Key & Critical Material Recycling Advanced Batteries, lithium to lanthanoids

EPA Region 8 Rare Earth Elements Workshop, May 10, 2012

Steven E. Sloop

OnTo Technology LLC

Overview, Introductions

- OnTo Technology Company
- Nickel Metal Hydride
  - Chemistry
  - Recycling Approaches
- Advanced Battery Recycling Developments
  - NiMH
  - Lithium-ion
    - Co, Mn, Fe based chemistries with critical and key elements

OnTo Technology Company

Advanced Battery Innovations and Materials Recycling

- Licensing and royalties business model
- The spectrum of technologies
  - Decommission for Safety
  - Disassembly processes
  - Direct rejuvenation of recycled materials
  - In-situ rejuvenation of whole batteries
- Alkaline
  - Single use and rechargeable
  - Nickel Metal Hydride: HEV, Plug-HEV, stationary storage
- Lithium
  - Small format: rechargeable & single use
  - Large format: HEV, EV, E-Bike, stationary storage
  - Repairing off spec. material

OnTo Technology Business

Widely covered patent pending positions for license
Contract research and development

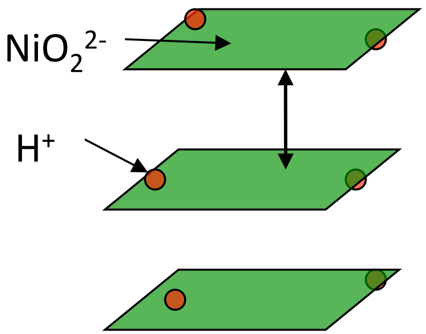
Activity\Area	Li-ion cells	Li-Primary cells	Off-Spec-Cathode material	Metal Hydride	Alkaline
Battery Decommission	Available for Full and hybrid E vehicle, bike, grid	Available for Industrial staves, remote power	(N/A)	Available for Hybrid E vehicle, bike, grid	Available for Consumer / municipal sourced
Material Rejuvenation	Available 8/12	Available 8/12	Available	Available	-
Battery Rejuvenation	Available for Full and hybrid E vehicle, bike, grid	-	(N/A)	-	-

<u>Contract Research Customers:</u>

Vehicle Recycling Partnership
Environmental Protection Agency
National Science Foundation
US Department of Energy
California Center for Sustainability
Sumitomo Corporation of America
InvenTek
EccoBat
Oregon Nanoscience and Microtechnologies Initiative
LG Chem / Apple
Tesla

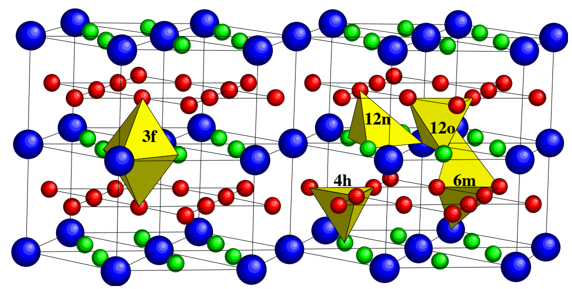
Nickel Metal Hydride Battery

What is AB5? An overview on nano-scopic scale



Proton to hydride charge cycle

KOH / H_2O electrolyte



Blue :A type, Red, Green: B type

Tetrahedra: H Storage Sites

$M(OH)_2 + OH^- \leftrightarrow MO(OH) + H_2O + e^-$
(Charge cycle)

$M + H_2O + e^- \leftrightarrow MH + OH^-$
(Charge cycle)

β-$Ni(OH)_2$ & $Co(OH)_2$ proton host

- Positive electrode composed of nickel oxyhydroxide, and 5-10% cobalt oxyhyrdroxide

AB5 metal alloy, hydride host
A=La, Ce, Nd, Pr…
B= Ni, Co, Mn, Al

- Negative electrode, AB5
- Problem 1: Rare Earth Elements become expensive 2010
- Problem 2: REE recycling

Metal Hydride Low Cost Development

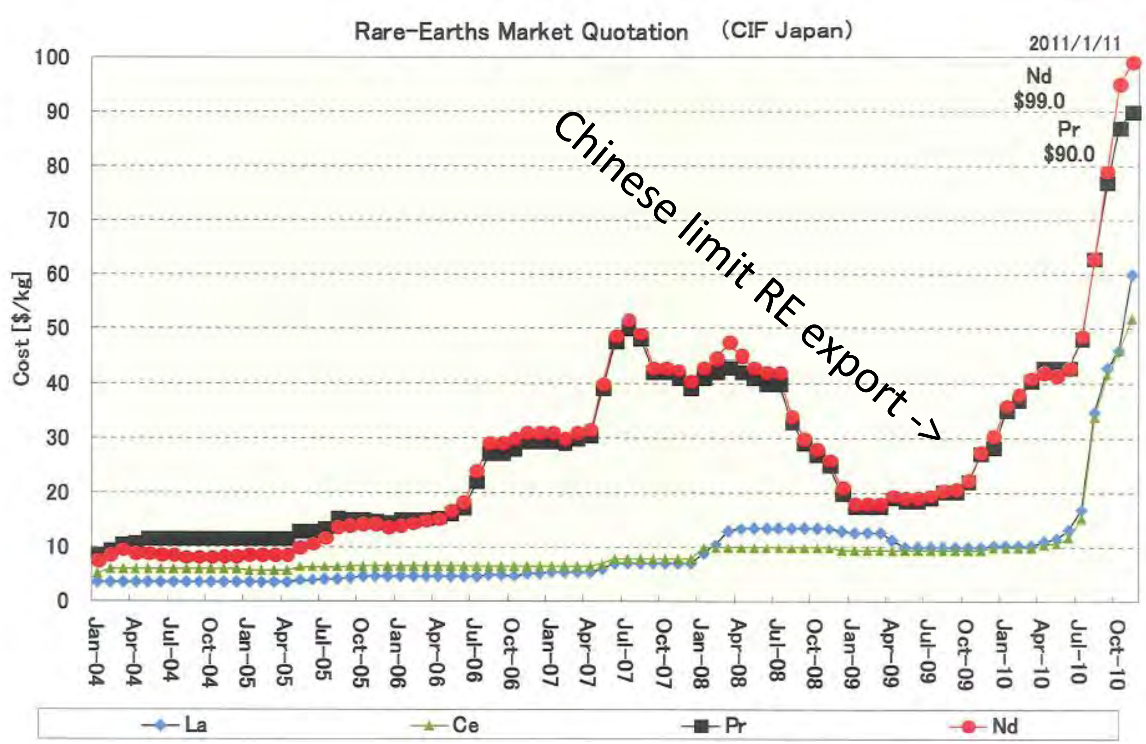
Manufacturing Response to High Priced Rare Earth Elements

High Prices, 2011

- Neodymium: $250/kg
- Praseodymium: $250/kg
- Cerium: $140/kg
- Lanthanum: $140/kg

Situation: Mining of REE's is 95% in China: now exports are severely limited.

Recent History: inexpensive REE's with good availability from China.



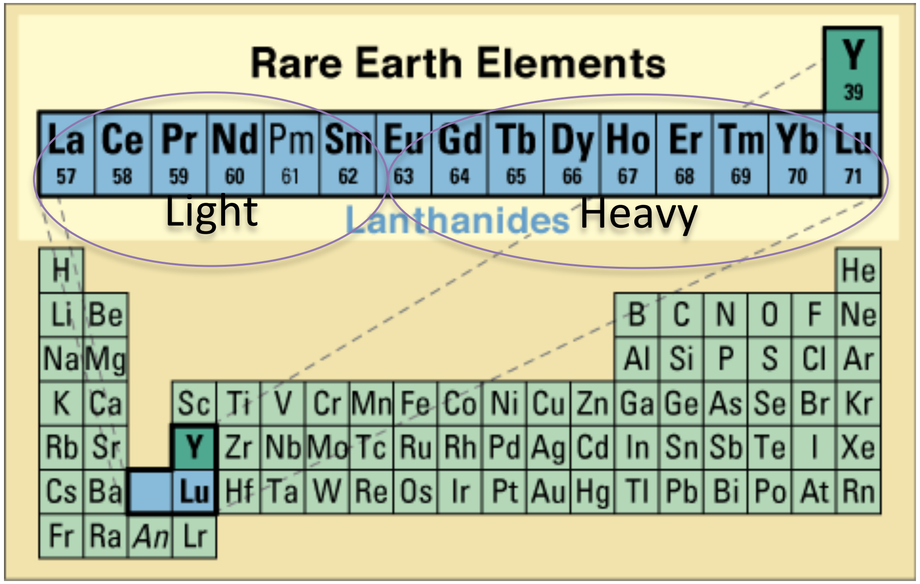
Conventional AB5 alloy	$82/kg
AB5 without Pr, Nd	$59/kg
AB2	$19/kg

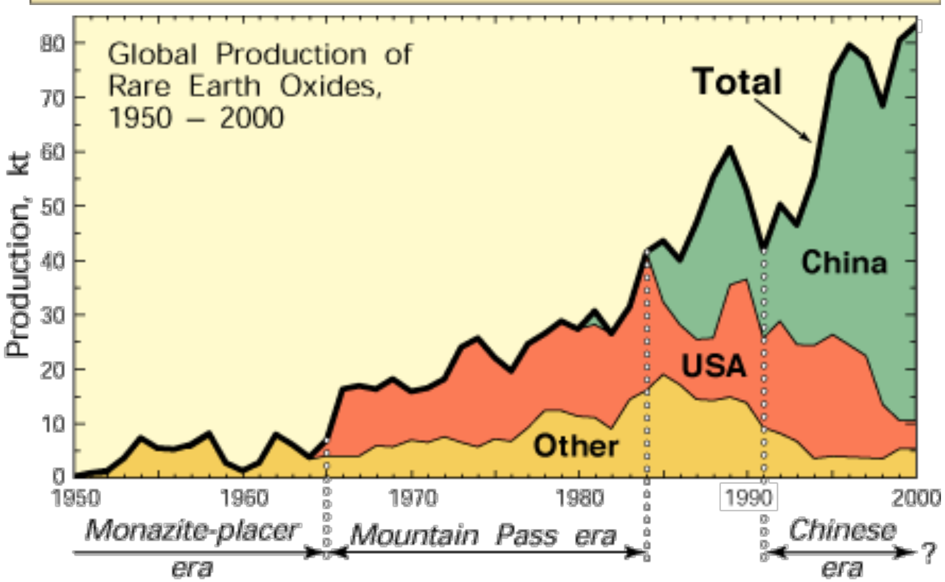
Elimination of Pr, Nd reduces AB5 formula 13%, AB2 alloy reduces costs 72% and increases capacity 26%

M. Fetcenko, 29th International Battery Seminar (2012)

Rare Earths, Lanthanides

light, Group I, lanthanides are used in AB5 alloys





USGS Fact Sheet 87-02

Groups according to MP, BP, VP & radioactivity*

Group I	Group II	Group III	Group IV
La	Gd	Dy	Sm
Ce	Tb	Ho	Er
Pr	Sc (REE)	Er	Yb
Nd	Y (REE)	Sc (REE)	Tm
	Lu		
	Group V		Actinides
	Pm*		Ac*, Th*, U*

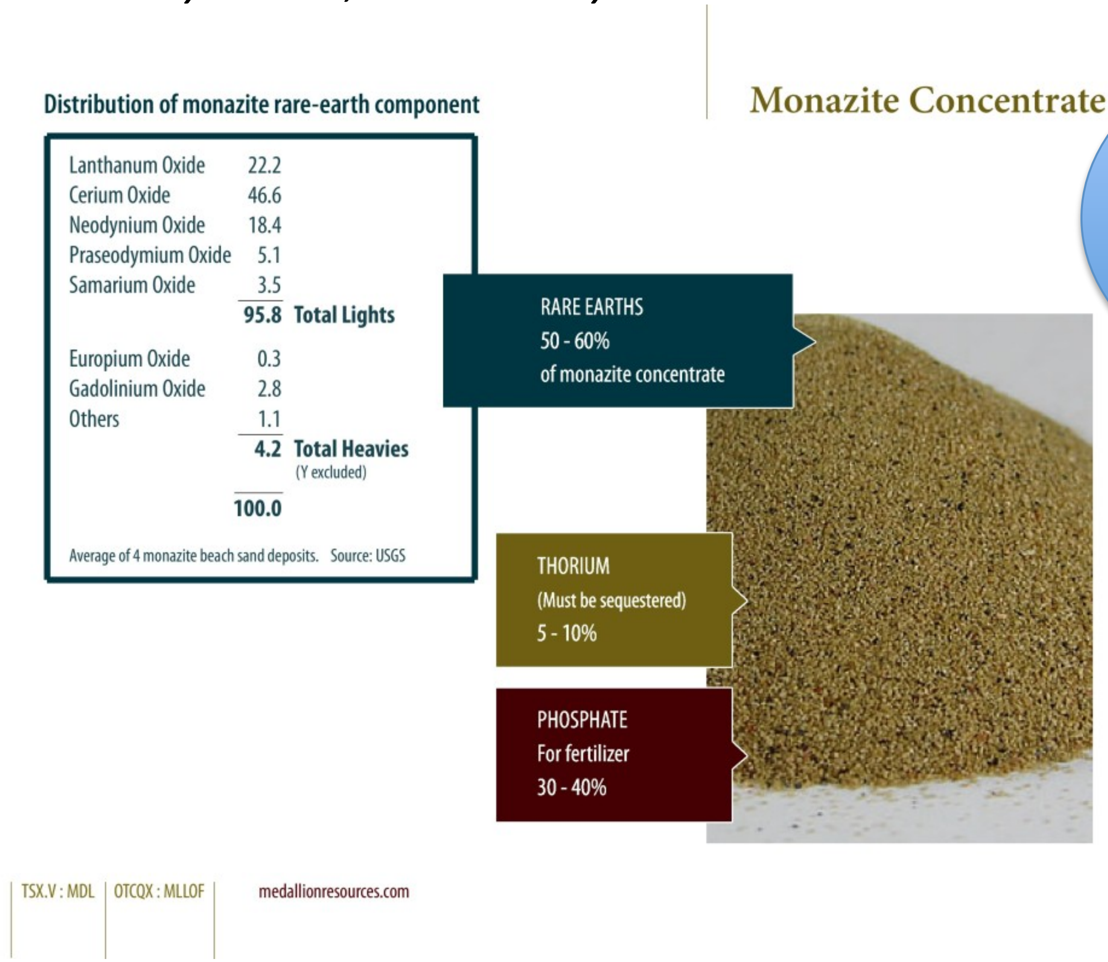
AB5 metallic alloy

A=La, Ce, Nd, Pr

(group I, low MP, high BP)

Rare Earth, Lanthanide processing

general overview, how are RE metals separated from minerals?
Chemically similar, all are easily oxidized



Medallion Resources (2012)

Acid opened $Ln_2(SO_4)_3$ or Base opened Ln_2O_3 Followed by thorium removal

NH_4OH

Th salts ppt

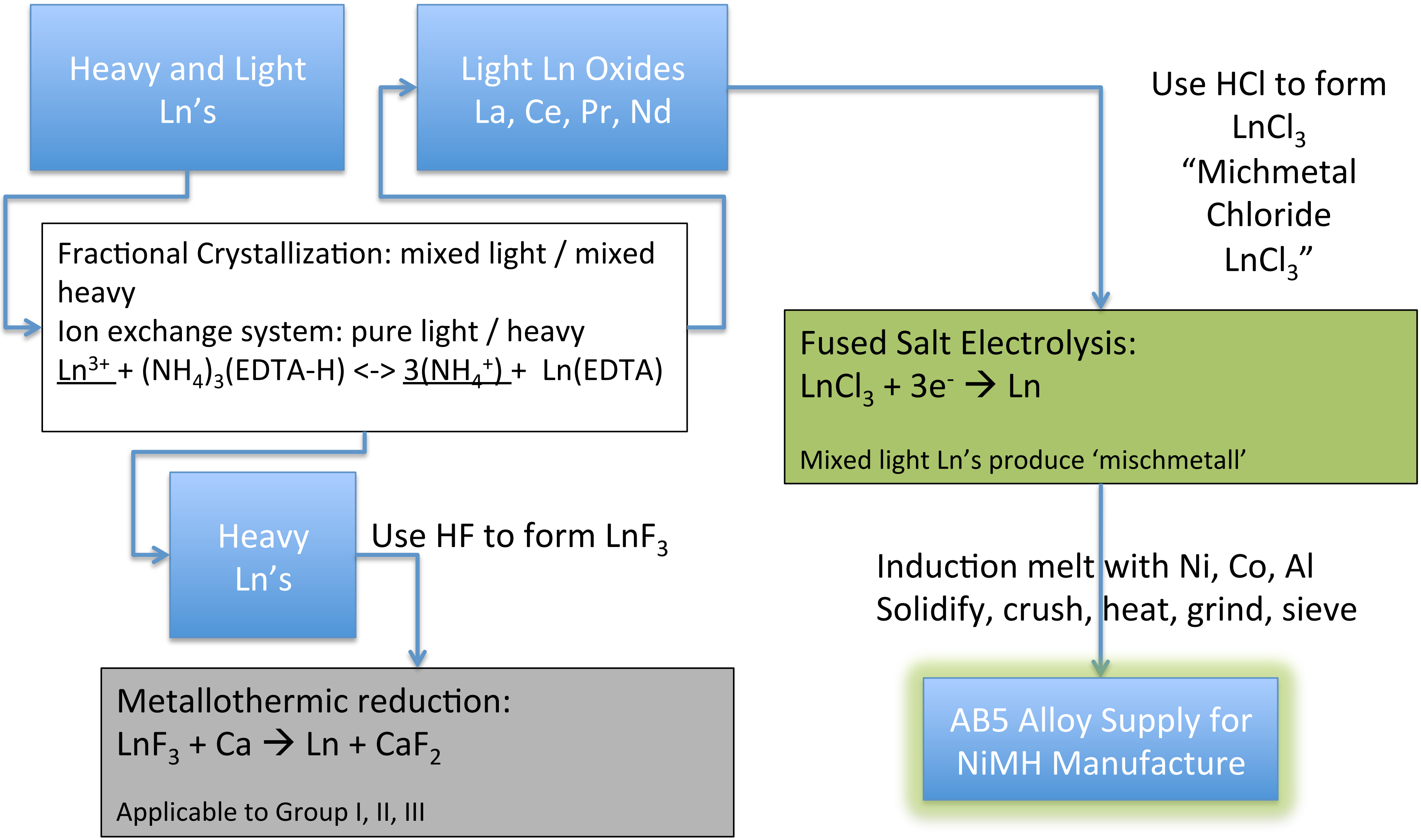
HCl

Radioactive Th removal

ThO_2 ppt

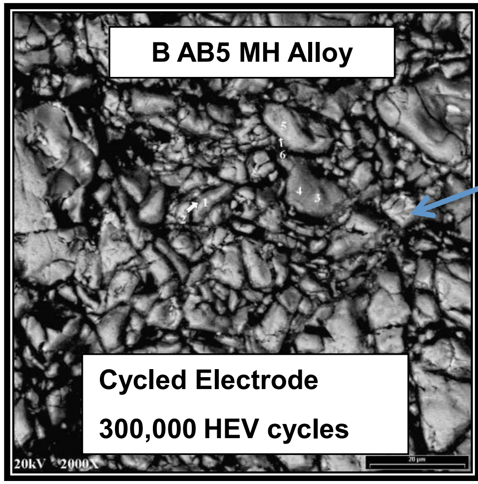
Oxide to metal to AB5 alloy

Two pathways to light Ln, Group I metals used in AB5

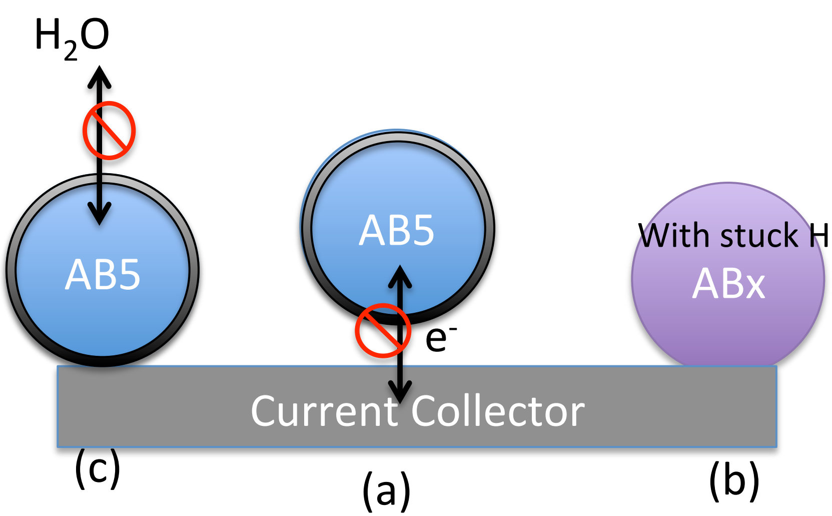


NiMH life limitations for (-) electrode

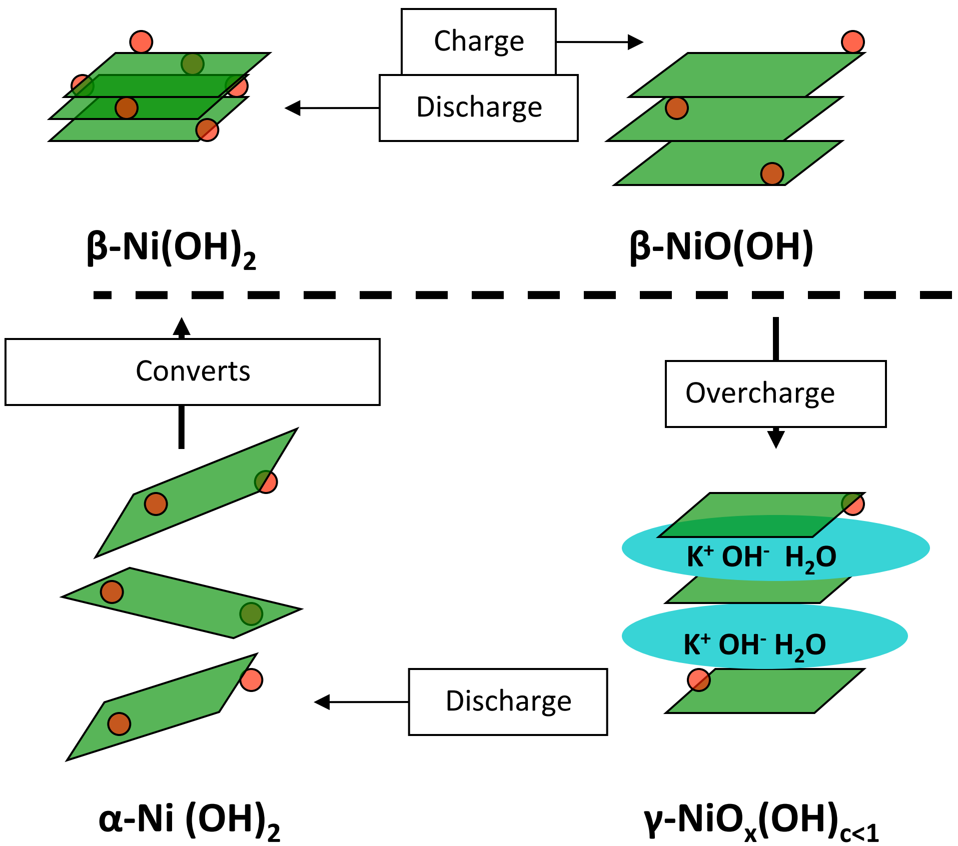
Alloy Pulverization & component oxidation



- Note cracks in the SEM of the used electrode
- (a) Disconnected material
  - Removed from the circuit
- (b) Phase changes
  - A less-active material, slow H diffusion
- (c) Surface oxidation
  - Coats the working material, decreases efficiency



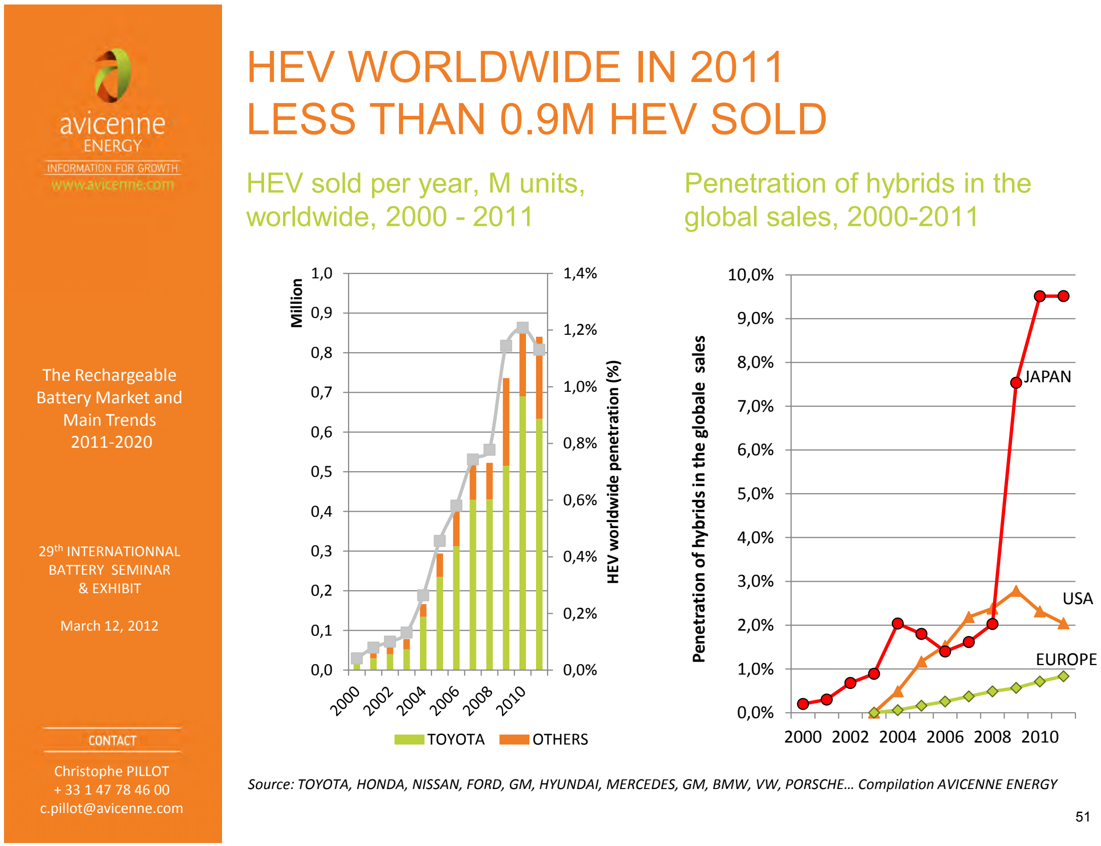
NiMH Life Limitations for (+) electrode

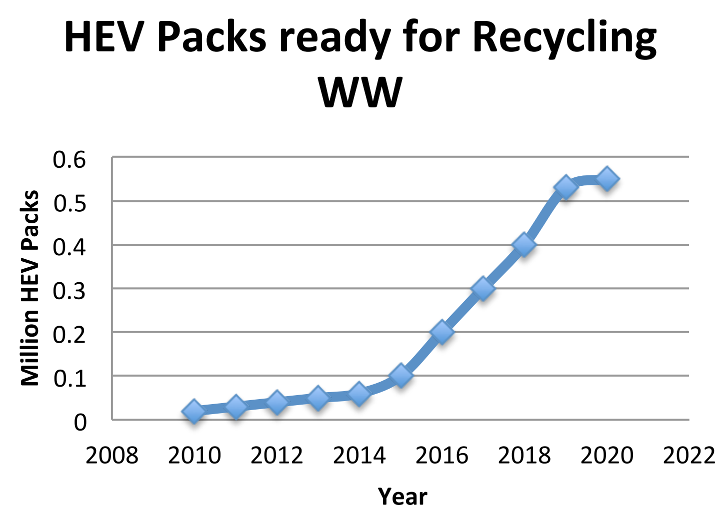


- Beta phase provides best performance
- Phase transformation hinders performance, consumes electrolyte

HEV pack recycling volume projection

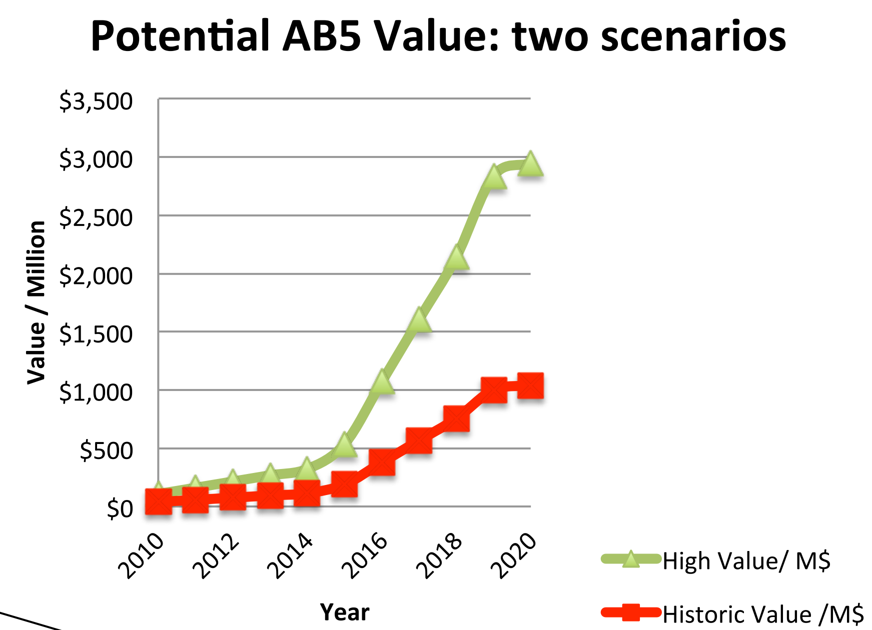
life-of-the-car battery,
assume 12 year life for NiMH





AB5 value projection in HEV pack recycling

AB5 comp.	Weight %	component price/kg	historic component price/kg	Embargo Era Value	Historic value
La	12.50%	140	30	$17.50	$3.75
Ce	3.20%	140	30	$4.48	$0.96
Pr	1.50%	250	30	$3.75	$0.45
Nd	14.90%	250	30	$37.25	$4.47
Ni	50.20%	30	30	$15.06	$15.06
Co	10.40%	35	35	$3.64	$3.64
Mn	5.30%	10	10	$0.53	$0.53
Al	2.00%	10	10	$0.20	$0.20
	100.00%			$82.41	$29.06



With Embargo, High $ REE, there is 'feasibility' for recycling

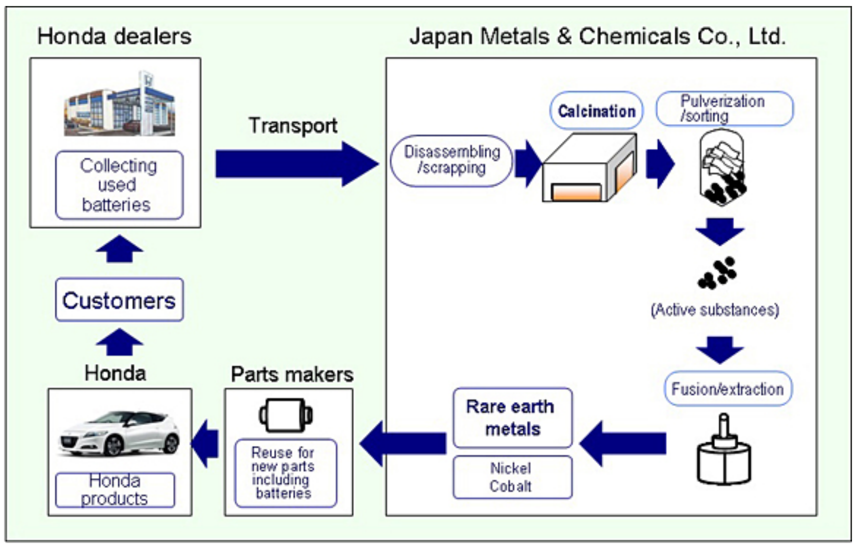
With historic values, nickel is the economic and technical driver

-produce stainless steel

-Possible REO side product

How to maximize the value potential of the metals in the end-of-life batteries?

Honda & Japan Metals & Chemicals Announcement for Rare Earth Recycle



- Operational April 2012
- Source is their HEV fleet of ~800,000 vehicles and other sources.
  - Near future throughput?
- Japan is the worlds largest RE importer.
- Used electronics disposed of in JP : 650,000 tons.
  - Contains 280,000 tons of RE and other metals: $1.03B

Ceramic Tech Today, April 23, 2012 Peter Wray Ed.

Metal Hydride Rare Earth Recovery

OnTo Approach

Process

- Decommission
- Disassemble
- Separate (+) and (-)
- Separate (-) oxides and metals
- Reintroduce metals to alloy manufacture
- Make metallic feedstock

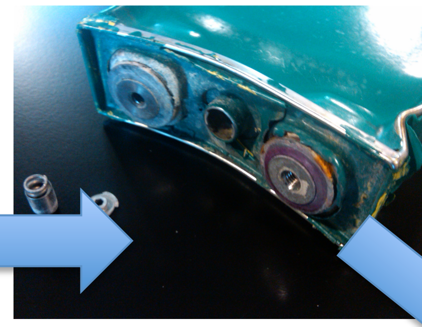
Intellectual Property Position

- Patent pending methods for decommission, disassembly and separation
- Conversion and reduction dedicated towards metal hydride battery using classical approaches and trade secret methods

Decommission, Disassembly and Recycling Process Overview, NiMH

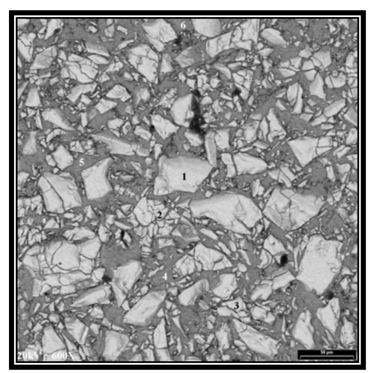
CO2 decommission

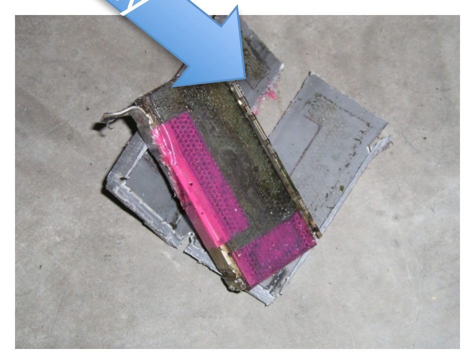
Article ready
for machine work



Disassembly

High RE content material
From (-) electrode





Components

Metal Hydride Recycling Safety

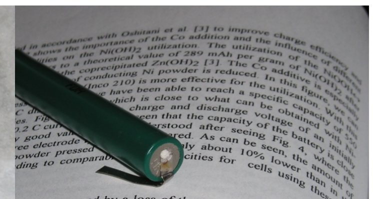
OnTo Solution for flammability of negative electrode, US Patent & PCT Pending

Current processing:
Fire results

- “Discharged” NiMH cell catches fire

$LnH + O_2 \rightarrow\rightarrow LnO_x + H_2O$

OnTo Processing :
Dry, No fire, No solvent



<u>No flames after opening CO_2 rinsed cells</u>

- How? converts KOH to $KHCO_3$, drop in pH quenches hydrides
- Pierce-point shows carbonate build up
- Cell was charged before CO_2 rinse.
- Environmentally benign
- Rapid process, simple, low cost, patent pending:

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Declarations under Rule 4.17:
— *of inventorship (Rule 4.17(iv))*

Published:
— *with international search report (Art. 21(3))*

Features and benefits of OnTo's process

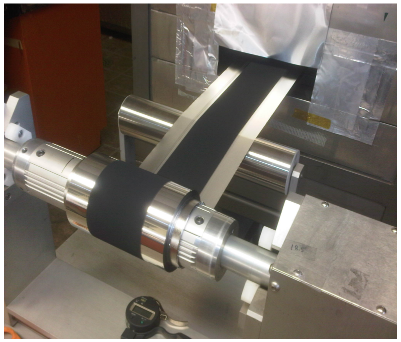
Feature

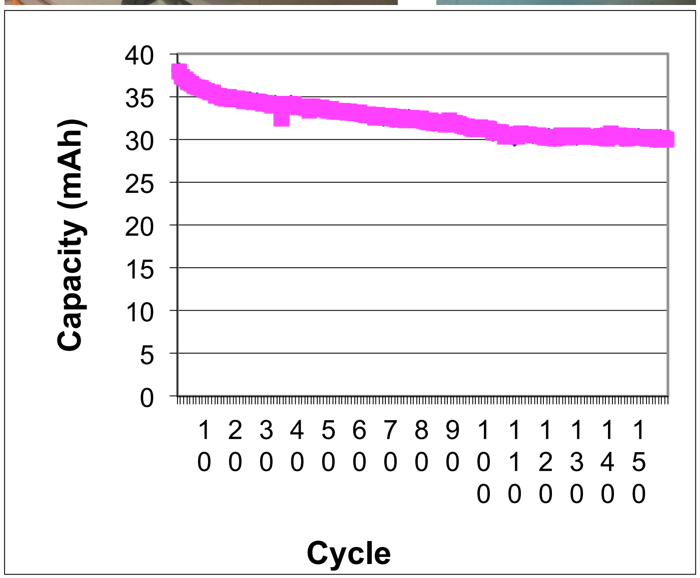
- Safe decommission reduces the hazards associated with large format storage batteries
- Flexible to various alkaline chemistries and lithium chemistries
- Low energy input process capability (low temp)

Benefit

- Saves $ by avoiding infrastructure for battery hazards.
- Saves $ by avoiding hazards and improved safety.
- Saves $ on high temperature process units.
- Creates a salable product.

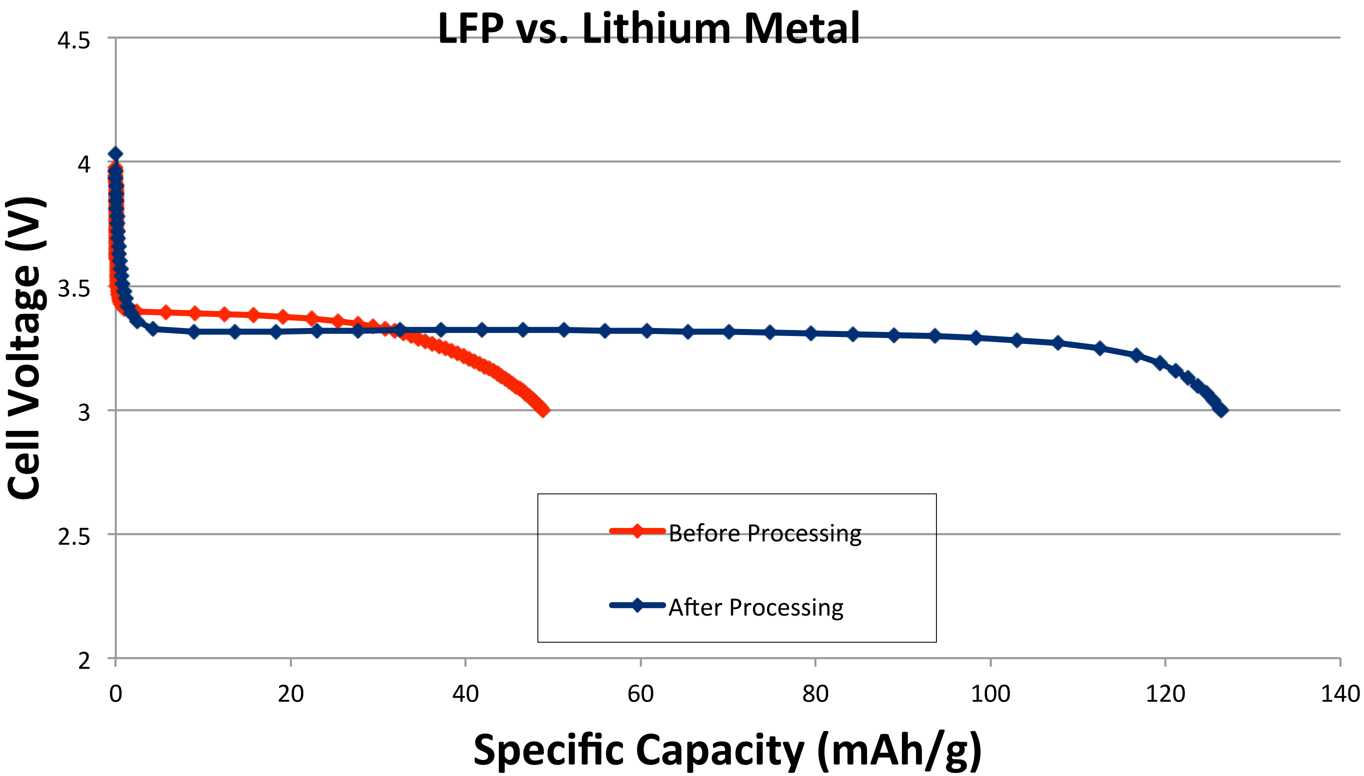
Lithium-ion battery recycling results: Manufacturing with recycled material: Co





- $LiCoO_2$ containing 100% recycled key and critical elements
- Manufacturing Qualification progress
  - Low trace metal (<100ppm)
  - High capacity (150mAh/g)
  - Coating on Al tape
  - Long life cycle full cells
- Low cost process
- Patent pending position

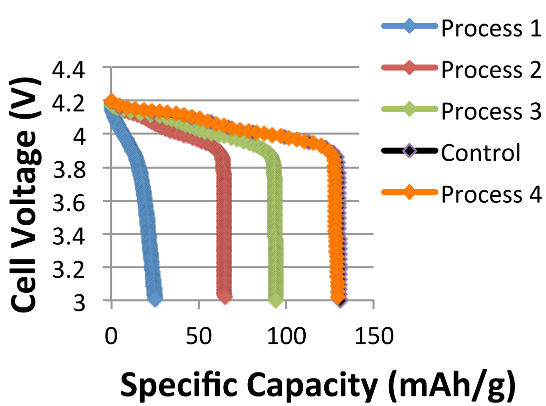
EV sourced Li-iron phosphate: Recycled and refurbished for a very low cost: Fe



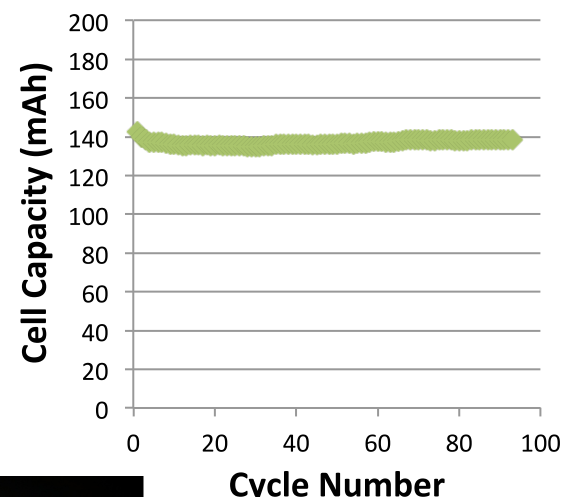
Harvested from a severely faded, abused, large format cell.
Original specific capacity of the material is ~130 mAh/g

Lithium-ion EV Battery Recycling
Manufacturing with rejuvenated material: Mn

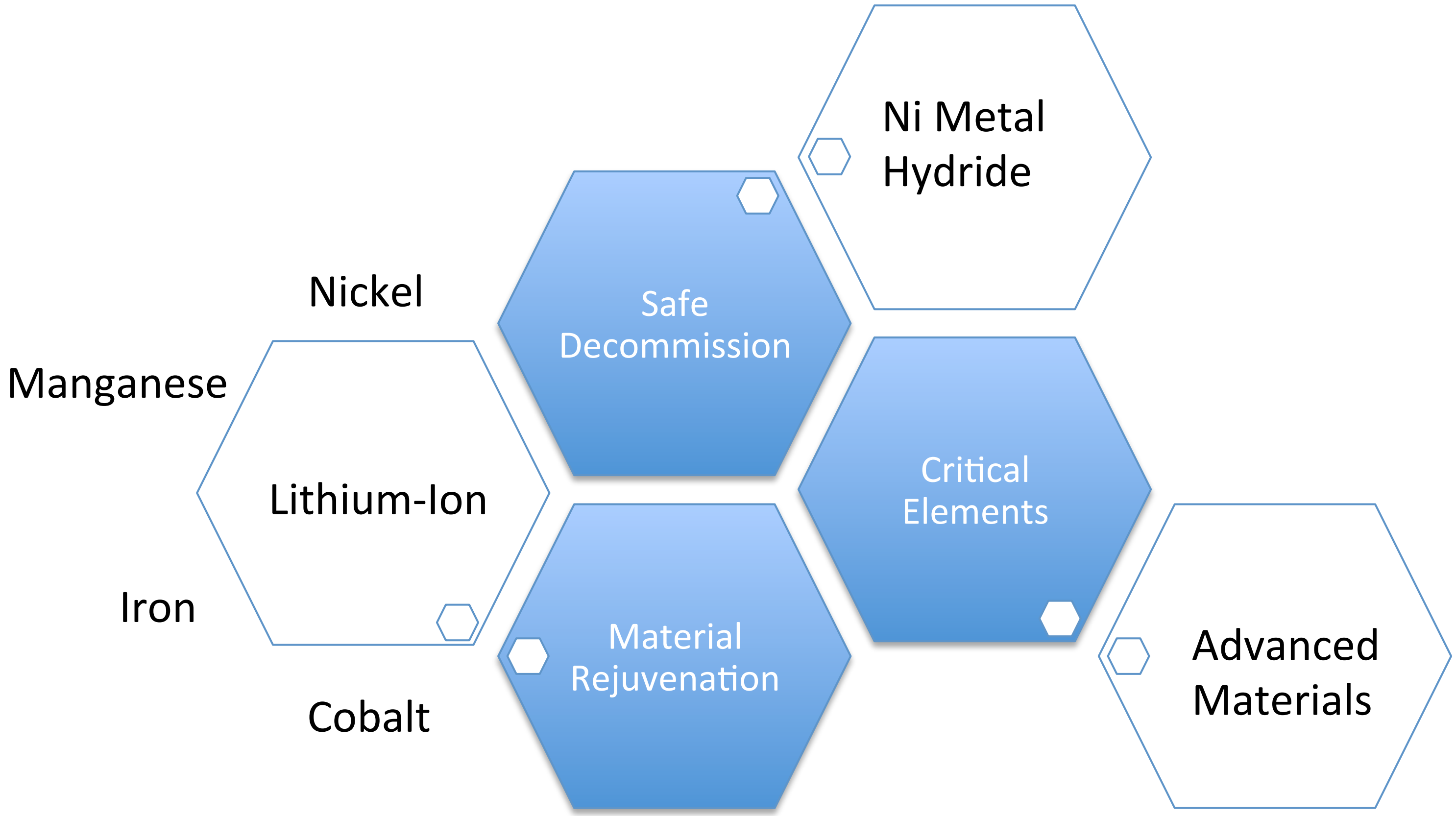
Recycling Process development results



Prototype Cell from Rejuvenated material harvested from Nissan EV



OnTo process developments for cradle to cradle critical materials



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