SOLVIONIC

POWERED BY INNOVATION

SOLVIOLYTE®

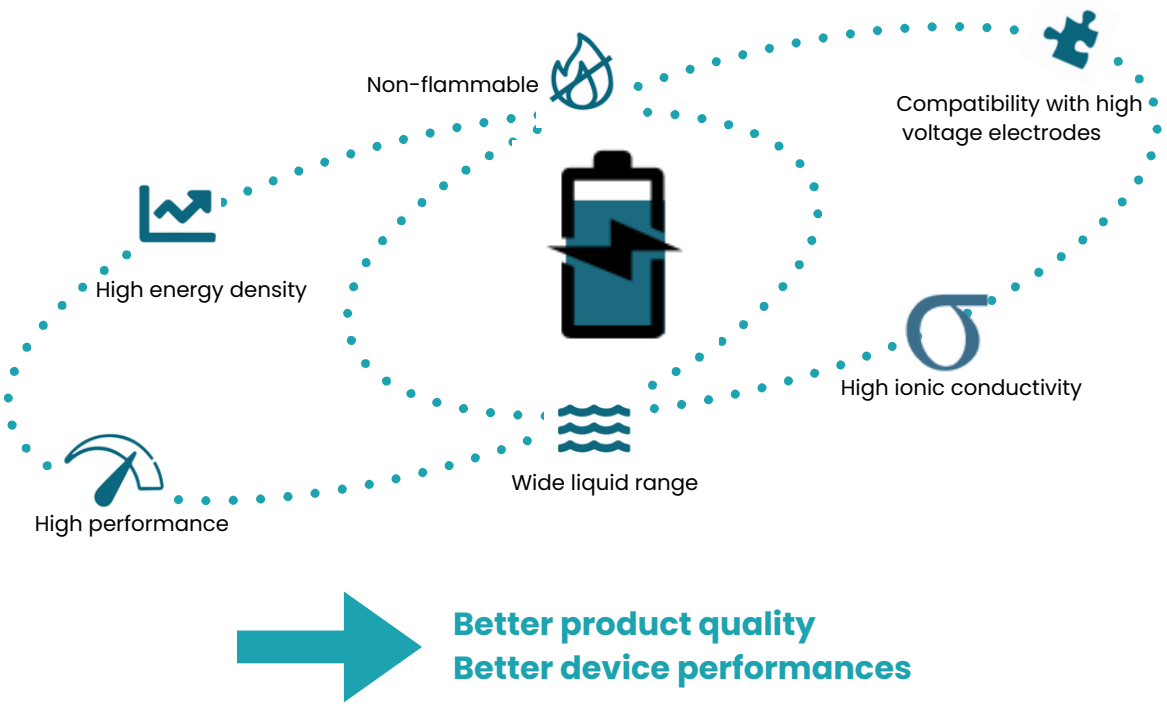
SAFE ELECTROLYTES FOR HIGH VOLTAGE LITHIUM BATTERIES

WHITE PAPER

About us

Solvionic, as a small and medium-sized enterprise (SME), specializes in the chemistry of **Ionic Liquids**. Our primary focus lies in the **electrochemical devices** market, specifically within the domain of **electrochemical energy storage systems**. Our production facilities and strategic approach facilitate a prompt and reliable scale-up of our products, ensuring effective fulfillment of industrial demands.

Beneficial properties of ionic liquid electrolytes



- The electrolyte's **wide stability range** allows devices to operate at significantly **higher voltages** compared to State of the Art (SoA) electrolytes, resulting in enhanced energy density.
- The ionic conductivity and Li^+ transference number are similar to SoA liquid electrolytes, offering good Li^+ transport properties.
- Operate over a **wide temperature range**, spanning from low to high temperatures, making them suitable for a variety of applications.
- **Non-flammable** electrolytes, reducing the risk of battery thermal runaway.

Electrochemical performances

TOPSOE's high-voltage spinel LNMO ($Li_1Ni_{0.5}Mn_{1.5}O_4$) a cutting-edge cathode material that holds immense promise in the field of energy storage. This **Co-free** innovation boasts significantly higher operational potential than State-of the-Art cathodes, providing superior stability even in fully delithiated states.

Combined with our **Solviolyte®** liquid electrolytes, known for their robust electrochemical stability, LNMO demonstrates an outstanding compatibility. In contrast to conventional electrolytes that encounter stability issues at higher voltage levels, Solviolyte® effortlessly sustains LNMO's **5V operational potential**.

A Solviolyte® range has been specifically optimized for the LNMO-Graphite and LNMO-Lithium metal cathode-anode systems.

Full cell LNMO - Graphite at 25°C

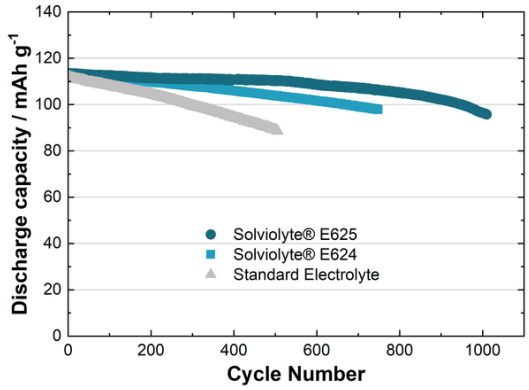


Figure 1 : Cycle life of LNMO-Graphite full cell at 25°C at C/2

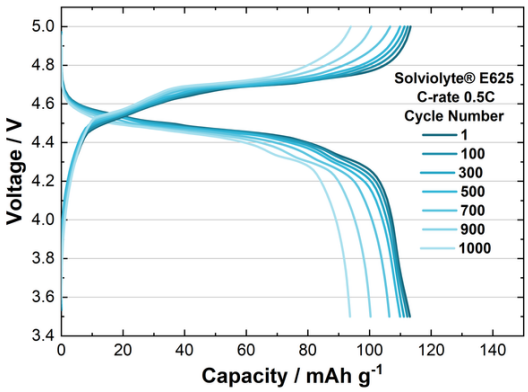


Figure 2 : Discharge and charge voltage during cycling of LNMO-Graphite full cell at 25°C

Figure 1 shows the improved cycling stability of a LNMO-Graphite cell at 25°C with a Solviolyte® **non-flammable electrolyte compared** to the performance of the identical cell employing a standard electrolyte.

Cell details
Coin cell 2032

LNMO (TOPSOE): 1 mAh.cm^{-2} – ∅ = 13 mm
Graphite: 1.25 mAh.cm^{-2} – ∅ = 14 mm
N/P 1.25
Separator : Glass fiber

Testing conditions
Standard Electrolyte: 1M $LiPF_6$ in EC:DEC 1:1(wt%) + 1wt% LiBOB+ 1wt% TMSP

Formation protocol: 2 cycles at C/20 from 3.5V to 5V (CC)
Cycle life test at C/2 between 5-3.5V (CC)
Galvanostatic cycling at 25°C at 100% DOD

Using Solviolyte® E625, a capacity retention of 90% at 0.5C is obtained after **900 cycles**. This is a substantial improvement compared to the standard electrolyte, which achieves the same retention capacity but only after 279 cycles. This highlights a significantly **enhanced performance** with **Solviolyte® E625**.

	Standard Electrolyte	Solviolyte® E624	Solviolyte® E625
Cycle number at 90% capacity retention	279	633	900
Coulombic efficiency at 90 %	99.74%	99.95%	99.80%

Good reversibility of charges/discharges is shown with a **coulombic efficiency of 99.80% after 900 cycles**. Diffusion, insertion and removal of Li^+ ions through the active materials remains efficient upon cycling.

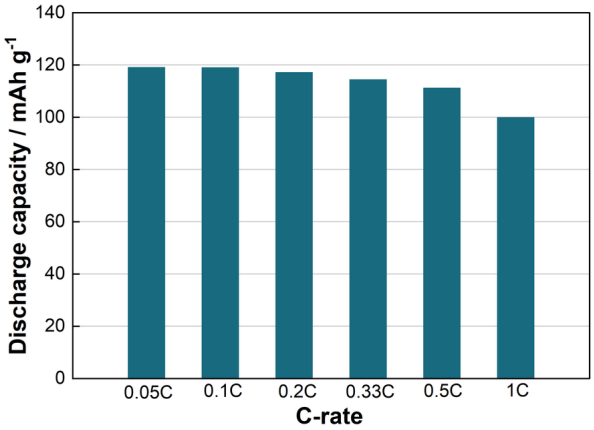


Figure 3 : Rate performance of LNMO-Graphite full cell with Solviolyte® at 25°C

The discharge capacity experiences gradually decreases when the discharge rate (Crate) is increased up to 1C. Nevertheless, this results in a capacity loss of only 15% compared to the slower rate of 0.05C.

Full cell LNMO - Graphite at 45°C

While cycling at 45°C, the capacity loss occurs nearly six times faster than at 25°C, resulting in a capacity retention of 90% after 250 cycles. This accelerated degradation is believed to be due to the well-known phenomenon of increased dissolution of cathode transition metals. Nonetheless, it is noteworthy that the capacity loss with Solviolyte® remains significantly lower compared to the degradation observed with the standard electrolyte.

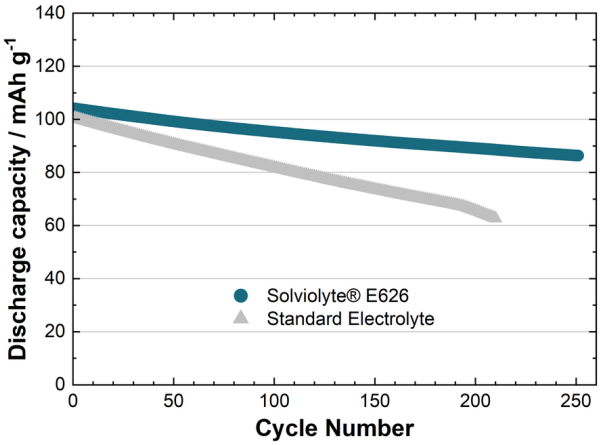


Figure 4: Cycle life of LNMO-Graphite full cell at 45°C at C/2

Cell details
Coin cell 2032

LNMO (TOPSOE): 1 mAh.cm^{-2} – ∅ = 13 mm
Graphite: 1.25 mAh.cm^{-2} – ∅ = 14 mm
N/P 1.25
Separator : Glass fiber

Testing conditions
Standard Electrolyte: 1M $LiPF_6$ in EC:DEC 1:1(wt%) + 1wt% LiBOB+ 1wt% TMSP

Formation protocol: 2 cycles at C/20 from 3.5V to 5V (CC)
Cycle life test at C/2 between 5-3.5V (CC)
Galvanostatic cycling at 25°C at 100% DOD

	Standard Electrolyte	Solviolyte® E626
Cycle number at 90% of rentention capacity	51	147
Coulombic efficiency at 90%	99.39%	99.73%

Full cell LNMO - Li Metal at 25°C

A similar assessment was conducted using lithium metal as the anode to showcase the stabilizing impact of our Solviolyte® electrolytes during charge/discharge cycles.

In Figure 5, both Solviolyte® E623 and E628 electrolytes show **strong performance,** maintaining over 94% of their capacity after 700 cycles at 100% Depth of Discharge (DoD). This indicates the **high stability** of our electrolytes and efficient mobility of Li^+ ions during the cycles.

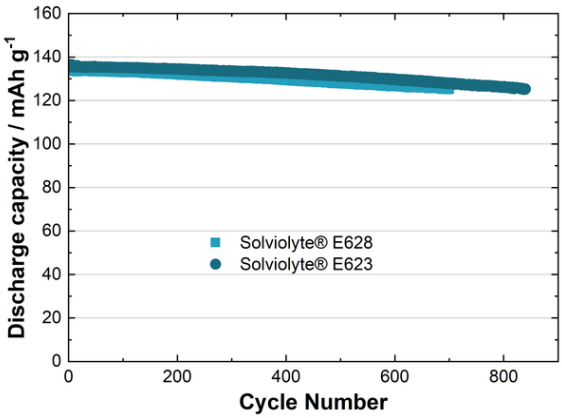


Figure 5: Cycle life of LNMO-Li Metal full cell at 25°C in 0.5C

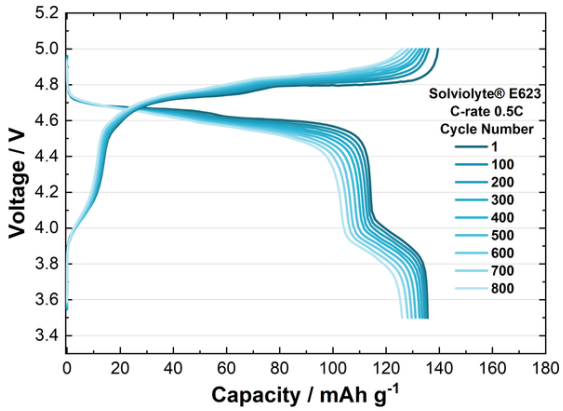


Figure 6: Discharge and charge voltage during cycling of LNMO-Li Metal at 25°C

Cell details

Coin cell 2032

LNMO (TOPSOE): 1mAh.cm^{-2} – ∅ = 13mm
Lithium Metal - ∅ = 14 mm,
thickness: 40 µm

Separator : Glass fiber

Testing conditions

Formation protocol: 2 cycles at C/20 from 3.5V to 5V (CC)
Cycle life test at C/2 between 5-3.5V (CC)
Galvanostatic cycling at 25°C at 100% DOD

By employing Solviolyte® non-flammable electrolytes, the cells still exhibit high retention capacity at C/2 even after 700 cycles and require higher number of charge and discharge cycles to reach end-of-life (retention capacity < 80%). This exceptionnal cycling stability cannot be achieved with any SoA carbonate-based (and flammable) electrolyte.

	Solviolyte® E623	Solviolyte® E628
Retention capacity at 700th cycles	94.50%	93.66%
Coulombic efficiency at 700th cycles	99.92%	99.95%

At lower C rates, the discharge capacity is 15% higher when switching the anode from graphite to Li metal. As the C rates elevate, this improvement is more noticeable.

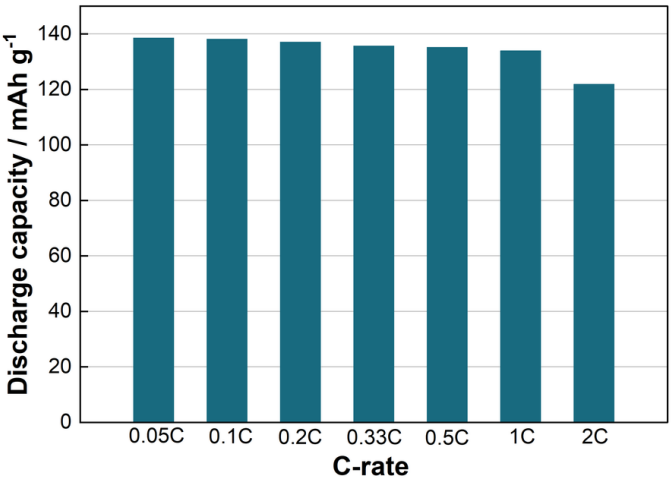


Figure 7: Rate performance of LNMO-LiM cell at 25°C

At 2C, utilizing a Li anode maintains a discharge capacity exceeding 120mAh.g^{-1}, representing only 10% reduction compared to 1C.
In contrast, the discharge capacity loss between 1C and 2C is significantly higher (30%) when employing a graphite anode.

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Solviolyte® multiple benefits

For over a decade, Solvionic has been at the forefront of innovation, providing **highly pure bis(fluorosulfonyl)imide (FSI) ionic liquids** that meet the demands of electrochemical applications. We are delighted to introduce the Solviolyte® range, a collection of ready-to-use electrolyte products, delivering the same exceptional quality under the new signature of our brand.

Offering **high energy density**, Solviolyte® non-flammable electrolytes significantly improve **safety** in cells and battery packs. These electrolytes not only enhance safety but also make operations more secure, convenient, and **cost-effective** throughout the battery's lifespan. This positive effect is seen in different stages, such as **manufacturing**, **protective measures**, **storage** & **transport compliance**, and **end-of-life procedures**.

The combination between TOPSOE's LNMO cathodes and Solviolyte® non-flammable electrolytes represents a **promising synergy for next-generation Li-ion batteries.** This pairing not only brings heightened energy density but also ensures an increased level of safety and an extended lifespan, surpassing the capabilities of current SoA Li-ion technologies.

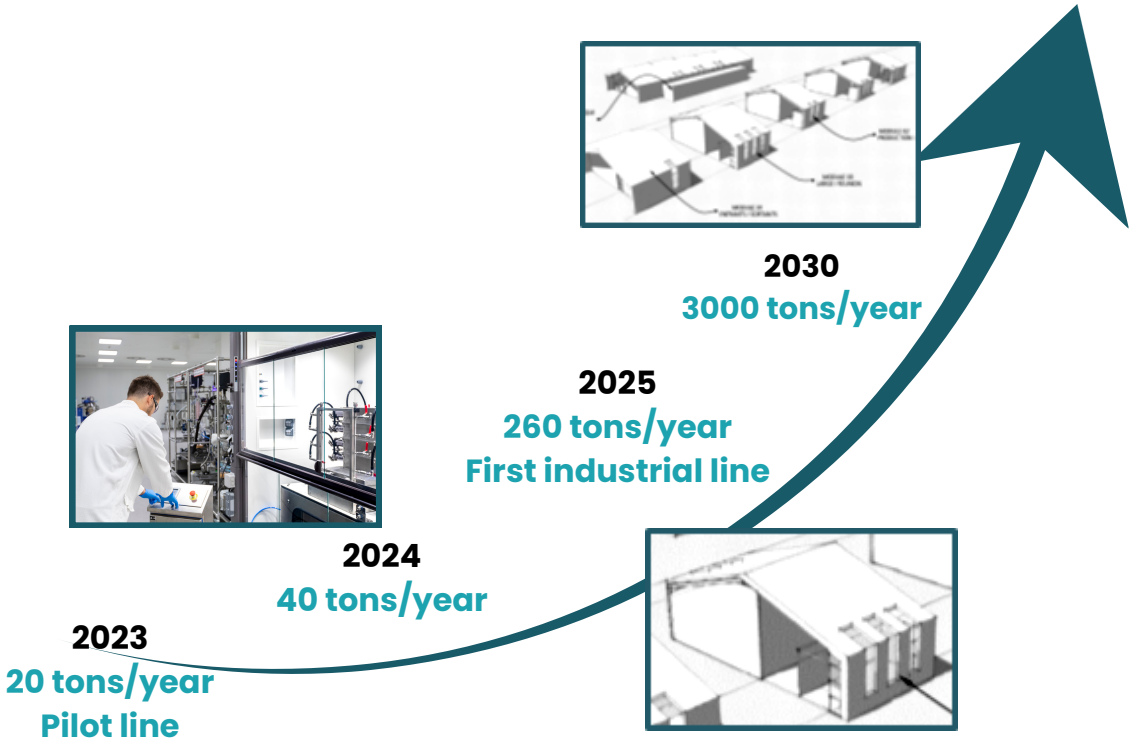
Experience excellence with Solviolyte® for unparalleled electrochemical performance.

Solviolyte®'s references

References	Formulation baselines*
Solviolyte® E623	3M LiFSI in N1113FSI
Solviolyte® E624	3M LiFSI in N1113FSI
Solviolyte® E625	1.5M LiFSI in PYR13FSI
Solviolyte® E626	1M LiFSI in PYR13FSI
Solviolyte® E628	2M LiFSI in N1114FSI

**Additives not mentionned*

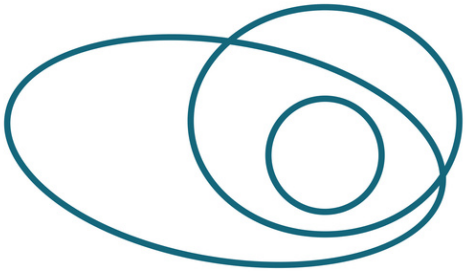
Business and Production Roadmap



Leveraging two decades of proficiency in ionic liquids, Solvionic seamlessly tailored this technology for a groundbreaking application. The integration of **non-flammable**, **non-toxic**, and **eco-friendly electrolytes** enhances the appeal and deployment of energy storage devices, especially in sectors prioritizing **safety** and **reliability**.

This roadmap outlines Solvionic's production capacity over the next six years, aiming to establish an **initial industrial line by 2025** with the capability to produce and market **260 tons per year** of **ionic liquid-based electrolytes**.

Unlock new possibilities for your energy storage materials and devices by pairing them with our Solviolyte® range. Let's explore the exciting benefits together!



SOLVIONIC

11 chemin des Silos
31100 Toulouse – France
Tel. : **+33(0)5 32.26.20.20 –** Email : **sales@solvionic.com**

www.solvionic.com