MG BATTERIES: CURRENT STATUS AND PERSPECTIVES

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WHY MAGNESIUM BATTERIES?

Appealing qualities of magnesium for energy storage:

- Relatively negative electrode potential, -2.37 V (vs. SHE).
- High volumetric capacity, 3832 mA h cm\(^{-3}\) (vs. 2061 mA h cm\(^{-3}\) for Li).
- Relatively low in cost and environmentally benign.
- Long shelf life
POTENTIAL ADVANTAGES

ECONOMICAL
Magnesium costs 100 times less than lithium, which is the key ingredient in lithium-ion batteries.

ABUNDANT
Earth has an inexhaustible supply of magnesium – the eighth most abundant element in the earth’s crust, and the third most abundant element in sea water. Global magnesium reserves are 300 times greater than those of lithium.

LESS VOLATILE/COMBUSTIBLE THAN HYDROGEN
No special fuel storage is needed and can be dry-stored indefinitely.

POTENTIAL FOR HIGH ENERGY GENERATION WITHOUT HAZARD
Aqua Power has already developed and tested low-cost magnesium energy cells with power output doubling that of lithium ion batteries.

SAFE
Can be safely developed for large scale application.

NONTOXIC

http://aquapowersystems.com
Mg BATTERIES OVERVIEW

Primary cells (mechanically rechargeable)

- Have been commercialized (developed since the early 20th century)

Mg batteries

Secondary cells (rechargeable)

- Under research (not commercialized) with challenges being electrolytes and cathode materials.
- Replacement of Li-ion batteries
PRIMARY Mg BATTERIES

Concept and various commercially successful types

Appealing qualities of magnesium in primary battery system:

- Relatively negative electrode potential, -2.37 V (vs. SHE).
- High volumetric capacity, 3832 mA h cm$^{-3}$ (vs. 2061 mA h cm$^{-3}$ for Li).
- Relatively low in cost and environmentally benign.
- Long shelf life.
PRIMARY Mg BATTERIES
Mg metal anodes

- Electrode / anode (electrolyte) design

> secondary phase fraction
  → alloying, activation

> impurity fraction
  (processing)

> surface structure
  → reaction kinetics
  → \( i_{H2} \) – self-corrosion current
  → film growth

<table>
<thead>
<tr>
<th>Type</th>
<th>Main constituents</th>
<th>Morphology</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple Mg</td>
<td>Commercial Mg</td>
<td>Mg</td>
<td>High corrosion rate, large negative difference effect</td>
</tr>
<tr>
<td></td>
<td>Nano/mesoscale Mg</td>
<td>Mg</td>
<td>Better corrosion resistance and high current density as well as higher rate discharge ability than commercial Mg</td>
</tr>
<tr>
<td>Mg-alloy</td>
<td>AZ31, AZ61, AZ91°</td>
<td>Mg/Al/Zn</td>
<td>Better corrosion resistance, better strength and tarnish resistance and higher working voltage than commercial Mg</td>
</tr>
<tr>
<td>AM50, AM60, MA8M06°</td>
<td>Mg/Al/Mn</td>
<td>—</td>
<td>Better corrosion resistance, smaller crystalline grains and higher working voltage than commercial Mg</td>
</tr>
<tr>
<td>Mg-Li alloys</td>
<td></td>
<td>Mg/Li</td>
<td>Better corrosion resistance, higher energy density and higher working voltage than commercial Mg</td>
</tr>
</tbody>
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Novel electrolyte-additives

- Stabilisation of the Mg – electrolyte – interface
- Controlled discharging: reduce remarkably self-corrosion rate resulting in high delivered specific energy (additive 1)
- Provide high discharge potential even at high applied current, along with improvement in specific energy (additive 2)

PRIMARY Mg BATTERIES

Current applications

- reserve batteries (military and telecommunication sites)
- land based backup system (hospitals, schools, earthquake accidents)
- undersea power sources (monitoring instruments, oil and gas infrastructures)

**PROTOTYPE SPECIFICATIONS:**
- 6 Volts (6 Watts)
- 0.5 - 2.0 Amps
- Dry weight: 4.8 lbs (2.2 kg)
- LED flashlight, lantern, AM/FM radio
- 10" (25.5 cm) x 5" (12.7 cm) x 10" (25.5 cm)
- 20+ year dry storage
- Operating temp: -4 F (-20 C) to 140 F (60 C)
- Multiple USB charging ports

60 hour fuel duration: simply replace cartridge (5 minutes) for additional 60 hours – repeat for months of power

**APPLICATIONS:**
- Expeditionary Operations
- Disaster response
- Small boat and lifeboat emergency power
- Emergency power for homes, schools, hospitals
- Portable power for camping, mining, leisure
- Emergency communications power
- Power source for rechargeable lithium batteries or solar cell batteries
Concept of Magnesium hydrogen fuel cell power supply

RECHARGEABLE Mg BATTERIES

Challenges on cathode materials

- Ensure the capability of bivalent Mg$^{2+}$ cation to be inserted into and extracted from the solid cathode materials.
- Request for good stability in electrolytes.

Potential cathode materials for Mg-ion system

- Chevrel phase, Mo$_6$S$_8$ and its derivatives
- MgS
- NASICON, e.g., Mg$_{0.5}$Ti$_2$(PO$_4$)$_3$
- MT2 (M = metal, T = S, Se)
- MgMSiO$_4$ (M = Mn, Co, Fe)
- Transition metal oxides
- Transition metal sulfide/boride
- V$_2$O$_5$
- MoO$_3$, α-U$_3$O$_8$
- First working Mg-rechargeable battery prototype with Mo$_6$S$_8$ cathode

The past 20 years have witnessed great progress and breakthroughs of rechargeable Mg battery with respect to electrolyte, cathode, anode as well as current collector.

**Challenges**

rechargeable Mg battery is still not commercially available due to:

- Low energy density, mainly constrained by cathode material.
- Incompatibility between high voltage cathodes and high-performance electrolyte solutions.
- Narrow potential window, corrosion, and safety problems posed by the electrolyte.
Mg BATTERIES PERSPECTIVE

There are now numerous attempts to innovate in the lab:

- High capacity conversion cathodes (S, air)
- AI-ion systems
- Mg-ion systems
- Li-metal based systems
- Non-aqueous flow molecules
- High voltage, high capacity cathodes
- Non aqueous sodium-ion
- Low temperature Na-S
- Silicon anodes
- New cell design
- Aqueous sodium-ion systems
- Modified aqueous flow molecules
- Advanced lead acid

Green: Grid
Blue: Vehicle

http://www.visualcapitalist.com/future-battery-technology/