



**SOLVAY**

asking more from chemistry®

# High Performance Materials for Batteries

# The Battery Revolution

Electrical and electronic devices, stationary energy storage systems as well as eco-friendly electric transportation have all become integral to our daily lives. A key factor that can either spread or limit their development is what's "under the hood": Li-Ion batteries.

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

The deployment of renewable energy sources poses the challenging task of balancing electricity demand and power supply over time. Here, Li-Ion batteries' performance linked to energy density, safety and cell degradation is now more than ever of utmost importance.

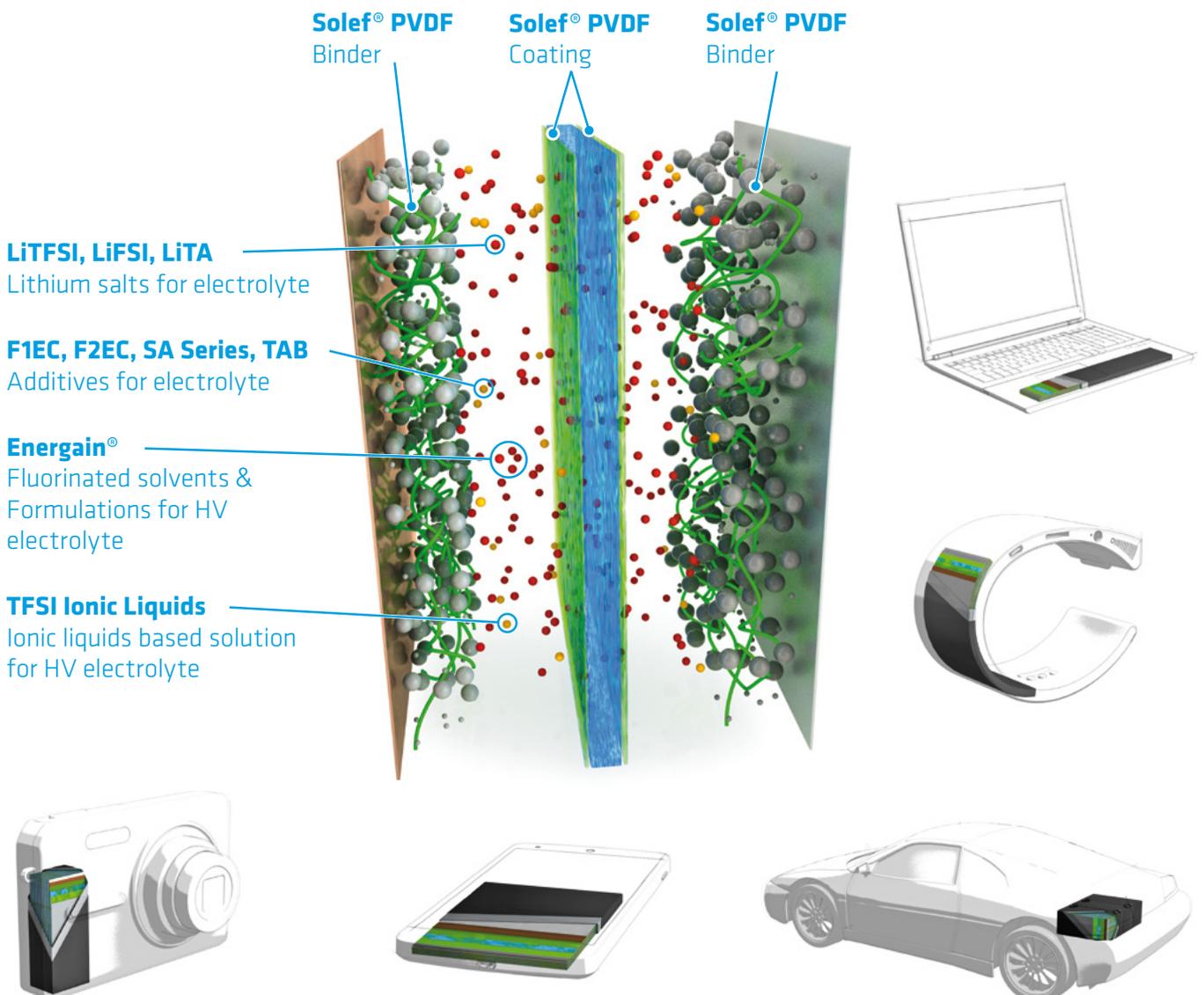
Substituting traditional vehicles with environment-friendly electric vehicles will continue to increase as batteries become more reliable. Innovative materials

and technologies are expected to increase durability, performance and safety during their lifetime.

Likewise, design freedom of battery packs and modulus, safe cooling systems and lightweight structures, represent another key challenge. This is especially true for the electric vehicles Industry that today is calling for increased efficiency, safety, and engine geometries able to fit with new design concepts, as mobility transforms cars as we know them.

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

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



# A Look Into the Future

Solvay leverages its broad array of technologies and materials to expand its offer for next generation batteries, with a strong focus on solid state batteries.

From organic molecules to polymers, from inorganics to composite systems, Solvay works with its partners to develop new solutions for safer, cost effective and more performing batteries, in full alignment with the industry roadmap.

Working with us will allow you to accelerate your development programs not only with binders and electrolyte ingredients but also with novel solutions to enable Li-Metal protection, to reduce corrosion on current collectors, to increase battery power and many others.

## Solvay Battery R&I Centers and Production Sites

Solvay's global presence of production and technical capabilities provides the best support to customers and markets on both a global and local scale, making possible to test materials even in real, large-size cells.



## Partnerships

The Li-Ion batteries industry is positioned at the crossroads of a large number of competencies. That is why Solvay is convinced that partnership projects are fundamental activities to combine expertise from different actors across the value chain and technology readiness levels 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 as well as in specific collaborations with top level academic research organizations and startups all over the world.

# High Performance Binders

## for High Energy Density and Long Cycle Life

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

### Solef® PVDF Binders

Even if binder is used in a relatively low concentration in electrode formulation, it is very important for achieving a high energy density and long cycle life.

With Solvay's proprietary polymerization technology, chemical modification has been introduced to Solef® PVDF. This has dramatically improved adhesion and long-term binding performance of Solef® PVDF. Therefore, higher energy density can be achieved by the reduction of binder content and at the same time a longer battery cycle life can be ensured.

### Solef® 5130 and Solef® 5140 – Best-in-class Binder

Today, the first chemical modified Solef® grade, Solef® 5130, has become the benchmark for cathode binder in the market. Millions of Lithium-ion batteries contain Solef® PVDF binder, from a cell phone to the most advanced full battery electric vehicles.

Recently Solef® 5140 has been commercialized to further enhance the binder's performance, providing highest cohesion and adhesion, extending life cycle and raising energy density with more reduced additions to the binder than ever before.

### Solef® 5120 – Easier Processing

Solef® 5120 has been designed to have a medium-high molecular weight with chemical modification in order to provide excellent adhesion and battery performance with easier processing in terms of PVDF solution and electrode slurry preparation.

### Solef® PVDF binder evolution

Grade Category	Description	General Characteristics
<b>Solef® 6020</b>	PVDF homopolymer, medium-high molecular weight	<ul style="list-style-type: none"> <li>• Standard binder grade</li> <li>• Very good adhesion and battery performance</li> <li>• Easy processing</li> </ul>
<b>Solef® 5120</b>	Modified PVDF, medium-high molecular weight	<ul style="list-style-type: none"> <li>• Proprietary polymerization technology</li> <li>• Excellent adhesion and battery performance</li> <li>• Easy processing</li> </ul>
<b>Solef® 5130</b>	Modified PVDF, high molecular weight	<ul style="list-style-type: none"> <li>• Proprietary polymerization technology</li> <li>• Excellent adhesion and battery performance</li> <li>• Reduced binder content for higher energy density</li> </ul>
<b>Solef® 5140</b>	Modified PVDF, ultra-high molecular weight	<ul style="list-style-type: none"> <li>• Proprietary polymerization technology</li> <li>• Ultra-high adhesion for minimized binder content for higher specific energy electrodes</li> </ul>

### Excellent Compatibility to Ni-rich Cathode Active Material

With the higher demand for energy density, Ni-rich cathode materials are widely used in high-end consumer electronic and electric vehicle batteries, Solef® PVDF provides the excellent anti-gelation performance during the battery cell production process to ensure that each cell delivers the best performance.

### 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.

# Separator Coating

## for Safe & Durable Li-Ion Batteries

In order to extend cycle life with a better interface between electrodes and separator as well as to achieve enhanced wettability and easy assembly, the separator can be coated with an additional layer of Solef® PVDF.

### Solef® PVDF Solvent Based Coating

Solef® PVDF copolymer is normally used in separator coating, because it is easier for copolymer to develop good adhesion to the electrode at a certain lamination condition and it can be dissolved in a wider range of solvents. It can either be formulated with ceramic or used alone to coat the polyolefin porous substrate.

The chemical modification technology has also benefited the separator coating application. Solef® 75130 was developed as the best combination of excellent chemical resistance in electrolyte and outstanding lamination to electrodes.

Owing to the different processing requirements, Solvay can provide two categories of unique PVDF products for both solvent and water-based separator coatings.

### Solef® PVDF Water Based Coating

As the leader among specialty polymer companies in the battery industry, Solvay is the first to commercialize water based PVDF for separator coating to avoid usage of irritant organic solvents for processing and to deliver its commitment of environmental protection in the separator industry.

With distinguished polymer characteristics and a unique production process, Solvay can now deliver various grades of water based PVDF emulsion XPH 800 series to meet different customer requirements.

### Solef® PVDF grades for separators

Grade Category	Description	Coating Process	General Characteristics
<b>Solef® 21510</b>	PVDF copolymer powder	Solvent based	<ul style="list-style-type: none"> <li>• Excellent lamination (dry and/or wet) to electrodes</li> <li>• High adhesion for ceramics particles</li> <li>• Low swelling</li> <li>• Excellent cycling stability</li> </ul>
<b>Solef® 75130</b>	PVDF copolymer powder, chemical modified	Solvent based	<ul style="list-style-type: none"> <li>• Outstanding chemical resistance in electrolyte, even at high temperature</li> <li>• Excellent adhesion between electrode and coated separator</li> <li>• Fast and complete wettability of separator</li> <li>• Longer cycle life</li> </ul>
<b>Solef® XPH 838</b>	PVDF homopolymer latex, chemical modified	Water based	<ul style="list-style-type: none"> <li>• Complete solvent-free coating process</li> <li>• Variety of grades with different properties to meet customer needs</li> </ul>
<b>Solef® XPH 884</b>	PVDF copolymer latex, low HFP content, chemical modified	Water based	<ul style="list-style-type: none"> <li>• Freedom for formulation to adapt to different lamination process (wet/dry)</li> </ul>
<b>Solef® XPH 882</b>	PVDF copolymer latex, medium HFP content, chemical modified	Water based	<ul style="list-style-type: none"> <li>• Excellent chemical resistance and good adhesion between electrode and separators</li> </ul>
<b>Solef® XPH 883</b>	PVDF copolymer latex, high HFP content, chemical modified	Water based	<ul style="list-style-type: none"> <li>• Coating with filler possible to further enhance the battery safety and cycle life</li> </ul>

# 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

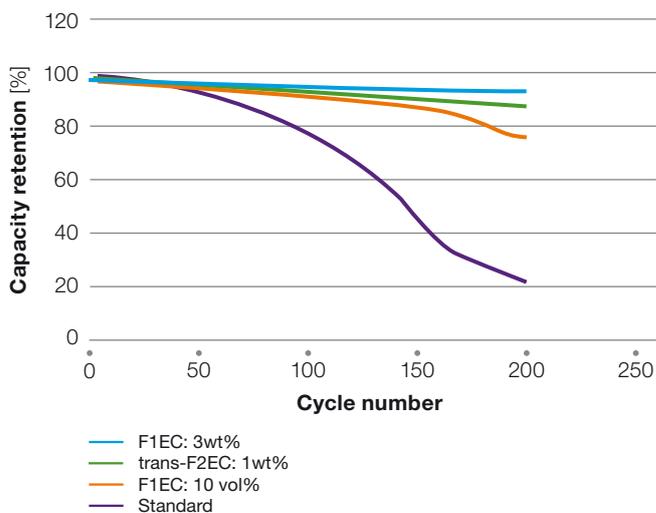
## F2EC

### 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<sub>6</sub> EC/DMC 1/2  
Pouch cell battery at room temperature, LCO/Graphite



# LiFSI Salts

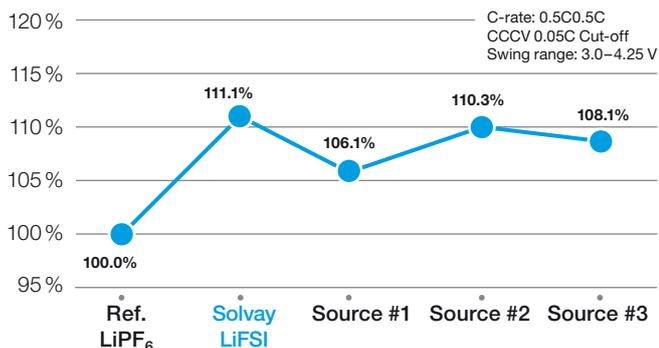
## to Improve Low Temperature Performance

Solvay took advantage of the decades of experience in producing high purity and competitively priced conductive salts (LiTA, LiTFSI) to introduce to the market LiFSI. Our LiFSI, commercialized as a concentrated solution in

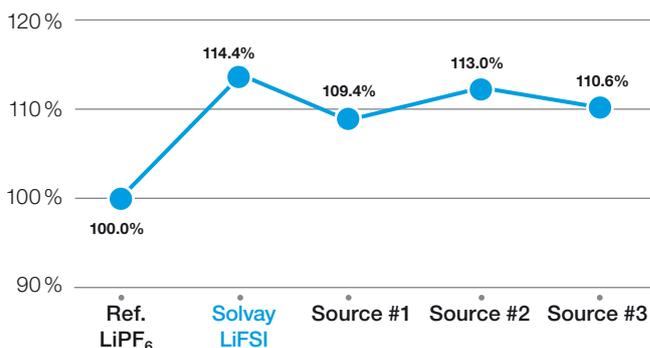
battery grade solvent, combines best in class impurities with a very competitive price, as well as hassle-free handling and transportation due to its liquid form. Solvay owns licenses to manufacture such material worldwide.

### Capacity at -20°C Comparison with 3 Different Sources of LiFSI

#### Charge capacity at -20°C

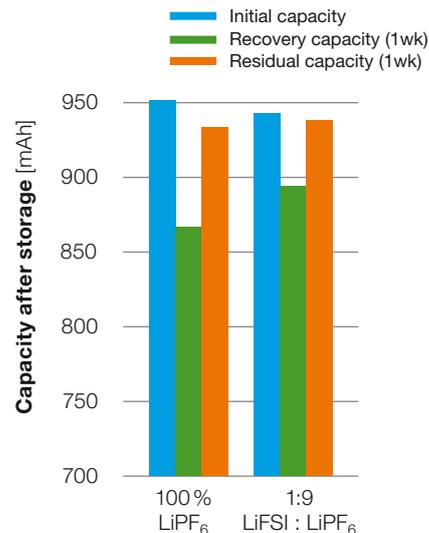
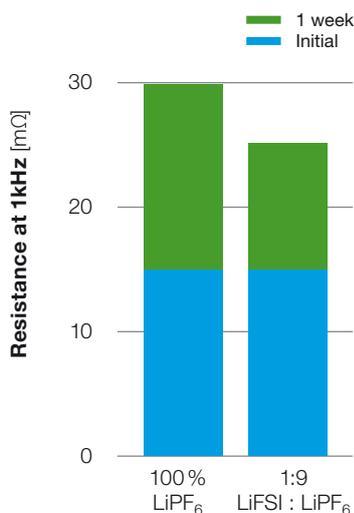
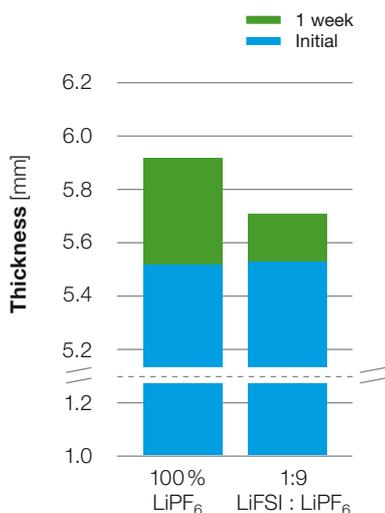


#### Discharge capacity at -20°C

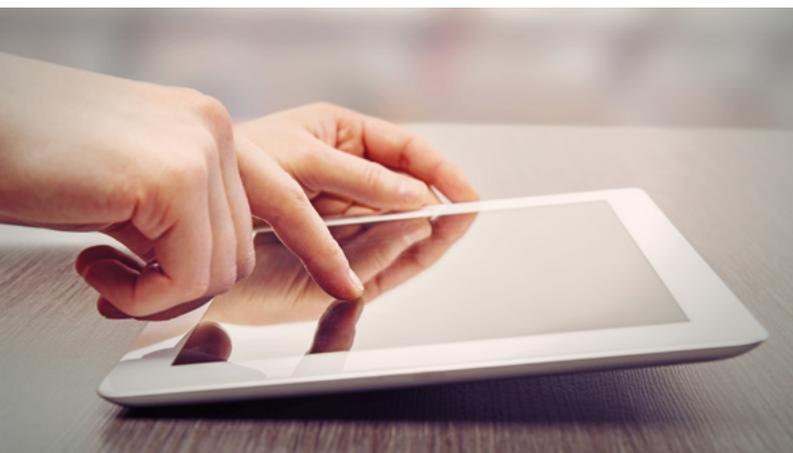


LiFSI improves low temperature performance (LiPF<sub>6</sub> alone). Solvay's LiFSI demonstrates good charge & discharge capacity.

### NMC622/Graphite storage test at 60°C, 1 week at 4.2 V

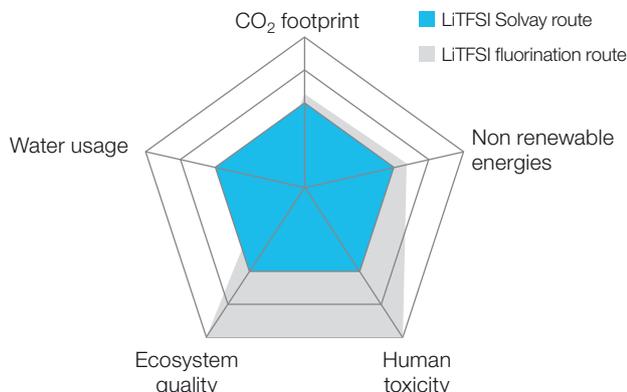


LiFSI improves swelling property, resistance, residual and recovery capacity compared to LiPF<sub>6</sub> alone.



# 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 Solution for Battery Applications

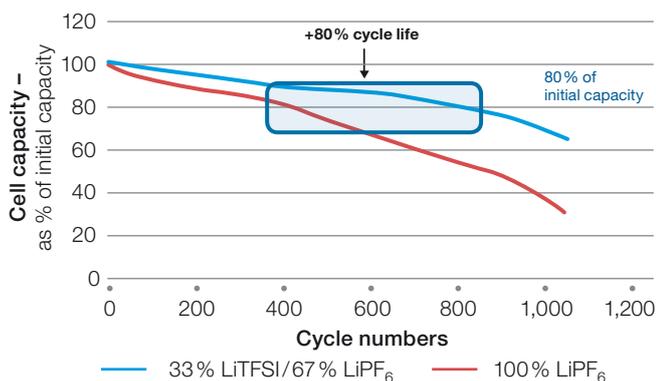
Thanks to its excellent chemical/thermal stability and conductivity, LiTFSI is used as an additive or main lithium salt to improve performance and safety of Li-Ion batteries liquid electrolyte and Lithium Metal Polymer (LMP) batteries, commonly used in computers, notebooks, mobile phones, power tools, 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<sub>6</sub> 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

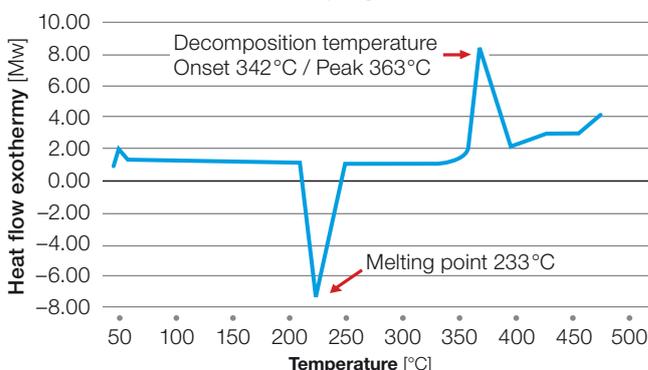
- Best conductivity and chemical stability in combination with conductive polymers
- Compatibility with heated cell technologies (80 °C)
- Compatibility with polymer film extrusion

### High Intrinsic Safety

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

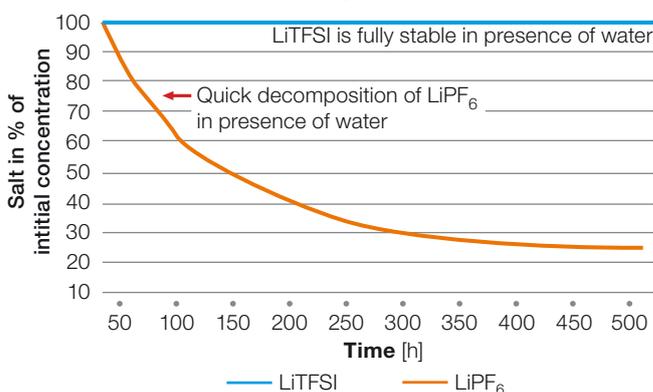
- High stability up to 342 °C
- Soluble, chemically stable without generation of HF in presence of water

### 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<sub>6</sub> – In house data  
Solvay 1M in EC:DMC, 20°C, H<sub>2</sub>O 1% p/p Heating*

### LiTA

LiTA is a high purity conductive salt used in primary batteries and in promising applications for the future such as Lithium Sulfur. Solvay has been a pioneer in the production of Triflic Acid, with over 20 years experience, and can supply Triflic acid (pure and in aqueous solution) and Lithium Triflate (LiTA) both in aqueous solution and powder Extra Dry form.



# Battery Module and Pack Cell Advanced Solutions

## Improved Safety, Performance and Lightweight

### High Performance Cell Gaskets to Guard Battery Safety

#### Hyflon® PFA/MFA®, Tecnoflon® FKM for Cell Gaskets

As the current Li-Ion battery technology evolves, the demand for battery safety in electrified transportation and stationary storage applications is becoming higher and higher. By leveraging Solvay's broad product portfolio and expertise in fluoropolymer technologies, we are now providing you with a broad list of products to ensure operational performance and safety of each cell.

Grade Category	Description	General Characteristics
<b>Hyflon® PFA P450</b>	Perfluoropolymer, medium molecular weight, high melt flow rate resin	<ul style="list-style-type: none"> <li>• UL 95 V-0</li> <li>• Chemical inertness</li> <li>• Inherent flame resistance</li> <li>• Exceptional dielectric property</li> </ul>
<b>Hyflon® MFA® 1041</b>	Perfluoropolymer, very high melt flow rate	<ul style="list-style-type: none"> <li>• Low post cure</li> <li>• Superior mold flow</li> <li>• Lack of mold fouling</li> <li>• Excellent mold release</li> <li>• Good chemical resistance</li> </ul>
<b>Tecnoflon® P959</b>	A medium viscosity, high fluorine (70%) peroxide curable fluoroelastomer	<ul style="list-style-type: none"> <li>• Low post cure</li> <li>• Superior mold flow</li> <li>• Lack of mold fouling</li> <li>• Excellent mold release</li> <li>• Good chemical resistance</li> </ul>

With the usage of above-mentioned products, the cell gasket can achieve:

- Excellent sealing performance during operation
- High CTI
- Electrochemical resistance vs electrolyte
- Good processibility



### Cell Frame and Module End-plate Solutions for Lighter & More Robust Batteries

#### Amodel® PPA, Ryton® PPS, Ixef® PARA

As the current Li-Ion battery technology evolves, the demand for battery pack energy density by volume is becoming higher, metal replacement by high performance specialty polymers provides various solution to reduce the weight of packaging while maintain the mechanical strength.

Solvay provides Amodel® PPA, Ryton® PPS and Ixef® PARA as the best candidate for the structural material within the battery module, such as cell frame or the module end-plate. Additionally, the high performance aromatic material can further provide:

- Component design flexibility (for complex part, few operation, etc.)
- Cost reduction
- Excellent chemical resistance
- Electrical insulation

# Immerse Battery Cooling Agent – Enhanced Safety & Efficiency

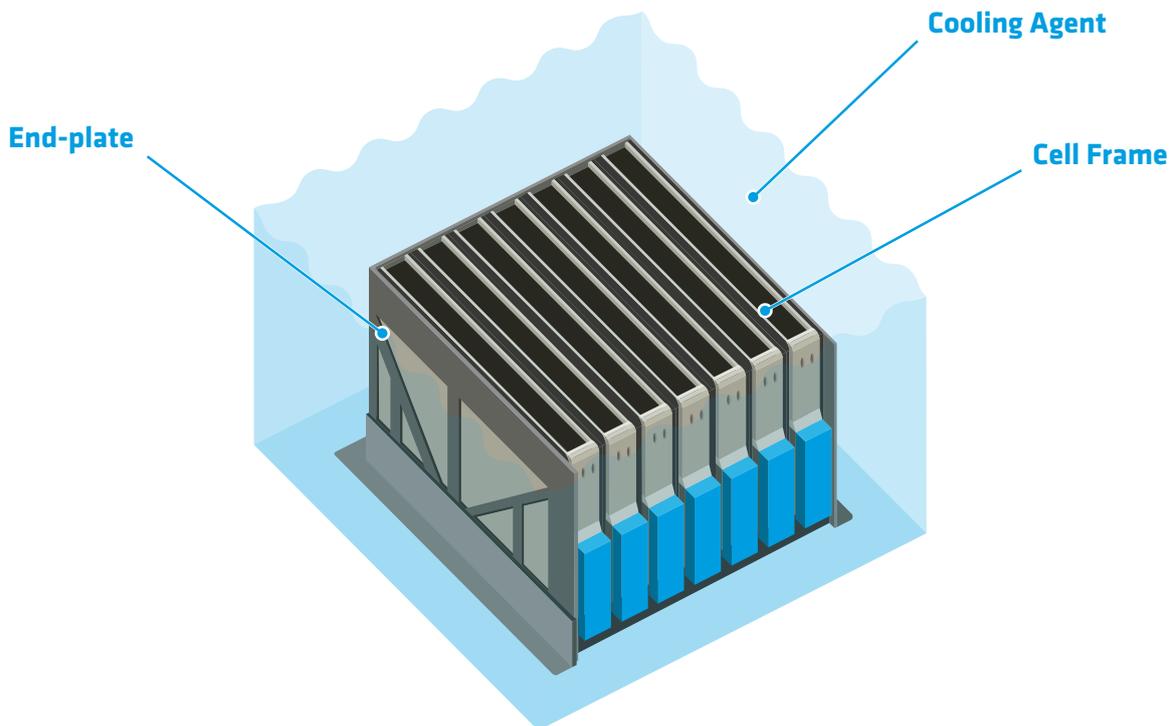
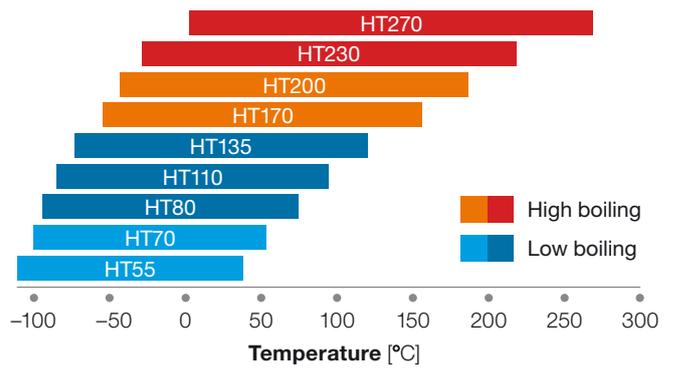
## Galden® PFPE Dielectric Fluid

As the mileage demand of electric vehicles increases to be comparable to conventional ICE vehicles, as well as the fast charging properties to ensure the continuous usage is required, the battery packs are now designed with higher energy density as well power density within the designated space. Safety, and the heat generation especially at fast charging mode brings the challenge to the traditional water-glycol cooling system. An innovative immersed battery cooling system with dielectric liquid fluoropolymers introduces the solution to the challenges faced by the industry.

Galden® PFPE is an excellent fluoropolymer liquid with extremely high dielectric property while good thermal conductivity, maintaining the battery in safe conditions, even at extreme cases (e.g. thermal runaway), providing:

- Excellent electrical insulation for high safety
- Inflammability even at very high temperature
- Good thermal conductivity by immersed cooling, e.g. heat dissipation during fast charging
- Higher volumetric battery energy density possible
- Broad product portfolio supporting an efficient system design flexibility

## Suggested operating temperature range





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