Issues around critical metals for new energy vehicles

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GENERAL MOTORS

Vehicle Application Map

- ICE Vehicles
  - Gasoline: light load – SUVs, large cars, mid-size cars, small cars
  - Diesel: high load and light load – trucks, SUVs, cars
- Hybrid Vehicles
  - SUVs, large cars, mid-size cars
- E-REVs
- Fuel Cell Vehicles
  - bus and cars
- BEVs
  - cars, SUVs – mainly for city and intra-urban use

Automotive Materials

- Increased variety and diversity of materials used in automobiles have resulted in much more significant technical advance over the past decade than in any other period
  - 8-10 thousand parts per vehicle and hundreds of different materials
- Critical automotive metals: 2% or less by vehicle weight,
  - rare earth metals, precious metals (Pt, Pd, Ni, Co, Li, Mn, Zr…), copper, and zinc etc. (Pd volatile and tied to automotive use)

Critical Automotive Metals

Critical Materials:

- Necessary in a number of essential industrial and defense applications – renewable energy applications (in automotive industry)
- Major sources of supply are vulnerable to disruption
- It is the properties that make them irreplaceable
- Critical nature is not static (DOE study)
  - Alternatives may be found to replace the metals in essential functions
  - Changing conditions may mean that the functions are no longer essential
  - Changes in technology will cause these materials to change in importance

Characteristics:

- Small amount, most important, most expensive or most subject to high price volatility
- REM (Nd, Pr, Dy, Tb, Ce, La, Sm, Eu, Y), PGM (Pt, Pd)

Pt – catalytic converters and fuel cell; Pd – catalytic converters

- Other metals such as Cu, as well as Li, Mn, Ni, Co, Zr

23 kg copper in ICE, 40 kg in HEV, 60 kg in PHEV, 83 kg in BEV, 224-369kg in BEbus (from ICA, 2017)

Key automotive components for renewable energy application:

- catalysts & separators, supercapacitors, batteries, permanent magnets

Examples of Automotive Uses for Rare Earth Elements

- LCD Screens: Cerium, Europium, Yttrium
- LED lighting (Rare Earth Phosphor-based): Yttrium, Europium, Terbium (Move toward REM free)
- Component Sensors: Yttrium
- Hybrid & Electric Traction Motor & Generator: Neodymium, Dysprosium, Terbium, Praseodymium
- Headlight Glass: Neodymium
- Small Electric Motors: Neodymium
- Catalytic Converter: Cerium, Lanthanum,
- Hybrid NMH Batteries: Cerium/Zirconium
- Diesel Fuel Additive: Cerium, Lanthanum
- Low UV Transmission Glass: Cerium
- Glass & Mirrors Polishing Powder: Cerium

Vehicle Electrification – Traction Motors

- Hybrid and electric vehicles can be propelled by several types of motors (PMSM, induction, switched reluctance, separately excited synchronous etc.)
- Permanent magnet synchronous motors are efficient and have high power density
- Rare earth permanent magnets in PMSM use Nd, Dy, Tb, Co, Ni … (ferrite magnets, “new” Dy-Fe-B magnets with reduced HR & R)
- Can alternative motor types replace PMSM?

  To meet cost, weight, volume, performance targets

Alternative Solutions for RE Permanent Magnets

- Concerned about availability and price of rare earth magnets
- Looking for additional supply of Rare Earth magnets
- Working to improve the global supply of REM
- Developing alternative types of motors to complement the permanent magnet motors
- Developing permanent magnets with reduced use, or even no use of rare earth metals, especially heavy rare earth metals
- Materials and system development will be key to significant reduction in RE usage
- Manufacturing and recycling technologies are important
    - Need creating sustainable business model similar to NiMH
    - Prevent future material scarcity
    - Recycle key materials (esp. Cobalt, Nickel)

Vehicle Electrification - Critical Materials in Batteries

- Lithium-ion batteries are predominant rechargeable batteries for EVs.
- Three types Li-ion batteries for different purposes:
  - Start-stop or power battery (NMC as cathodes, Li titanate as anode)
  - HEV battery (a mix of NMC and LMO as cathode, graphite as anode
  - EV battery: NMC as cathode, graphite as cathode.
- Battery cell chemistry modified to meet energy density and cost needs
  - e.g. NMC 811 is usually used in HEVs and NMC 622 in EVs. The trend is to use NMC 811 for higher capacity (power/gram).

    lithium manganese oxide, $LiMn_2O_4$ (LMO)
    lithium nickel manganese cobalt oxide, $LiNi_xMn_yCo_2O_2$ (NMC)
- Most interesting development in Li-ion battery: silicon/silica anode for a higher energy density. Hope to use pure Si anode (Challenge: Si anode has lower cycle life and introduces hysteresis problem which makes it more difficult to estimate the battery state of charge)

Vehicle Electrification - Critical Materials in Batteries

- **Li-air battery potentially has 5–15 times the specific energy (J/kg) of a Li-ion battery**

Girishkumar, G.; McCloskey, B.; Luntz, A. C.; Swanson, S.; Wilcke, W. (2010). "Lithium–Air Battery: Promise and Challenges". The Journal of Physical Chemistry Letters. 1 (14): 2193–2203

- **Practical power and life-cycle of Li-air batteries need significant improvements before they can find a market niche**

Christensen, J.; Albertus, P.; Sanchez-Carrera, R. S.; Lohmann, T.; Kozinsky, B.; Liedtke, R.; Ahmed, J.; Kojic, A. (2012). "A Critical Review of Li–Air Batteries". Journal of the Electrochemical Society. 159 (2): R1

- **Four approaches are active: aprotic, aqueous, solid state and mixed aqueous–aprotic**

Younesi, Reza; Veith, Gabriel M.; Johansson, Patrik; Edström, Kristina; Vegge, Tejs (2015). "Lithium salts for advanced lithium batteries: Li–metal, Li–O2, and Li–S". Energy Environ. Sci. 8 (7): 1905–1922

- **Other metal-air batteries, specifically zinc–air battery also received attention**
- **Na battery and Mg battery got attention years ago. With current technique, the cell-level cost of Na or Mg battery has no advantage than Li battery**
- **Newer Li-S batteries promise highest performance-to-weight ratio**

•Badwal, Sukhvinder P. S.; Giddey, Sarbjit S.; Munnings, Christopher; Bhatt, Anand I.; Hollenkamp, Anthony F. (24 September 2014). "Emerging electrochemical energy conversion and storage technologies". Frontiers in Chemistry. 2: 79

- **Researches on solid state electrolyte and Li metal batteries are still in academic field**
- **Research areas for Li-ion batteries include life extension, energy density, safety, cost reduction, and charging speed among others**

Vehicle Electrification - Critical Materials in Batteries

•Li-ion battery elements including iron, copper, nickel and cobalt are considered safe for incinerators and landfills, and can be recycled. Mining generally remains cheaper than recycling

•Not much invested into recycling Li-ion batteries due to cost, complexity (recycling process and battery structure) and low yield. Recycling needs to be adapt to constant evolution in battery structure. Most expensive metal involved in construction of the cell is cobalt. Lithium is less expensive than other metals used. Recycling could prevent a future shortage (60% cobalt demand from DRC, very high risk due to child labor and human rights violation)

•Manufacturing processes of nickel and cobalt and the solvent present potential environmental and health hazards

•Li-ion battery industry is a complex multi-stage business - Long supply chain (150+ companies in 2017 to supply nine of the main components of the final cells) – cathodes, anodes, electrolyte salts and solutions, separators, copper and aluminum foils, binders and cell cases

•Demand for Li-ion batteries grew 27% per year between 2000 and 2017

•Capacity expansions will face technology risks derived from preferences for higher energy density materials (mostly cathode) - 86% of the companies located in Asia

•Nickel is expected to increase from just over 30kt in 2017 to 600kt in 2027 as cathode material for Li-ion batteries

From Market Development & Raw Materials 2018, Roskill

Measures Mitigating Critical Material Impact

- Diversifying sources
- Development of domestic processing capabilities
- R&D for affordable alternative minerals and more efficient use of these minerals
- Support for recycling and reuse of minerals
- Focus on: Recovery & Separation, Elimination & Substitution, Reduction, Sustainable & Adaptive Use

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