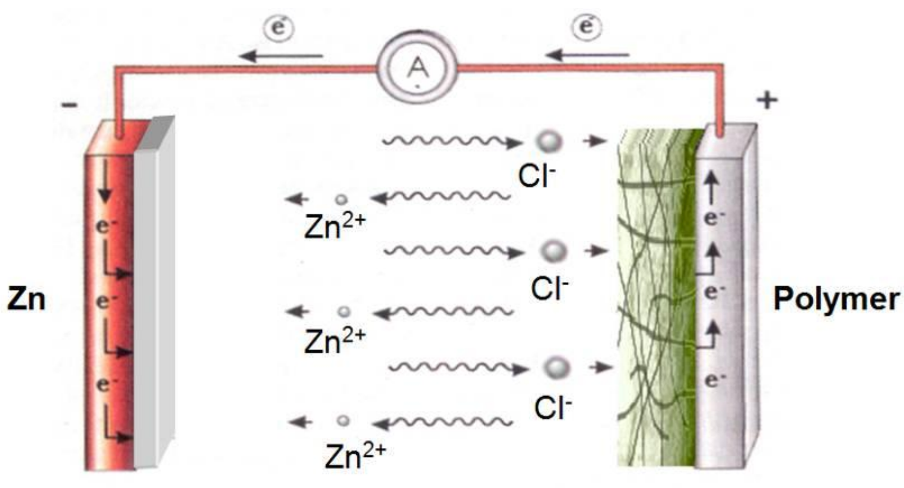
PolyZion: Zn Polymer Rechargeable Battery

The €3.5 million research project, PolyZion[i], was funded under the EU Seventh Framework Programme and combined world-class research organisations in investigating ionic liquids, conducting plastics, zinc deposition, pulse charging and batteries. The concept of this project was to create a novel class of fast rechargeable zinc battery for hybrid electric vehicle (HEV) and small electric vehicle (EV) applications. The project approach focused fundamental advances being made in several innovative and rapidly developing materials disciplines towards the common goal of a new type of rechargeable zinc battery. The project combined a new class of ionic liquids, a zinc half cell and conducting polymers.

Mass introduction of HEVs and EVs is widely expected within the next 8-15 years, driven by rising fuel pump prices, the looming shortage of oil and regulatory commitments towards lower CO_2 emissions. With predictions that the rapid growth of the global market for EV and hybrid EVs is expected to top $2 billion by 2015 there is good promise for new battery technologies. However, the currently available commercial battery technology (nickel metal hydride, NiMH) is unable to keep pace with the increasing demand for HEVs and EVs and does not meet power and energy needs. The main competing technology under development is the Li-ion battery which does perform better in terms of energy and power density, but brings new challenges such as reduced lifetime, high cost, low abuse tolerance and poor low temperature performance, as well as ongoing safety concerns. The only other valid alternative is the lead-acid battery currently being re-invented into new lightweight and more powerful designs, but obviously, still with environmental drawbacks.

Zn Polymer Battery: The Principle

The project combines a new low-cost, air & moisture insensitive and environmentally benign class of ionic liquids, zinc deposits, pulse charge injection and conducting polymers for use in a rechargeable battery system.



Zinc Electrode

Controlling the reactions of the zinc electrode is the key novelty of the project. Although zinc has been used as a battery electrode material in many battery types, these are largely primary (non-rechargeable) batteries. Zinc is an excellent material for battery applications; it is abundant, inexpensive, non-toxic and lightweight relative to most metals. Up until now, recharging zinc cells have been faced with two major difficulties:

1. Charging the cell involves the deposition of metallic zinc at the electrode and in aqueous electrolyte this results in hydrogen formation. This is not only a safety concern (exploding cells) but also lowers cell efficiency and shelf-life.

2. Zinc deposits from aqueous electrolytes often take the form of dendrites, with the consequence of both poor adhesion and the possibility of short circuits (from long needle-shaped crystallites).[ii]

In this project, the problems and issues associated with conventional aqueous rechargeable Zn batteries, (hydrogen evolution and dendritic growth), have been overcome by the use of this new class of ionic liquid as an electrolyte at charging rates below 5C (charging time of 12 minutes).

Ionic Liquid Electrolyte

Some of the PolyZion partners were previously involved in the successful development of a novel class of ionic liquids (EU funded project: *IONMET* [iii]) specifically aimed at the metal finishing industry. These ionic liquids are based on a binary stoichiometric mixture of a quaternary ammonium salt, and a hydrogen bond donor, also known as deep eutectic solvents (DES).

The use of these ionic liquid electrolytes has eliminated hydrogen gas evolution due to the absence of aqueous electrolytes. These ionic liquid electrolytes have the additional advantage of permitting a larger cell voltage compared to aqueous systems. The new group of eutectic based ionic liquids can be prepared readily from renewable, non-toxic, naturally occurring chemicals, are very inexpensive and can be tailored to specific uses. These ionic liquids are stable to air and moisture, and environmentally benign with good biodegradability.

Conducting Polymer Electrode

Conducting polymers are organic polymers that conduct electricity. Such compounds may have metallic conductivity or can be semiconductors. The biggest advantage of conductive polymers is their processability (mainly by dispersion). Conductive polymers are generally not plastics, i.e., they are not thermoformable. But, like insulating polymers, they are organic materials. They can offer high electrical conductivity but do not show mechanical properties as other commercially used polymers do. The electrical properties can be fine-tuned using the methods of organic synthesis and by advanced dispersion techniques.

Consequently under this programme we have developed and tested conducting polymer anode materials together with underlying substrates and protocols for deposition of suitable morphology and electrochemical properties for use in combination with the reversible zinc cathode for a completely new type of rechargeable cell.

Initial Lab Results

Our lab coin cell data for Zn Polymer cells were very promising: we can exceed both the power and energy density of NiMH in a battery with good cycleability. With regards to the developing technology, we can match the power density of Li ion, however, currently we can't match the energy density.

The results from the lab scale devices indicated that this type of Zn/polymer battery lends itself more towards a HEV where high power density and good cyclability are the more important characteristics. We cannot currently compete with Lithium Ion on energy density for pure EV applications, but we can argue improvements in safety and environmental credentials.

	Lead Acid	**Li ion**	**NiMH**	**Project target**	**Lab cell results**
Power density (Wh/kg)	180	1000	300	1000	1034
Energy density (specific energy) (Wh/kg)	40	150+	75	100+	123
Cycling				1000	2,000+

Celaya Emparanza y Galdos SA (Cegasa) have constructed of the first generation Zn/polymer prototype cells during 2012 and these have undergone commercial testing processes at KEMA Nederland BV. The Zn Polymer chemistry was successfully scaled up to cells of nominal 1Ah capacity, but replication of the encouraging lab scale performance from these cells has not been achievable within project timeframe.

In conclusion, advances in material science made during the course of this research project could lead to, not only a new class of battery for electric vehicles, but also further advanced research into zinc rechargeable batteries for a host of different applications.

The Consortium:

CTECH	ULEIC	IREQ	FCUP	IrICH	RC	CIDETEC	CEGASA	KEMA
Management Dissemination & Exploitation LCA	Ionic Liquids Zn Electrodes Pulse Charging & Conducting polymers	Ionic Liquids Battery development	Conducting Polymer Zn half cells	Novel Polymer Synthesis (unsaturated heteroatomic Compounds)	Novel Polymer Synthesis (Polyaniline) & Polymer Scale-up	Pulse charging Battery Development	Battery prototype Exploitation	Battery testing

The institutions and organisations involved with the project are: **University of Leicester, C-Tech Innovation, Fundacion CIDETEC, Celaya Emparanza y Galdos SA (Cegasa), University of Porto, KEMA Nederland BV, AE Favorsky Irkutsk Institute of Chemistry, Institute de Recherche d'Hydro-Québec and Rescoll.**

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The key features of the Zinc Polymer Battery we are developing are:

- Low cost construction materials, with good security of supply, as sources of all raw material are abundant.
- Environmentally benign battery. The life cycle analysis has been completed and initial studies indicate low environmental impact (relative to the current state of the art competitive technologies).
- Improved safety performance, depending on the electrolyte composition, due to the use of non-flammable and low toxicity ionic liquid electrolytes.
- Good power density, with promising results already demonstrated at laboratory scale.
- Competitive Energy density (specific energy), compared to current state of the art NiMH batteries.
- Good cycleability, with the potential to significantly exceed the original 1000 cycle target.
- The technology is being scaled up and the overall aim of the project was to produce prototype modules and benchmark their performance against the current state-of-the-art for EV and HEV applications.
- The project is of 42 months duration and funded under the Cooperation category of the European Union Seventh Framework programme (FP7) http://cordis.europa.eu/fp7/understand_en.html

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[i] Details of the PolyZion project can be found at www.polyzion.eu. This project was completed 31/01/2013 and a non-confidential summary of the project results is being prepared for publication. Publication of technical progress has been heavily restricted to protect the IP position of the consortium.

[ii] Lee CW., Sathiyanarayanan K., Eom SW., *J. Power Sources*, 2006, **160,** 1436-1441; Vatsalarani J., Trivedi DC., Ragavendran K., J. Electrochem. Soc, 2005, **152,** A1974-A1978; Kan JQ., Xue HG., Mu SL., J. Power Sources, 1998, **74**, 113-116; Bass K., Mitchell PJ., Wilcox GD., J. Power Sources, 1991, **35**, 333-351

[iii] Details of the IONMET consortium can be found at www.ionmet.eu