Challenge for recycling advanced EV batteries
EV Segment addressed very well CO2 emission and low energy consumption,

But........ What about resources???

resources aspect must be integrated to access to a sustainable segment
Sustainability of natural resources

Years of availability

<table>
<thead>
<tr>
<th>Resource</th>
<th>Years of Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tin</td>
<td>17</td>
</tr>
<tr>
<td>Silver</td>
<td>18</td>
</tr>
<tr>
<td>Gold</td>
<td>25</td>
</tr>
<tr>
<td>Zinc</td>
<td>25</td>
</tr>
<tr>
<td>Lead</td>
<td>28</td>
</tr>
<tr>
<td>Sulphur</td>
<td>35</td>
</tr>
<tr>
<td>Copper</td>
<td>40</td>
</tr>
<tr>
<td>Manganese</td>
<td>43</td>
</tr>
<tr>
<td>Aluminum</td>
<td>220</td>
</tr>
<tr>
<td>Potassium</td>
<td>310</td>
</tr>
<tr>
<td>Iron</td>
<td>440</td>
</tr>
</tbody>
</table>

Sources: USGS 2010, OMPM 2011
The “Raw Materials Initiative”: a new challenge for the EU recycling industry: DG Industry and enterprise Madrid Report July 2010
The solution is around us!

For old mine

... To URBAN MINE(**)

Registered by Recupyl in 2004  N° 79083906  Int. TM Register
Sustainability: the choice

To produce 1 Ton of Lithium We need

250 T of ore (spodumène)

Or

750 T of brines

28 T of Li ion batteries from mobiles/laptops

Or 256 batteries for EV
HISTORY OF RECUPYL
IN RECYCLING OF LITHIUM BATTERIES
Up to 10 years experience

• 2002 : First study on HydroQuebec Lithium metal/polymers Batteries (now out of NDA)

• 2003 : Continuation of study on new chemistry

• 2004 : Pilot project under European Support 5th FP VALIBT

• 2005 : World Patent granted including LiFePO4(claims 6)

• 2006 : Pre-industrial facility in France 50 T/y

• 2007 : 1\textsuperscript{nd} industrial facility in Singapore 450 T/y

• 2009 : 2\textsuperscript{nd} industrial facility in England 450 T/y

• 2010 : 3\textsuperscript{nd} industrial lines in USA (Michigan) 450 T/y

• 2011-2012 : Pilot plant for EV Batteries (patent pending) supported by 2 EU projects

• 2013 : Industrial Demonstration facility for EV batteries (600T/y) supported by French Program of “Investment for the Future”
Value chain and second life of batteries

Battery (pack) end-of-life

Test Evaluation

Partial active tests of cells

Fully discharged

Active cells

Second life (stationary, solar etc...)

Non active cells

Recycling
THE EV BATTERY CHAIN

Battery production concept for construction Li-ion for EV

Materials processing cell module pack

RECUPYL concept for « de-construction » Li-ion battery for EV

Pack module cell processing materials
Dismantling of packs/ modules is mandatory for resource recovery?

To dismantle, Eco-conception is the real challenge for:

- 1 safety of operator during dismantling
- 2 selective access to materials
- 3 allows a second life for cells
Even the non active parts contributes to the sustainability of the end-of-life

Average mass balance of NMC battery

Dismantling is mandatory for resource recovery
Why to dismantle (1)?
Safety aspect

Pack 120 à 400 V, > 30 kWh
Module 46 - 60 V, 1 -3 kWh
Cell 3.7 V, 0.1 kWh
Why to dismantle (2)?
Access to expensive specific spare parts and second life of cells
But strong need of eco-conception « *designed for recycling* » pack N°1
pack N°2
pack N°3

Gants 5000 V
Example of pack « designed for recycling »
pack N°4

Pack

BMS

Packaging

Cells

Steel and non ferrous
Flows sheet of the non thermal developed process

- Electrical control, discharge
  And dismantling

- Dry & room temperature
  Physical treatment

- Chemical treatment
Dry & Room Temperature
Physical Treatment
Equipement for Treatment of complete prototype cells

Safe and efficient mechanical treatment
Safe and Clean mechanical treatment: First step

Recovered product after shredding:
Mix of (NMC) oxides and Cu/Al/polymers
Temperature control during mechanical treatment
Mechanical treatment
Step 2

Mix of plastics

metals

Mix Cathode, anode
Treatment of scrap production
Industrial pilot treatment on mechanical steps

Recupyl France site
Recycling of modules and cells

Recupyl Michigan site
(recycling of EV packs and cells)
Separator and solvent recovery
Separator form Battery EV1, 2 and 3

Polyoléfine Type PP-PE

C-H

alcenes
Solvent separation strategy
Recovery first solvent online

Recovery point
Chemical Treatment
NMC Chemistry
NMC: Strategy of treatment

<table>
<thead>
<tr>
<th></th>
<th>Co</th>
<th>Ni</th>
<th>Li</th>
<th>Mn</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2,1%</td>
<td>8,6%</td>
<td>2,4%</td>
<td>23,2%</td>
</tr>
</tbody>
</table>

Route 2
Selective leaching
Ni+Co

Recovery of Cobalt
Or mixed Ni-Co compound

Route 1
Total leaching

Mn Carbon cake for Métallurgy or Mn chemistry

Carbon and binders

Solution for NMC precursors
Cobalt recovery from NMC

Using a strong difference of kinetic oxidation between Co and Ni§Mn

Seed → oxidation → Co(III) oxide
Selective recovery of Cobalt (III) Oxide

<table>
<thead>
<tr>
<th>élément</th>
<th>content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co</td>
<td>52.50%</td>
</tr>
<tr>
<td>Cu</td>
<td>0.75%</td>
</tr>
<tr>
<td>Al</td>
<td>0.59%</td>
</tr>
<tr>
<td>Ni</td>
<td>0.49%</td>
</tr>
<tr>
<td>Fe</td>
<td>0.02%</td>
</tr>
<tr>
<td>Mn</td>
<td>0.17%</td>
</tr>
</tbody>
</table>

CoOOH
Chemical Treatment
LFP Chemistry
Chemical treatment of LPF based cathodes

Black powder

Redox leaching

Fe(II)

Hydrolyse

FeOOH

Phosphate/carbon

Lithium recovery

Li2CO3
Recovered iron oxide
Recupyl already familliar with iron oxides production extracted from steel dust
The last challenge: Lithium salt suitable for the market

<table>
<thead>
<tr>
<th>Compound</th>
<th>Average composition</th>
<th>Request from technical market</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li2CO3</td>
<td>99,5%</td>
<td>99,00%</td>
</tr>
<tr>
<td>Fe</td>
<td>6 ppm</td>
<td>10 ppm</td>
</tr>
<tr>
<td>Cu</td>
<td>5 ppm</td>
<td>10 ppm</td>
</tr>
<tr>
<td>Ni</td>
<td>&lt; below LoD</td>
<td>10 ppm</td>
</tr>
<tr>
<td>K</td>
<td>83 ppm</td>
<td>100 ppm</td>
</tr>
<tr>
<td>Ca</td>
<td>133 ppm</td>
<td>150 ppm</td>
</tr>
<tr>
<td>Na</td>
<td>55 ppm</td>
<td>800 ppm</td>
</tr>
</tbody>
</table>
Hydrometallurgy treatment at pilot level
Hydrometallurgy treatment at pilot level
Approach on Recycling Rate

in regards to EU Directive 066-06

Lithium ion batteries must recycled at minimum of 50% explained as metals
Recycling of NMC chemistry (hydro process)
Sustainability also in the model of implementation
UN Class 9
But....

Proximity?

COMMITTEE OF EXPERTS ON THE TRANSPORT OF DANGEROUS GOODS AND ON THE GLOBALLY HARMONIZED SYSTEM OF CLASSIFICATION AND LABELLING OF CHEMICALS

Sub-Committee of Experts on the Transport of Dangerous Goods

Thirtieth session
Geneva, 4-12 (a.m.) December 2006
Item 2(a) of the provisional agenda

PROPOSALS OF AMENDMENTS TO THE RECOMMENDATIONS ON THE TRANSPORT OF DANGEROUS GOODS

Model Regulations on the Transport of Dangerous Goods

Special provision 188 concerning lithium batteries

Transmitted by the expert from the United States of America

Background

Special Provision 188 provides an exception from the provisions of the UN Model Regulations for lithium cells and batteries provided certain conditions are met. Currently, except when installed in equipment, packages containing more than 24 lithium cells or 12 lithium batteries must also meet the following additional requirements:
Avoiding the "Tourism of waste" and heavy management of far shipment?

To be close to collection

model already implemented for portable batteries by RECUPYL

USA
Recupyl Battery Solutions - Michigan
• 2 mechanical lines
  → AZ batteries
  → LI batteries

Europe
Recupyl Polska - Poland
• 1 sorting line
• 1 mechanical line
  → AZ batteries
Recupyl España - Spain
• 1 sorting line
• 1 mechanical line
  → AZ batteries

Asia
Recupyl Tes-Amm - Singapore
• 1 mechanical line
  → LI batteries

CO2 credit can also be claimed with the good choice of implementation
Conclusion

- Some metal are becoming more and more strategic due to limitation resources.
- Better environmental technologies are needed with lower energy consumption, lower CO2 emissions and better efficiency.
- Shipment of waste is more and more difficult (Basel Convention, UNEP etc.).
- New approach of waste recycling is needed, close to collection, close to market and close the loop!!!
And ......If Resources are finite

Innovation is infinite  !!!!!!!

A also great thanks to the Team of RECUPYL

Thank you for your attention