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# Opportunities for Ionic Liquid Commercialization

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# Definitions of Ionic Liquids

- “Organic salts with melting points under 100C, often below room temperature”
- “Liquids . . . composed entirely of anions and cations in contrast to molecular solvents”
- “Liquids with a wide temperature range and no vapor pressure”
- “. . . liquids containing only ions”
- “Salts that are liquid over a wide temperature range including room temperature”



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# Essential Characteristics of Ionic Liquids

- Composed of ions
- Negligible vapor pressure
- A large liquid range (extends below 100 °C)

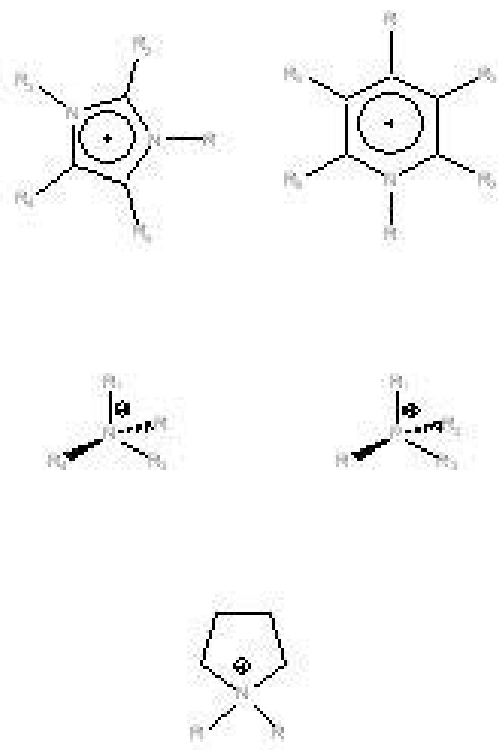


# Properties

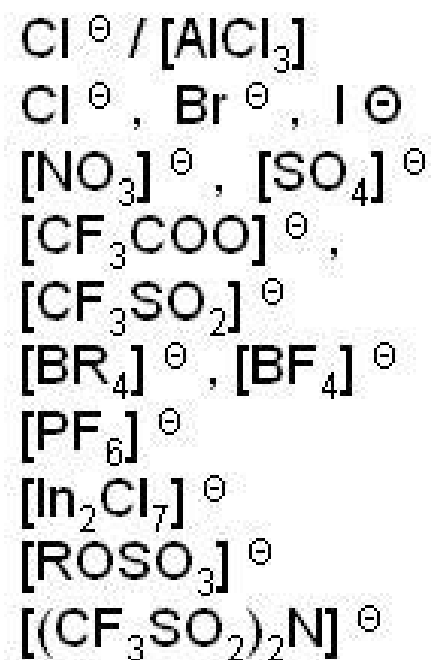
- Ionic in composition with m.p.  $< 100$  °C
- Negligible vapor pressure and miniscule flammability
- Large liquid ranges
- Good thermal stability
- Variable polarity and ionic strength
- Good dissolving power, yet non-coordinating
- High heat capacity
- Large electrochemical working range
- Susceptible to multiple permutations

# Virtually unlimited permutations

## ■ Cations



## ■ Anions



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# Classes of Ionic Liquids

- Water reactive
- Water miscible
- Water immiscible



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# Controlling the Properties of Ionic Liquids

## ■ Cations influence

- Water miscibility
- Toxicology
- Biodegradability
- Viscosity
- Cost

## ■ Anions influence

- Water stability
- Water miscibility
- Viscosity
- Cost



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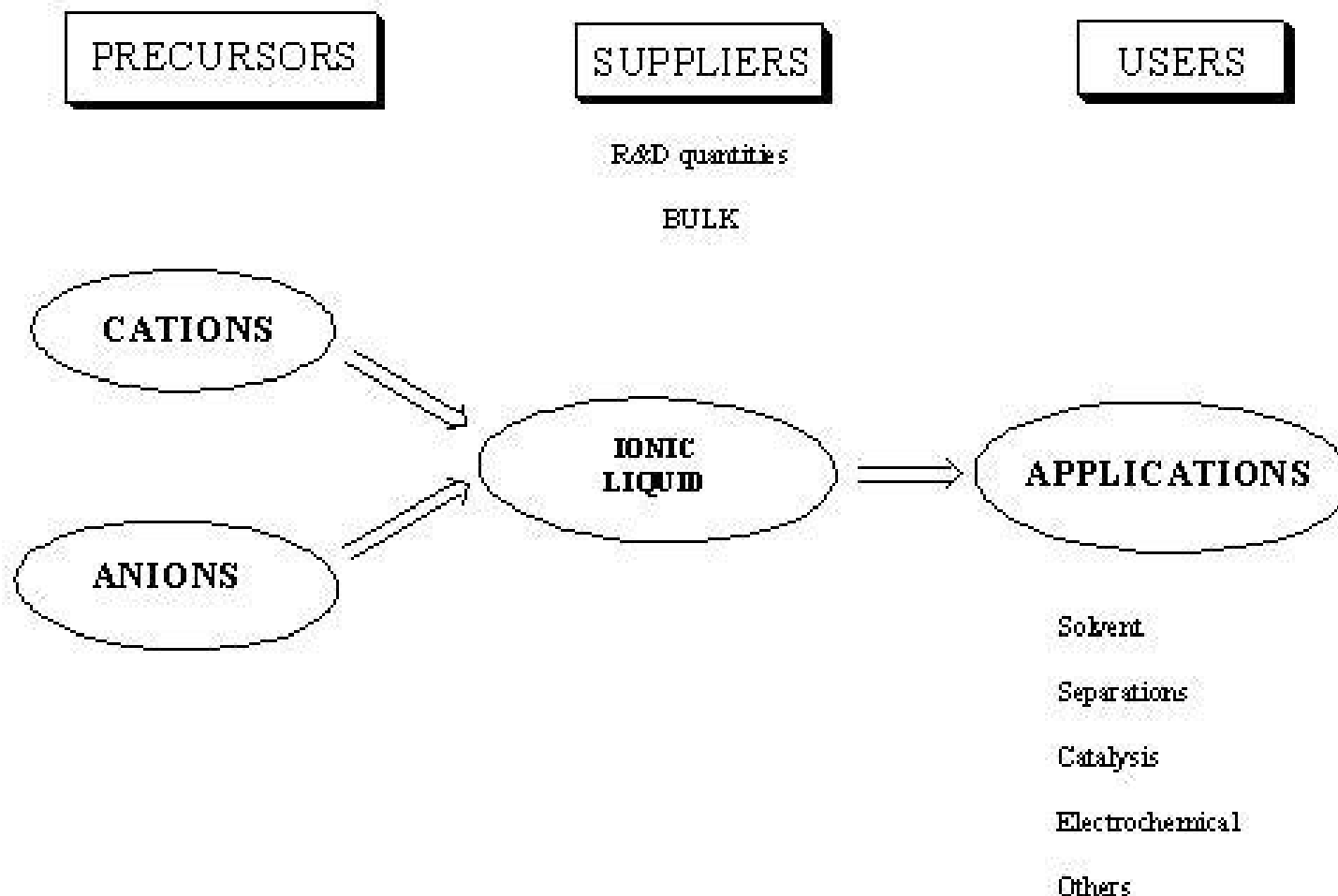
# Industry Trends Favoring the Commercialization of Ionic Liquids

- Regulatory
  - Increasing regulation of volatile organic compounds (VOCs)
  - Waste disposal
- Developments in “clean” or “atom efficient” synthesis
- High Energy Costs
  - Greater efficiency in chemical processing
  - Alternative hydrocarbon sources
  - Electrochemical devices and processes





# The Ionic Liquid Food Chain



# Component Suppliers

## ■ CATION suppliers

- Borregaard
- SACHEM
- BASF
- CYTEC
- Reilly
- GFS
- Cognis
- Nippon Goshei
- Dishman
- numerous others

## ■ ANION suppliers

- E. Merck
- ARC
- DuPont
- others



# Assemblers and Suppliers of Ionic Liquids

## ■ ASSEMBLERS & BULK SUPPLIERS

- E. Merck
- BASF
- CYTEC
- Solvent Innovations
- others

## ■ *R&D quantities*

*Sigma Aldrich*

*ACROS*

*Alfa Aesar*

*Lancaster Synthesis*

*Strem Chemical*

*TCI*

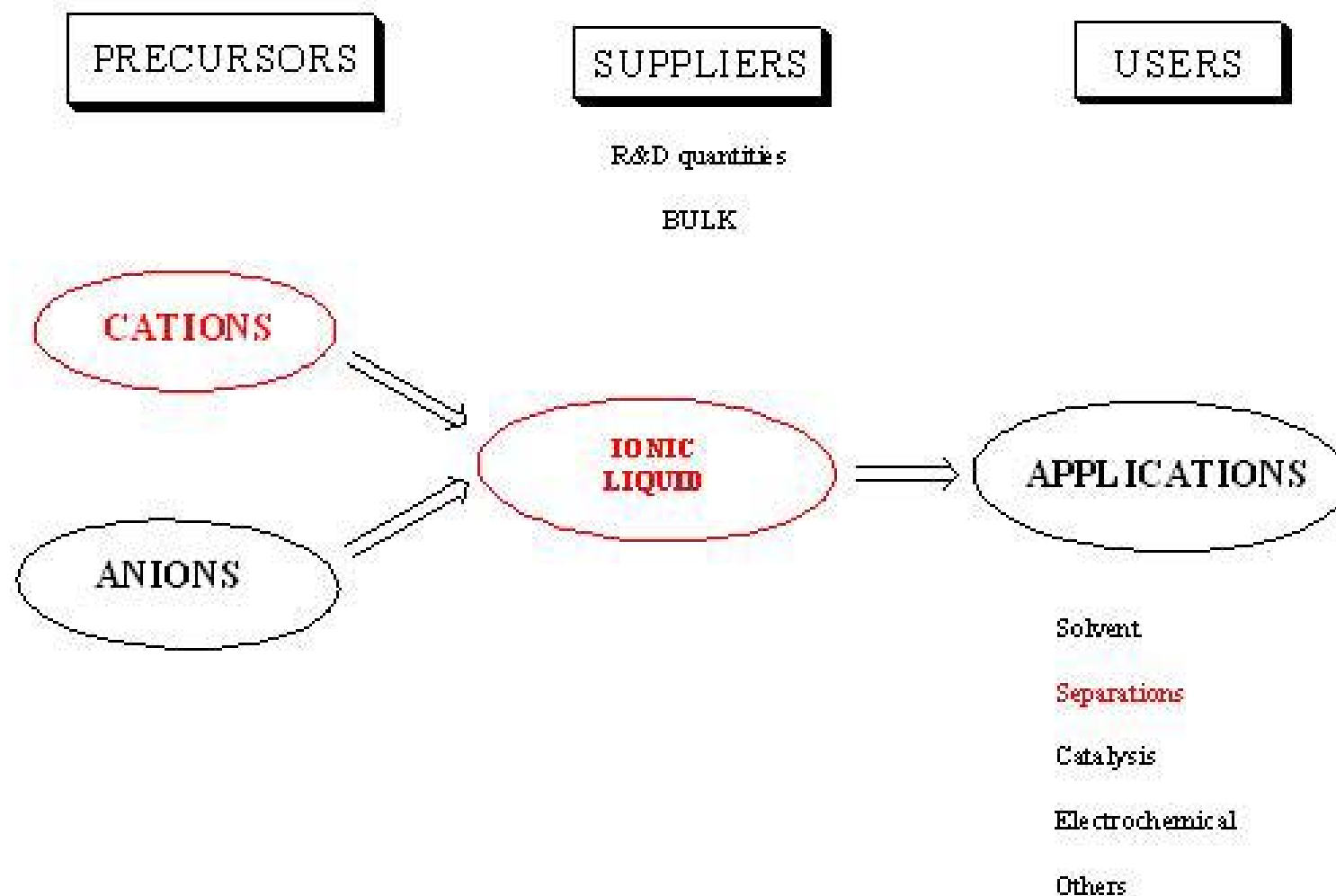
*Covalent Associates*

*Fluka*

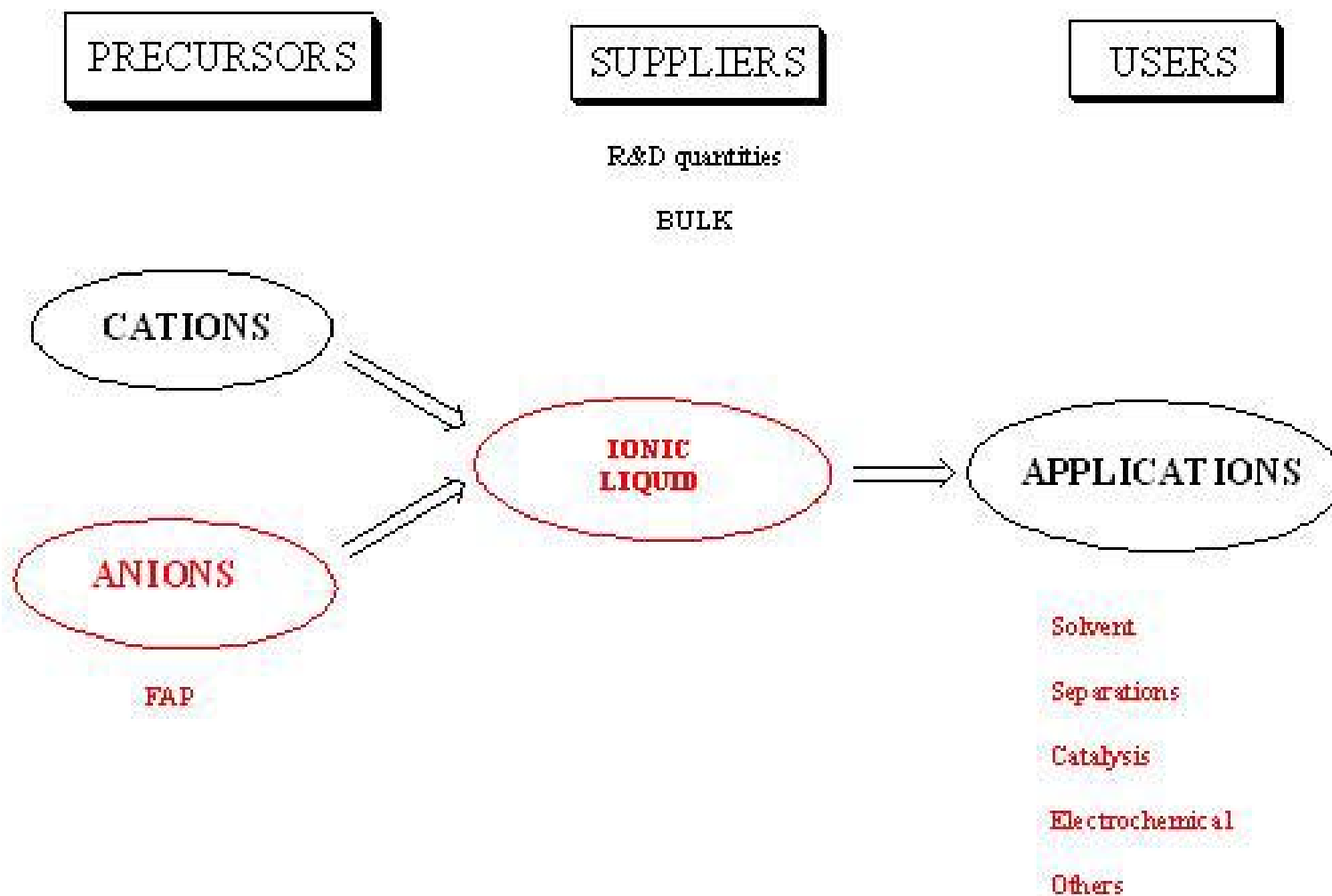
*others*



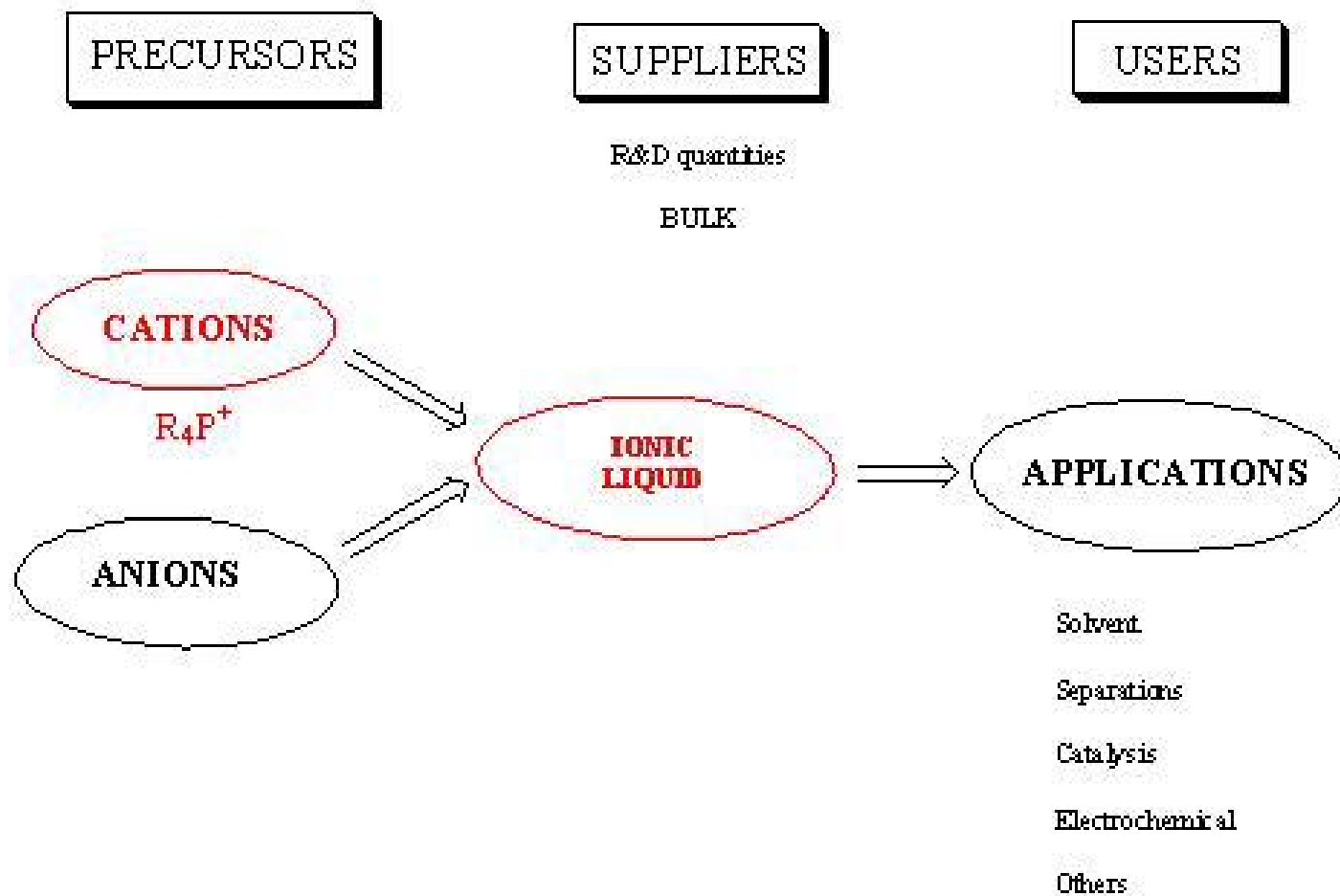
# BASF – The BASIL™ process



# Merck KGAA (EMD)



# CYTEC



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# Selected Application Areas

- ❑ Reaction Media
- ❑ Extractions and Separations
- ❑ Electrochemical
- ❑ Materials



# Selected Applications (1)

- **REACTION MEDIA**

- **Solvents for synthesis**

- **Solvents for catalysis**

- Innocent solvent
    - Ligand precursors
    - Co-catalyst
    - Catalyst





# Selected Applications (2)

- EXTRACTIONS AND SEPARATIONS
  - scCO<sub>2</sub>
  - Purification and storage of gases
  - Gas/liquid and liquid/liquid
  - Natural product extractions

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# Gas Separation

- **Ionic Liquid Based Absorption System**
  - **Remove volatile pollutants from wood dryer & press exhaust**
  - **Weyerhaeuser (Eugene OR) veneer dryer**
    - 3 day mill trial – April 2006
    - Removal of methanol and formaldehyde
    - Achieved MACT standard
  - **Funded by DOE Industrial Technologies Program**
    - University of Oregon
    - Weyerhaeuser, Boise Cascade, Louisiana Pacific

**[www.woodscience.oregonstate.edu](http://www.woodscience.oregonstate.edu)**



# Gas Separation

- Storage and Delivery of Hazardous Gases
  - Move to replace high pressure cylinders for hazardous gases (toxic, flammable, reactive)
  - Inherently safer (sub-atmospheric) systems
  - Air Products – vacuum delivered system for  $\text{PH}_3$  and  $\text{BF}_3$
  - Commercial packages customer qualified

[www.apci.com](http://www.apci.com)



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# Selected Applications (3)

- ELECTROCHEMICAL CELLS & DEVICES
  - Batteries
  - Electroplating
  - Double layer capacitors
  - OLEDs
  - Sensors
  - Fuel cell membranes

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# Electrochemical – Metal Finishing

- Plating solutions based on ionic liquids
  - Air and moisture insensitive
  - Reduction/elimination of chromic acid
  - Avoid corrosive/caustic solutions
  - Recyclable, relatively inexpensive
  
- Scionix Ltd.
  - JV –The University of Leicester and Genacis, Ltd.
  
- Green Chemistry Award from Crystal Faraday

**[www.scionix.co.uk](http://www.scionix.co.uk)**



# Selected Applications (4)

## □ MATERIALS

- Lubricants (high temp/low temp)
- Non volatile plasticizers
- Heat transfer fluids
- Hydraulic fluids
- Coatings
- Cleaning agents



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# Other Issues

- Toxicity and potential environmental impact
- Finding the “needle in the haystack” – 1 in  $10^{18}$
- Registration – TSCA, EINECS
- Process engineering data
- Costs

# Cost

- R&D prices should not impede commercialization
- Building blocks are cheap and available
- Prices will approach those for “specialty solvents”
- Recycle, cost of registration, safety
- Cost will depend on value





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# The Future?

- Two classes of ionic liquids

Bulk (cheap, rugged, “green”)

Boutique (task specific, optimized for performance)

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# Final Thoughts

- Major strides have been made in research, development and commercialization
- Ionic Liquids are at the “tipping point”
- There will be multiple commercial successes in the next few years

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# Acknowledgments

- Intertech / PIRA
- Elizabeth Armour

**[www.ArmourAssociates.com](http://www.ArmourAssociates.com)**

