

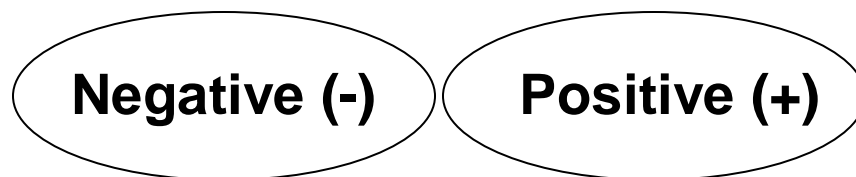


# **Introduction to Ionic Liquids**

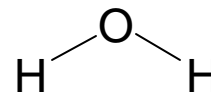
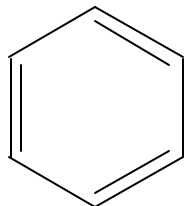
Covalent Associates, Inc.  
10 State Street  
Woburn, Massachusetts, USA 02148  
*[www.covalentassociates.com](http://www.covalentassociates.com)*

# What are Ionic Liquids?

- **Ionic liquids are materials that are composed solely of anions and cations.**



- **Molecular solvents are composed of neutral species such as benzene, methanol, chloroform, water.**





# Covalent's Ionic Liquid Technology

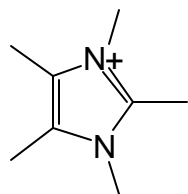
U.S. Patent 5,827,602 (Hydrophobic Ionic Liquids)

U.S. Patent 6,531,241 (Cyclic Stabilized Cations  
Connected by Spacer Groups)

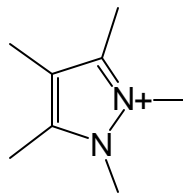
*These two core composition of matter patents and their foreign equivalents protect millions of combinations of heterocyclic delocalized cations and large polyatomic anions in various countries worldwide.*



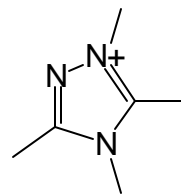
# Covalent's Ionic Liquid Cations



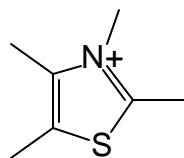
Imidazolium



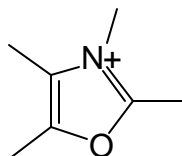
Pyrazolium



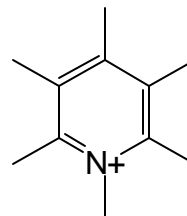
Triazolium



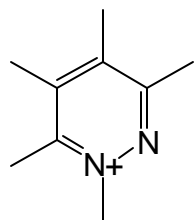
Thiazolium



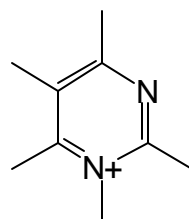
Oxazolium



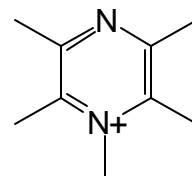
Pyridinium



Pyridazinium



Pyrimidinium



Pyrazinium

# Some of Covalent's Large Ionic Liquid Anions

## Inorganic



## Organic

Sulfonate



Imide



Methide



**R = halide,  $\text{CF}_3$ ,  $\text{C}_2\text{F}_5$ , and other electron withdrawing aryl or alkyl substituents**



# Prior Art Ionic Liquids Based On Small Anions

## Anion



## Problem

hydrophilic—poor thermal stability

hydrophilic—poor thermal stability

hydrolytically unstable--forms HF

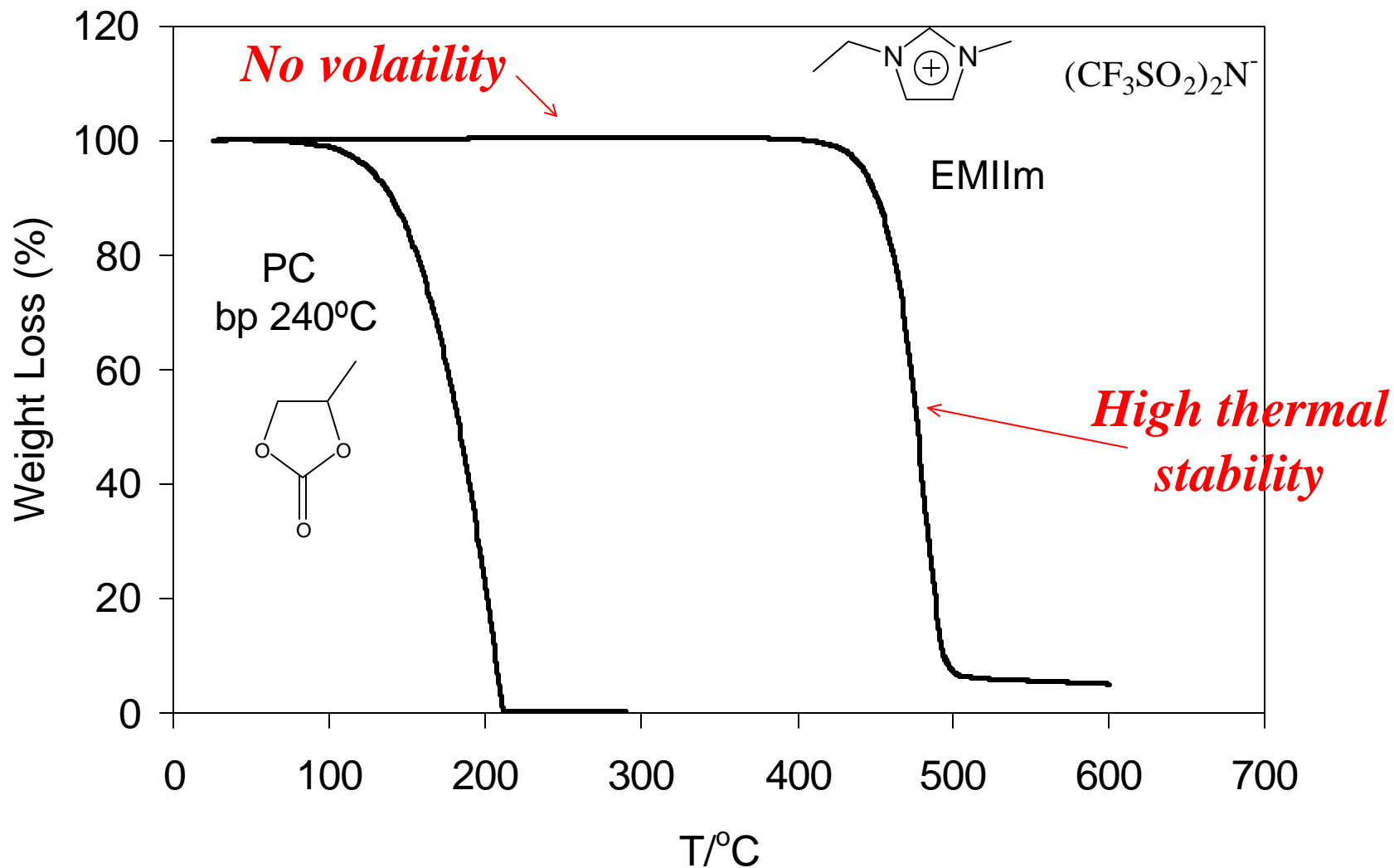
hydrolytically unstable--forms HF



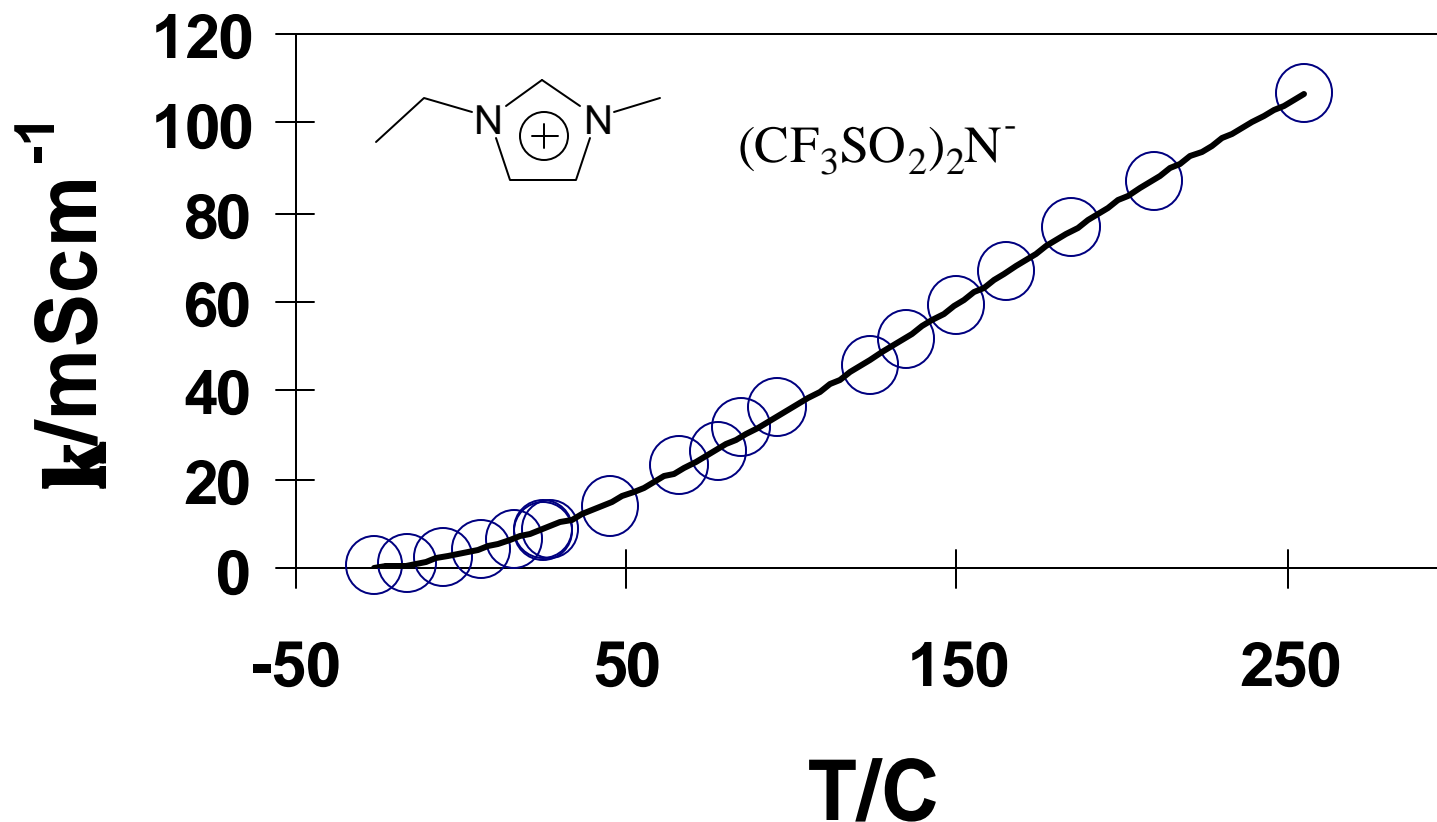
# Advantages of Covalent's Ionic Liquid Electrolyte Technology

- Non-flammable and non-corrosive
- Thermally and hydrolytically stable
- Wide liquid range
- No measurable vapor pressure
- Tunable viscosity and electrochemical window

# Critical Thermal Stability



# Ionic Conductivity of EMIm With Temperature





# **Technological Applications of Ionic Liquids-I**

- **Non-volatile plasticizers**
- **Thermal fluids**
- **Hydraulic fluids**
- **High temp/low temp lubricants**



# Technological Applications of Ionic Liquids-II

- **Electrochemical cells and devices**
  - **Li metal and Li-ion batteries**
  - **double layer capacitors (“Ultracapacitors”)**
  - **electrochromic displays (OLEDs)**
  - **sensors**
  - **fuel cell membranes**



# Ionic Liquids as Novel Media for Various Reactions

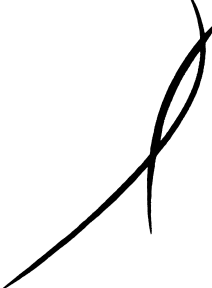
- hydrogenation
- hydroformulation
- epoxidation
- free-radical polymerizations
- Friedel-Crafts acylation and alkylation reactions
- Diels-Alder reaction
- Heck reaction
- Suzuki coupling reaction
- Trist-Tsuji coupling reaction
- HKR reaction



# Ionic Liquids as Advanced Lubricants

<u>Base fluid</u>	<u>Wear scar area, mm<sup>2</sup></u>
IL-111	0.16
IL-112	0.17
IL-113	0.17
Pennzane 2000	2.75

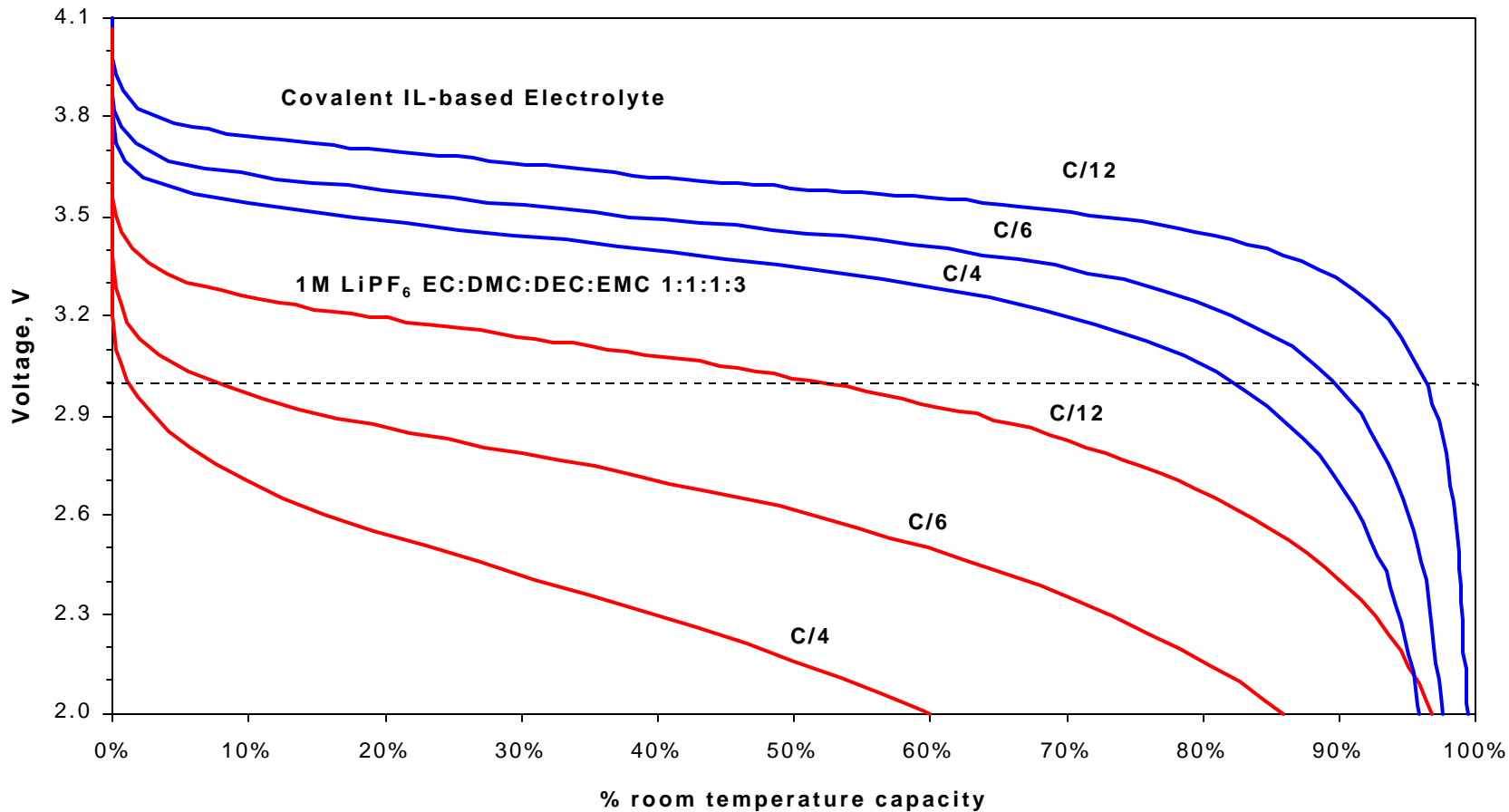
*Non-volatile lubricants with high thermal stabilities and a wide liquid range are required for advanced IC engines and microelectromechanical systems (MEMS).*



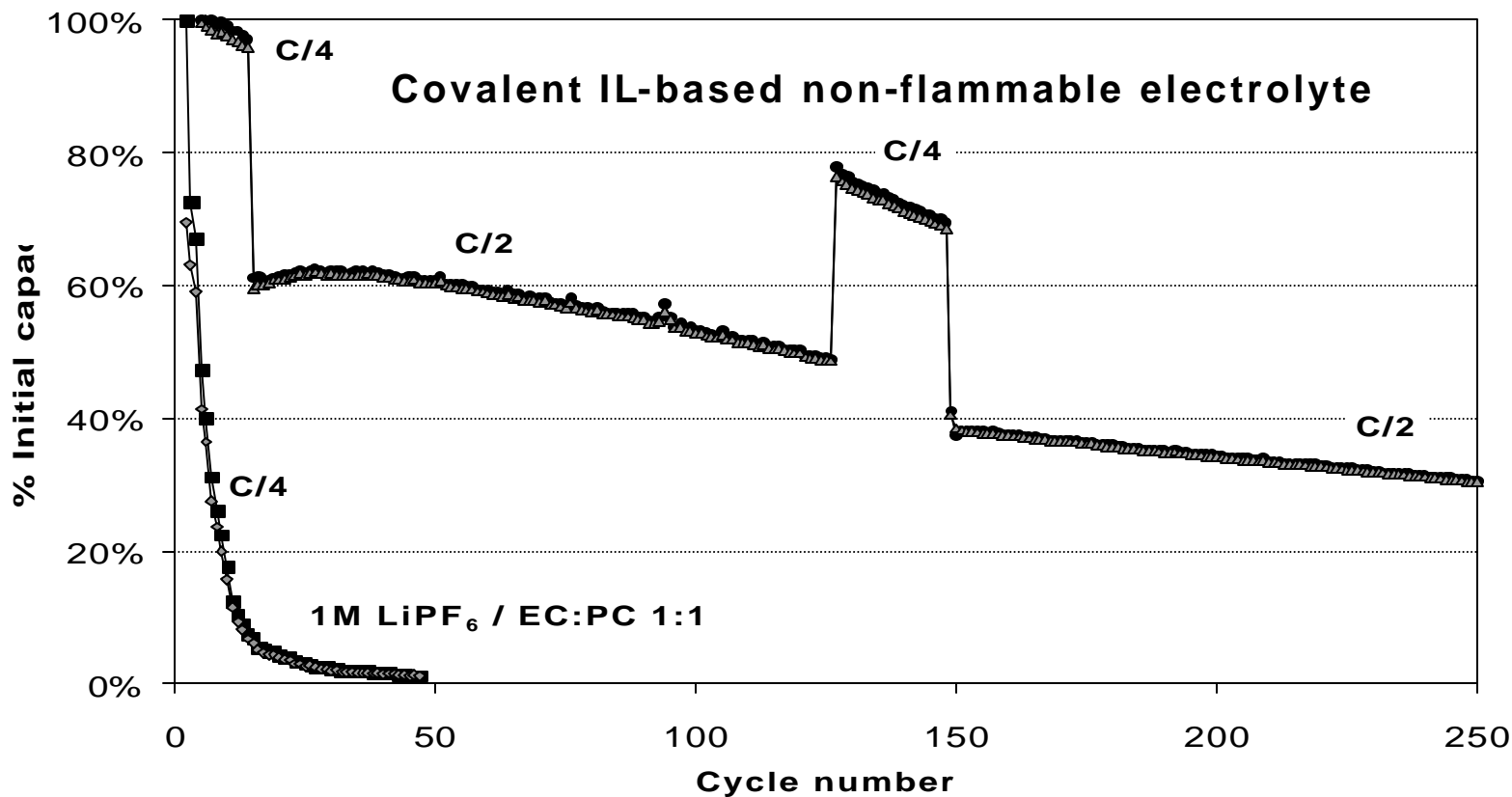
# Properties of Low Temperature Li-ion Battery Electrolytes

<b>Electrolyte</b>	<b>Conductivity, mS/cm, 22°C</b>	<b>Conductivity, mS/cm, and physical appearance at -50°C</b>
<b>1.0M LiPF<sub>6</sub>/EC:EMC (1:3)</b>	<b>8.8</b>	<b>0.56 (<i>glass</i>)</b>
<b>1.0M LiPF<sub>6</sub>/EC:DMC: DEC:EMC (1:1:1:3)</b>	<b>9.0</b>	<b>0.68 (<i>viscous liquid</i>)</b>
<b>Covalent IL-A</b>	<b>21.0</b>	<b>6.35 (<i>liquid</i>)</b>
<b>Covalent IL-B</b>	<b>19.2</b>	<b>6.00 (<i>liquid</i>)</b>
<b>Covalent IL-C</b>	<b>16.7</b>	<b>4.80 (<i>liquid</i>)</b>

# IL Based Electrolyte Performance at $-40^{\circ}\text{C}$ vs. State-of-the-Art Li-Ion Battery Electrolyte

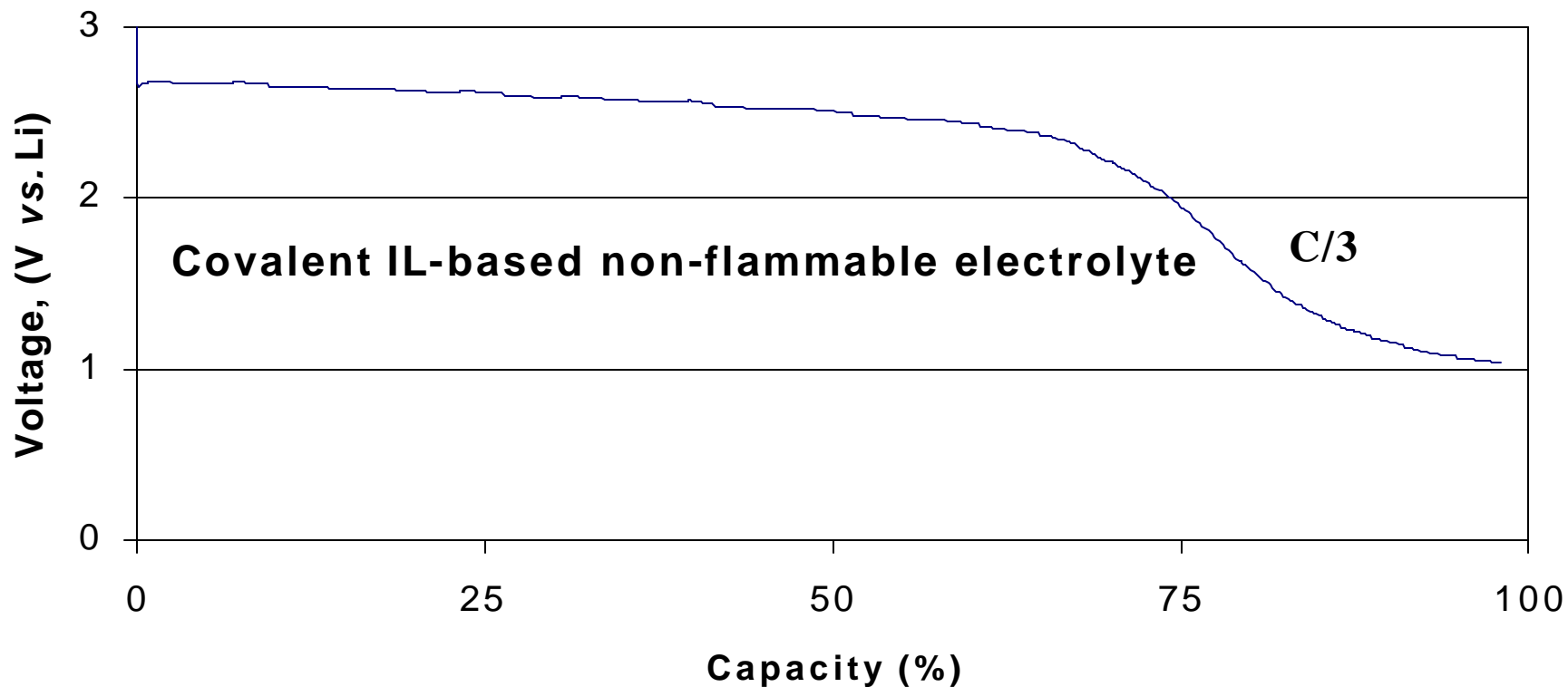


# Li-ion Cycling Performance at 100°C





# Li/CF<sub>x</sub> Discharge Performance at 150°C





# Summary

**Hydrophobic ionic liquids are a promising class of new materials with a bright technological future. These materials are now being used in applications that are enabled by their presence, as well as in applications where device or process performance outweighs their higher cost.**