SOLVAY

asking more from chemistry®

High Performance Materials for Batteries

Solvay Introduction

Electrical and electronic devices as well as eco-friendly transportation have all become integral to our daily lives. These conveniences keep us connected both to each other and to the world around us, allowing us to work more efficiently while travelling safer as we reduce the overall impact on the environment.

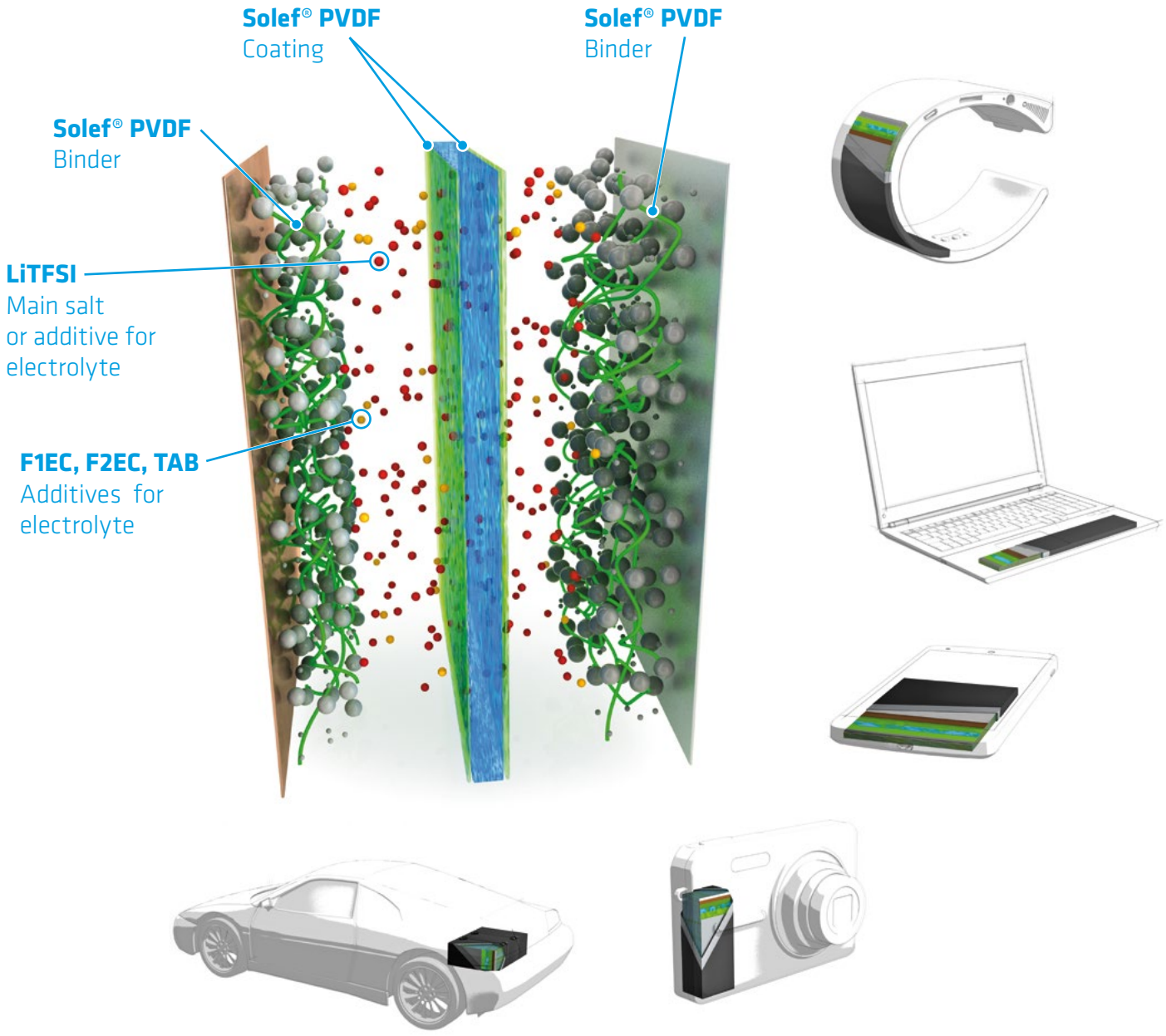
A key factor that can either spread or limit their development is what's "under the hood": Li-Ion batteries.

The power and duration of Li-Ion batteries dually determine the efficiency and reliability of smartphones, tablets, laptops as well as other electronic devices. New materials and technologies that extend battery life while shortening charging time are in great demand.

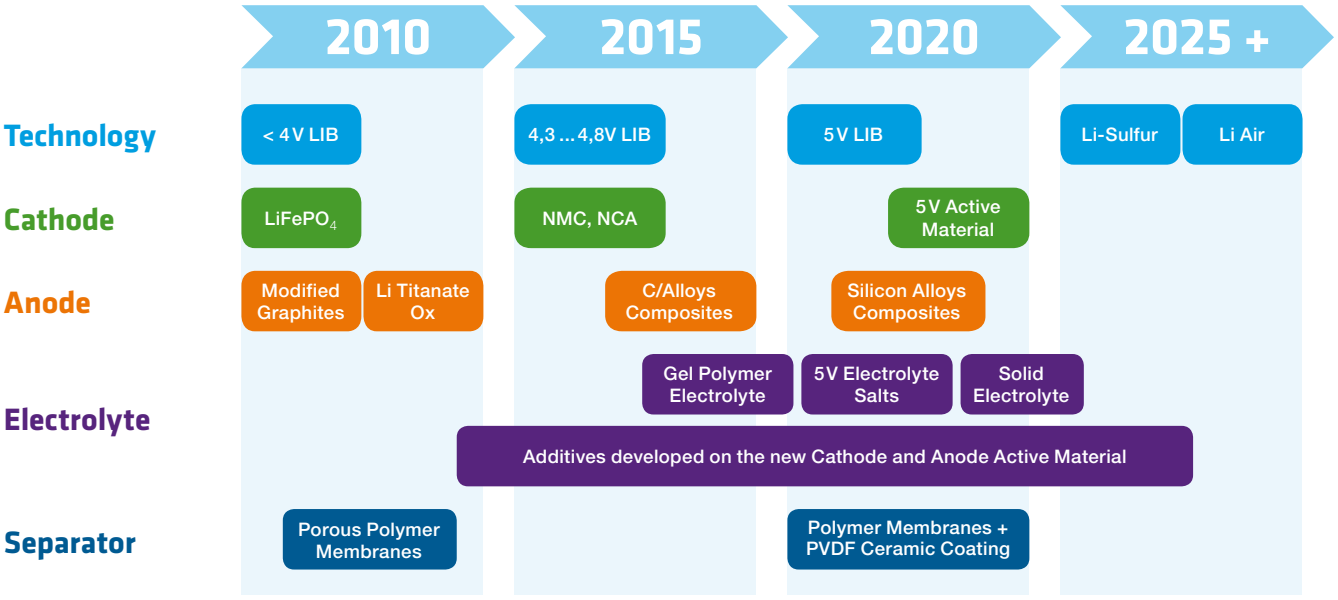
Likewise, substituting traditional vehicles with environmental-friendly electric vehicles will continue to increase as batteries become reliable. Innovative materials and technologies are expected to increase durability up to 15 %, thereby adding 1 year or more to their lifetime.

The dynamic Li-Ion batteries technology roadmap brings lot of challenges that can only be met thanks to a smart fit between new processing technologies and innovative materials.

Solvay's high-performance solutions are helping to address the challenges of Today and Tomorrow in a variety of different ways:



Technology Roadmap



To keep pace with this technology roadmap, Solvay will continue to make significant investments in Materials' Research, Partnerships and Innovation to provide solutions that meet market needs.

Developments needed for binders (at cathode and anode), separator and electrolyte, aligned to the requirements of the future batteries roadmap:

- Cell Voltage
- Electrolyte interaction
- Safety
- Aging
- Cost

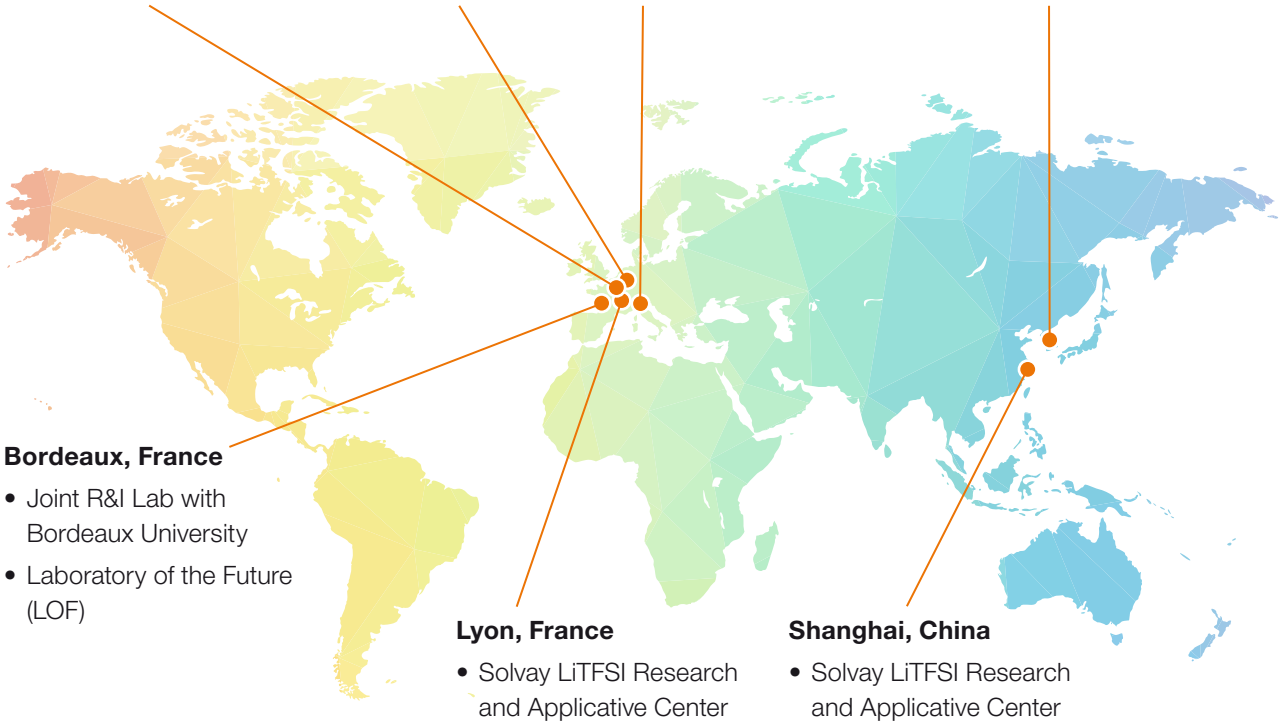
Solvay Battery R&I Centers

Paris, France
- Solvay Group R&I Center

Brussels, Belgium
- Solvay Group R&I Center

Bollate, Italy
- Solvay Specialty Polymers Main R&I Center

Seoul, South Korea
- Solvay Group R&I Center



Bordeaux, France
- Joint R&I Lab with Bordeaux University
- Laboratory of the Future (LOF)

Lyon, France
- Solvay LiTFSI Research and Applicative Center

Shanghai, China
- Solvay LiTFSI Research and Applicative Center

Solef® PVDF Binders and Materials for Separators

Solvay is the only PVDF supplier that uses both emulsion and suspension polymerization technologies, thereby producing a broader PVDF portfolio for anode, cathode and separator applications in Li-Ion batteries.

Binders for Long-Term Stability of the Cathode

A material used in a relatively low concentration, as is the case for binders, can significantly improve battery pack performance while reducing cost.

A reduction of binder concentration that corresponds to a 2 % increase of active material will reduce cost at the cell level which translates to a significant savings on the EV battery pack.

Cost savings are realized by both battery relative capacity and increased lifetime (life cycle and calendar life). Solvay is using its in-depth knowledge of fluoromaterials to increase the stability and lifetime of these polymeric binders to the Li-Ion cells.

Solef® 5130 and Solef® 5120 are third generation binders that combine high adhesion and good processability for increased battery performance.

Thanks to the achievements of Solvay's unique polymerization technology, in the Solef® 5140 grade PVDF Solvay's researchers were able to combine ultra-high molecular weight with the extremely effective chemical modification already demonstrated with Solef® PVDF 5130. This new binder offers the highest cohesion between active material particles and conductive agents, so extending life cycle and raising energy density with more reduced additions to the binder than ever before.

PVDF grades for binder

Solef® 6010	PVDF standard homopolymer	Standard for cathode and anode	1st Generation
Solef® 6020	PVDF homopolymer, medium-high molecular weight	Improved binder for cathode and anode	2nd Generation
Solef® 5120	Modified PVDF, medium-high molecular weight	High adhesion grade for fast dissolution and easy processing	3rd Generation
Solef® 5130	Modified PVDF, high molecular weight	Superior binder for cathode and anode with highest performances	3rd Generation
Solef® 5140	Modified PVDF, ultra-high molecular weight	New grade for higher specific energy electrodes	New Generation

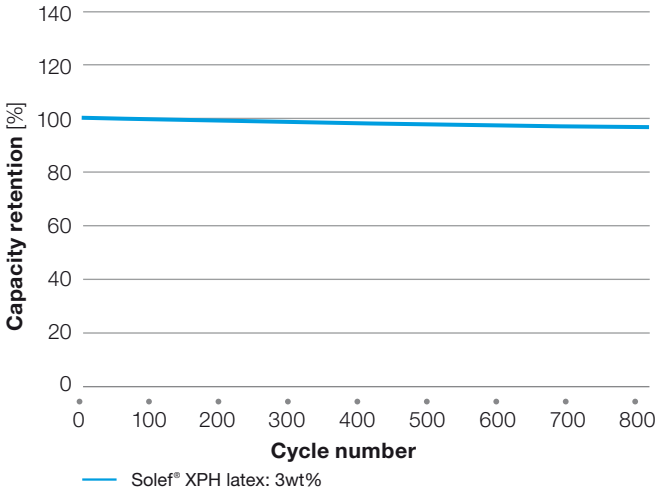
Ensuring electrochemical stability up to 5V cells

The global Li-Ion battery technology roadmap suggests that one of the best ways to increase capacity is to increase the cell voltage. Because PVDF has adequate electrochemical stability for 5V cells, it can add value when used as a reference binder at the cathode.

Water-Based PVDF Binders for Anodes

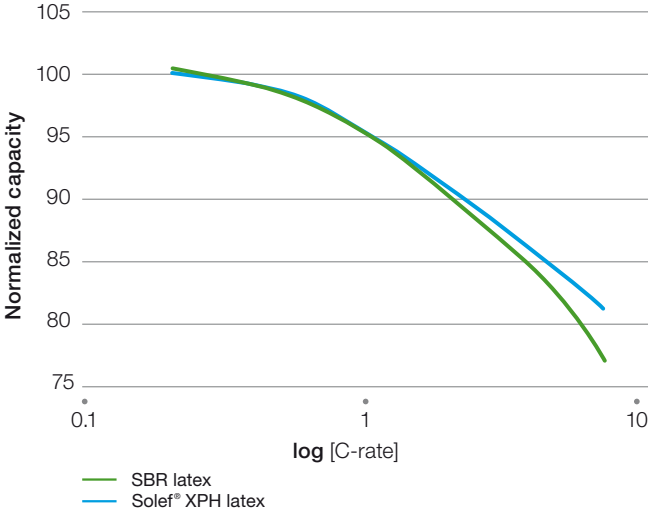
Solvay offers a latex anode binder which use the same functionalized PVDF types as the ones used for the third generation binder at cathode. Solef® PVDF represents the best choice as it increases the lifetime of the binder, thus making it ideal for applications such as electric vehicles where long-lasting batteries are essential. In addition to that, the use of Solef® PVDF as binder for anode can increase the power response of the batteries.

Long cyclability curve



Test: Cycling at 1C at room temperature
Testing system: Full cell (pouch cell 383562)
Anode formulation: 94 % SCMG, 3 % SuperP, 1.2 % Solef® Latex, 1.8 % CMC

Cycle-rate



Test: C-rate at room temperature
Testing system: Full cell (pouch cell 383562)
Anode formulation: 94 % SCMG, 3 % SuperP, 1.2 % Solef® Latex, 1.8 % CMC

PVDF Separator Coating for Safer, Long-Lasting Li-Ion Batteries

In order to extend life cycle with a better lamination effect between electrodes and separator as well as to achieve enhanced wettability and high temperature safety, the separator can be coated with an additional layer of Solef® PVDF.

Owing to the different processing requirements, Solvay can provide two categories of unique PVDF products for both solvent and water-based separator coatings. Various and specific designs of molecules support the user with different coating processes, lamination temperatures, fillers, etc., in order to reach various performance requirements.

PVDF grades for separators

Grade Category	Process	General Characteristics
Solef® PVDF Copolymer	Solvent based processing	• Excellent lamination (dry and/or wet) to electrodes • High adhesion for ceramics particles • Low swelling • Excellent cycling stability
Solef® XPH PVDF Latex	Water based processing	• Solvent free process • Low T drying process • Different grades designed for different lamination conditions • Good lamination force to electrodes • Chemical modification for improved adhesion

Fluorinated Compounds and Derivatives for Li-Ion Batteries' Electrolyte

The use of fluorine has become a key element in the electrolyte of Li-Ion batteries.

Solvay offers F1EC (monofluoroethylene carbonate), F2EC (difluoroethylene carbonate) and TAB (tert-amylbenzene) additives together with a variety of new organic and inorganic fluorinated compounds, to be used in the electrolyte of Li-Ion batteries.

These materials help achieve high voltage and safety of electrolyte systems, which are critical requirements for next-generation batteries.

F1EC

Improve the Safety and Energy Storage of the Battery

Once the Li-Ion battery starts to be charged, F1EC constitutes a Solid Electrolyte Interphase (SEI) coating layer with high thermal stability on the surface of a negative electrode.

Compared to the common Vinylene Carbonate, F1EC creates a more flexible SEI layer with lower resistance value in the battery.

The use of F1EC leads to two main advantages:

- Improved battery safety: it inhibits rapid exothermic reaction when the battery is exposed to high temperature
- Improved energy storage: it doesn't allow lithium loss in the battery caused by the reaction between lithium and electrolyte, and reduce the decomposition of the electrolyte

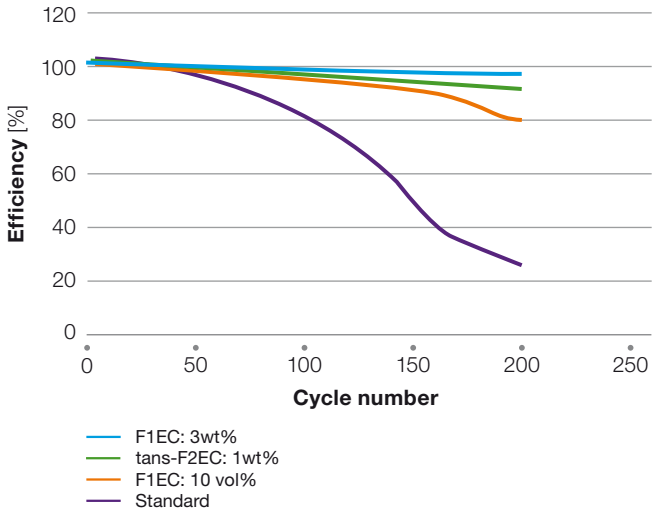
F2EC

Providing a Longer Cycle-Life to the Battery

High purity trans-F2EC and cis-F2EC are effective agents for the coating layers of the negative anode.

Especially when in combination with new anode materials such as Si/C composite or Si-anode, these higher fluorinated ethylene carbonate derivatives lead to higher capacity and a longer cycle life of the battery.

Battery test by F1EC & trans-F2EC graph



Standard electrolyte: 1M $LiPF_6$ EC/DMC 1/2
Pouch cell battery at room temperature, LCO/Graphite, 3.6V

TAB

For Improved Overcharge Protection

TAB has a higher oxidation initiation voltage (vs. Li/Li^+) compared to the operating voltage of the cathode, which helps to prevent the ignition and explosion of the battery in case of overcharge.

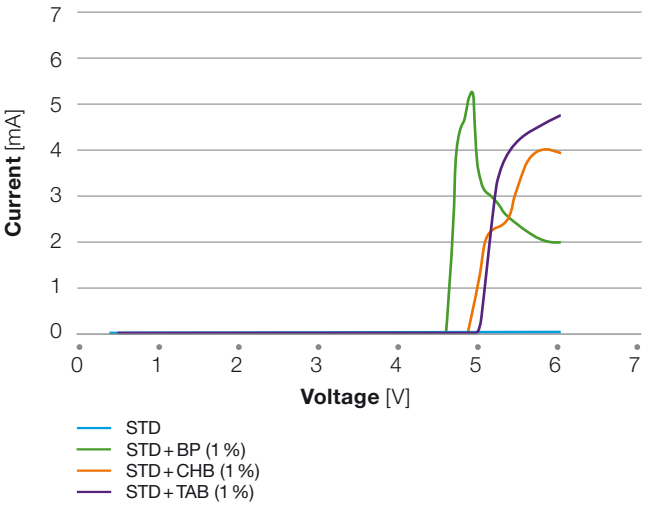
Particularly, through oxidation of TAB, it can directly generate gas and heat, or it can cause the shut-down of a separator by an increase in internal temperature that results from heat generation.

Therefore, indirectly TAB contributes to the improvement in the risk of the battery under overcharge or thermal runway situation.

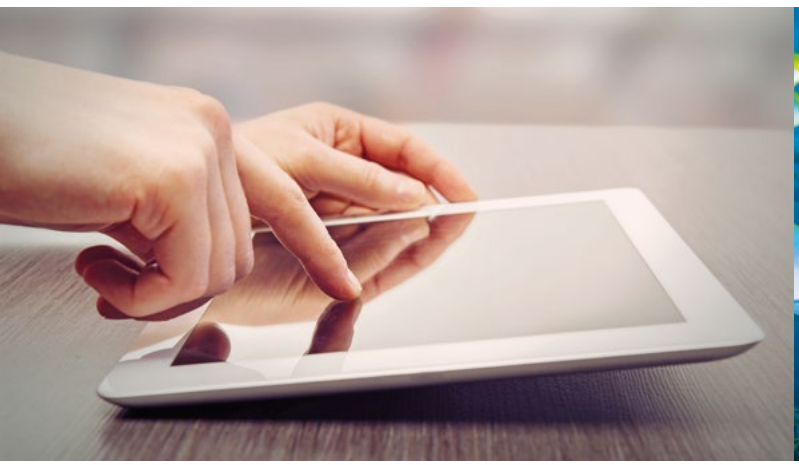
Solvay's TAB has very low moisture level, which is a critical factor in electrolyte performance.

LSV (Linear Sweep Voltammetry) comparison test

STD EL [1.0M $LiPF_6$/EC+DMc (1/2 vol.%)]+[Additive (1wt.%)]



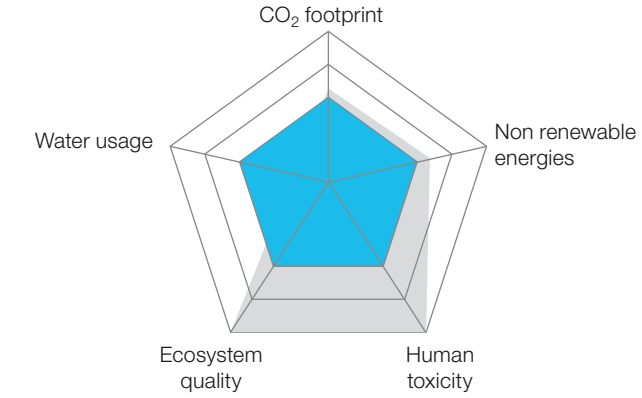
TAB shows a higher oxidation potential than BP (Biphenyl) and CHB (CycloHexyl Benzene), the typical compounds for overcharge protection.



LiTFSI as Main Salt and Additive

Solvay is a global leader in the advanced fluorinated technology (LiTFSI) which is based on a unique, sustainable, integrated and competitive patented production process.

The High Performance and Versatile



LiTFSI Solvay route

LiTFSI fluorination route

Solution for Battery Applications

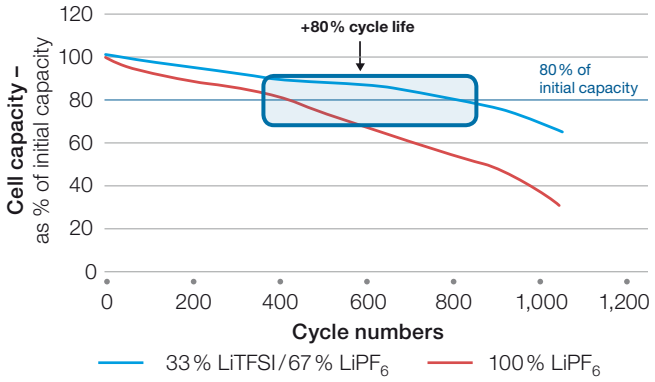
Thanks to its excellent chemical/thermal stability and conductivity, LiTFSI is used as an additive or main lithium salt to improve performance and safety of Li-Ion batteries liquid electrolyte and Lithium Metal Polymer (LMP) batteries, commonly used in computers, notebooks, mobile phones, power tools, e-bikes and electrical vehicles.

With a look to the future, LiTFSI processes the chemical resistance and solubility requested for use in the next-generation Li-Sulfur and Li-Air batteries.

LiTFSI salt additives for Li-Ion battery liquid electrolyte provide:

- Increased battery performance
- High intrinsic safety thanks to chemical and thermal stability
- Reduced battery costs over product lifetime
- Reduced battery filling time
- Aluminium collector passivation against corrosion in LiTFSI + $LiPF_6$ blends for high performance in high voltage and density battery

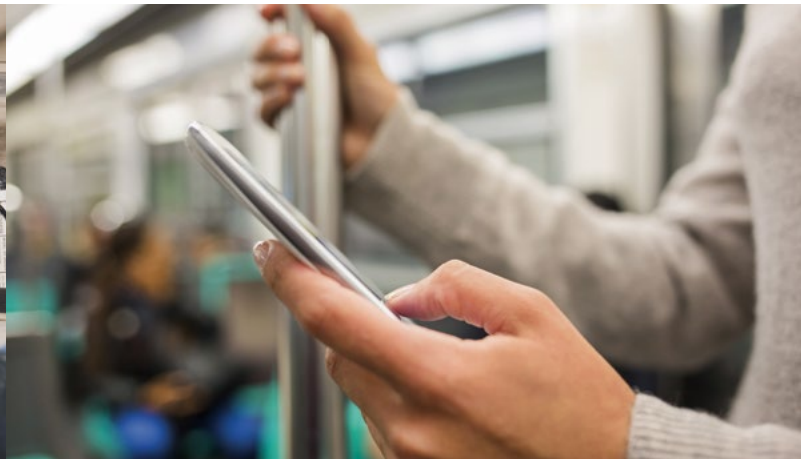
Up to 80 % increased lifetime with LiTFSI



In-house Solvay-CEA tests on NMC batteries (Pouch cells/ Energy) – Cycling 1C at room temperature, 1M salt in EC:DMC

Benefits of LiTFSI as main salt for LMP batteries

- Best conductivity and chemical stability in combination with conductive polymers
- Compatibility with heated cell technologies (80 °C)
- Compatibility with polymer film extrusion

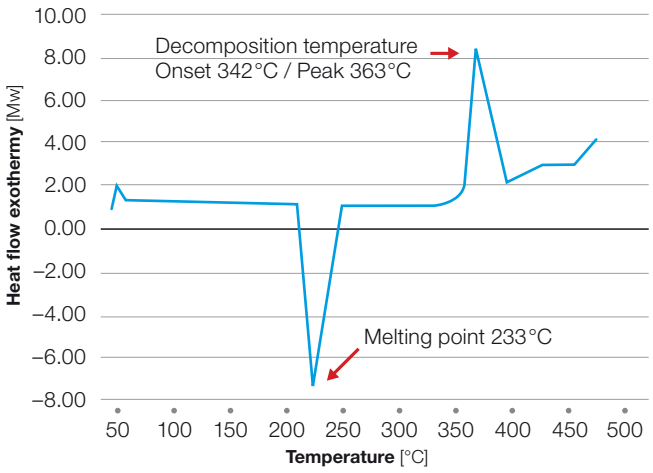


High Intrinsic Safety

LiTFSI ensures high intrinsic safety thanks to its chemical and thermal stability

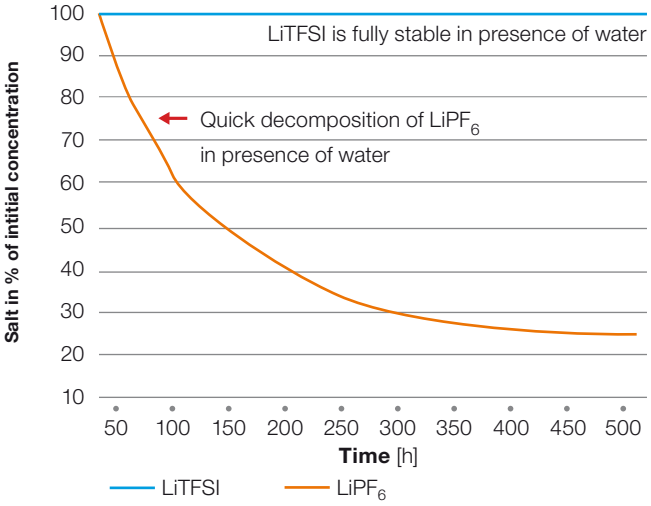
- High stability up to 342 °C
- Soluble, chemically stable without generation of HD gas in presence of water

LiTFSI: Thermal stability up to 342 °C



DSC LiTFSI anhydrous – In house data
Solvay Heating rate 2°C/min

LiTFSI: Chemical stability in water



Hydrolysis LiTFSI compared to $LiPF_6$ – In house data
Solvay 1M in EC:DMC, 20°C, H_2O 1% p/p Heating

A Look Into the Future

Beyond PVDF
Binders and Materials for Separators

Innovative LiB manufacturers have obtained favorable results in using Torlon® PAI as binder or material in separators, thanks to its excellent mechanical and thermal stability up to 260 °C for cells used at high temperatures. Algoflon® PTFE can be used as well in specific binder applications for cells and supercapacitors.

Materials for Safer, More Robust and Lighter Battery Modules/Packs and Cooling Systems

Metallic materials are used in many xEV battery modules and packs. Traditionally they have been selected for their excellent crash and fire resistance, together with their electromagnetic shielding properties. Nonetheless, their weight definitely penalizes a battery's total specific energy.

Specialty polymers provides the best solution to this problem thanks to the offer of intrinsic lightweighting properties combined with an exceptional mix of performance characteristics.

Such Solvay aromatic polymers as Ixef® PARA, Amodel® PPA, KetaSpire® PEEK and other high performers may all be selected among the best candidate materials to replace metal parts for weight reduction as well as to provide electrical insulation that will not compromise the mechanical properties within battery modules and packs.

Solvay's specialty polymers also offer lower initial mold shrink and warpage tolerance with a lower moisture uptake that minimizes dimensional and mechanical property changes. Moreover, according to UL 94 V-0, flame retardancy is adapted to many product grades.

Compared to a battery pack designed completely in aluminum, the partial subsititution of metal parts with specialty polymers and composites can potentially reduce mass in an xEV pack to up to 30 %.

The optimum solution would be that of a design which includes a smart combination of metallic parts, specialty polymers and composites. Solvay currently leverages its longstanding experience to support part-design that use CAE tools (Computer-Aided Engineering).

The solution in pack-cooling system is Galden® PFPE – an inert, dielectric, high-performance heat transfer fluid allowing for more precise pack temperature control thanks to its applicability as a coolant in direct contact with the cells within the module.

Solvay Corporate Research & Innovation

This function brings an additional long-term vision and support projects on advanced technologies.

The focus is on the electrolyte, the key enabling component to answer the major unmet needs of the Li-Ion battery market: energy and power density, safety, cost, cycle life and freedom in form factor.

Based on the main technology trends addressing those market needs, three new business opportunities are targeted for both consumer electronics and automotive segments:

- Gel polymer and solid state electrolyte ingredients and formulations
- Electrolyte additives and solvents for high voltage cathodes and high capacity anodes

Partnerships

The Li-Ion batteries industry is positioned at the crossroads of a large number of competencies. That is why Solvay is convinced that public partnership projects are fundamental activities to combine expertise from different actors and move forward the research on Lithium batteries.

Solvay is involved with a large number of partners in global funded projects which validate the utilization of its new innovative materials in real batteries projects.

Several partnerships are in place, either with such academic research organizations as CEA-Liten, such public governmental partnerships in Japan as Mie Prefecture and in Europe with a large number of FP7 or H2020 projects. The most important European projects in which Solvay is involved were/are AMELIE, ELIBAMA, MAT4BAT and national projects in France and Germany. All these projects demonstrate the importance that new materials have in the research of Li-Ion batteries.

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