The Power of Minerals

Industrial minerals and alternative energy

Mike O’Driscoll
Editor, Industrial Minerals
Since 1967, providing premium information on news and trends in global supply and demand of industrial minerals

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Since March 2009

INDUSTRIAL MINERALS

= IM magazine + www.indmin.com

- Breaking news email alerts
- Daily email news from the end-use markets
- Weekly email summary
- Pricing data for over 40 mineral grades
- Historic price trend graphs
- News and Features Archive

Please visit our booth #538
The Power of Minerals: industrial minerals and alternative energy
Mike O’Driscoll, Editor, IM

Outline

1. Alternative energy: drivers

2. Where do IMs come in?
   a. Li-ion batteries
   b. Fuel cells
   c. Photovoltaic cells
   d. Wind turbines

3. Summary & conclusions
Alternative energy

Drivers

Satellite images of Arctic ice cover

September 1979

September 2007

Source: NASA/Goddard Space Flight Center
Alternative energy Drivers

May 2009
US Fuel Efficiency Policy: vehicles manufactured between 2012 and 2016 will be required to have 40% lower emissions and an efficiency of 35.5 miles per US gallon (6km/litre) by 2016

December 2009
China: by 2020 the country is expecting to have about 15% of its total electricity demand met by renewable energy sources.

USA: by 2020, 17% reduction in CO₂ emissions.
Alternative energy Drivers

February 2010
Sanyo to increase Li-ion battery market share from 30% to 40% by 2015 and targeting 25% market share of EV market by 2020.

Mitsubishi to invest $152m. in UK wind turbine research

China to target EV output of 500,000 units in 2011

China Petroleum & Chemical Corp. (Sinopec) and Beijing Capital Sci-Tech Group Corp. joint venture to develop Sinopec's gas stations available for both fuel-based and EVs.

UK government puts up $45.7m. for electric car chargers
Alternative energy
Forecast use 2000-2100

- Solar
- Wind

World in Transition – Towards Sustainable Energy Systems
Source: German Advisory Council on Global Change, 2003
Alternative energy
Li-ion batteries
Li-ion batteries
Li-ion batteries

US passenger vehicle sales by technology 2007-2030

SOURCE: International Energy Agency
Li-ion batteries
Li-ion batteries
## Li-ion batteries

### Battery cell types and properties

<table>
<thead>
<tr>
<th>Cell Type</th>
<th>Nominal Voltage</th>
<th>Storage Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead Acid</td>
<td>2.1 volts</td>
<td>30 Wh/kg</td>
</tr>
<tr>
<td>Nickle Cadmium</td>
<td>1.2 volts</td>
<td>40 to 60 Wh/kg</td>
</tr>
<tr>
<td>Nickle Metal Hydrige</td>
<td>1.2 volts</td>
<td>60 to 80 Wh/kg</td>
</tr>
<tr>
<td>Circular Lithium Ion</td>
<td>3.6 volts</td>
<td>90 to 100 Wh/kg</td>
</tr>
<tr>
<td>Prismatic Lithium Ion</td>
<td>3.6 volts</td>
<td>100 to 110 Wh/kg</td>
</tr>
<tr>
<td>Polymer Lithium Ion</td>
<td>3.6 volts</td>
<td>130 to 150 Wh/kg</td>
</tr>
</tbody>
</table>
Li-ion batteries

Anode: carbon - graphite (spherical)

Cathode: lithium cobalt oxide - lithium carbonate

Electrolyte: Li salt in organic solvent - lithium carbonate; monofluoroethylene carbonate F1EC - fluorspar
## Li-ion batteries

<table>
<thead>
<tr>
<th>Battery material</th>
<th>Lithium product</th>
</tr>
</thead>
<tbody>
<tr>
<td>metal oxide cathodes</td>
<td>carbonate, hydroxide</td>
</tr>
<tr>
<td>Li titanate anode</td>
<td>carbonate</td>
</tr>
<tr>
<td>electrolyte salts, and additives</td>
<td>carbonate, bis(oxalato)-borate, hydroxide</td>
</tr>
</tbody>
</table>
Li-ion batteries

Li battery chemistry

<table>
<thead>
<tr>
<th>Active Material Chemical Formula (discharged state)</th>
<th>Storage Capacity mAh/g</th>
<th>Nominal Voltage Volt</th>
<th>Active Material Cost Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>LiCoO$_2$</td>
<td>145</td>
<td>3.6</td>
<td>30 - 40</td>
</tr>
<tr>
<td>Li(Ni$<em>{0.85}$Co$</em>{0.1}$Al$_{0.05}$)$_2$</td>
<td>160</td>
<td>3.6</td>
<td>28 - 30</td>
</tr>
<tr>
<td>Li(Ni$<em>{1/3}$Co$</em>{1/3}$Mn$_{1/3}$)O$_2$</td>
<td>120 (200)</td>
<td>3.6 (3.9)</td>
<td>22 - 25</td>
</tr>
<tr>
<td>LiMnO$_2$</td>
<td>100</td>
<td>3.9</td>
<td>8 - 10</td>
</tr>
<tr>
<td>LiFePO$_4$</td>
<td>150</td>
<td>3.3</td>
<td>16 - 20</td>
</tr>
</tbody>
</table>

Active Material Cost Range

<table>
<thead>
<tr>
<th>$/kg</th>
<th>$/kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 - 40</td>
<td>57 - 75</td>
</tr>
<tr>
<td>28 - 30</td>
<td>~50</td>
</tr>
<tr>
<td>22 - 25</td>
<td>~55 (~30)</td>
</tr>
<tr>
<td>8 - 10</td>
<td>~25</td>
</tr>
<tr>
<td>16 - 20</td>
<td>~35</td>
</tr>
</tbody>
</table>

Peter Harben, IM July 2008
Li-ion batteries

Advantages over NiMH batteries:

• higher voltage
• lower weight
• smaller volume
• greater power and performance
• longer life
• wider temperature range performance
• less environmental impact
Fuel cells
Fuel cells

Fuel cell infrastructure vs capital investments*

*Data source: International Fuel Cell Corporation
Fuel cells
Fuel cells

Ammonia borane, sodium borohydride fuel - *borates*
Fuel cells

**Expanded single fuel cell**
- Flow field plate
- Anode - graphite
- Hydrogen fuel: ammonia, borane, sodium borohydride - borates
- Air
- Flow field plate

**Complete fuel cell stack**
- cathode - graphite

*Image credit: Ballard Power Systems*
## Fuel cells

<table>
<thead>
<tr>
<th>Type of fuel cell</th>
<th>Fuel</th>
<th>Electrode composition</th>
<th>Electrolyte composition</th>
<th>Main IM’s consumed</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phosphoric acid</td>
<td>Hydrogen</td>
<td>Platinium on carbon paper</td>
<td>Phosphoric acid</td>
<td>Phosphate rock, graphite</td>
<td>Large stationary installations</td>
</tr>
<tr>
<td>Alkaline</td>
<td>Hydrogen</td>
<td></td>
<td>Potassium hydroxide in water</td>
<td>Borates, graphite</td>
<td>Portable units: vehicles</td>
</tr>
<tr>
<td>Molten carbonate</td>
<td>Methane</td>
<td>Anode: nickel chromium. Cathode: nickel oxide (lithium doped)</td>
<td>Lithium, sodium, potassium or magnesium carbonates</td>
<td>Lithium minerals (spodumene, Li enriched brines)</td>
<td>Large stationary installations</td>
</tr>
</tbody>
</table>

**Fuel cell designs and IM consumption**
### Fuel cells

#### Fuel cell designs and IM consumption

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<th>Type of fuel cell</th>
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<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid oxide (SOFC)</td>
<td>Methane</td>
<td>Anode: Nickel zirconia. Cathode: lanthanum</td>
<td>Calcium or zirconium oxide</td>
<td>Zircon, rare earths, calcite, dolomite, gypsum</td>
<td>Large stationary installations</td>
</tr>
<tr>
<td>Proton exchange membrane (PEM)</td>
<td>Hydrogen</td>
<td>Anode: graphite Cathode: graphite</td>
<td>A solid fluorocarbon polymer film</td>
<td>Graphite</td>
<td>Portable (vehicles), Small stationary (homes)</td>
</tr>
<tr>
<td>Direct methanol (DMFC)</td>
<td>Methanol</td>
<td></td>
<td>Polymer membrane</td>
<td></td>
<td>Small portable (laptops, music players, mobile phones)</td>
</tr>
<tr>
<td>Reversible</td>
<td>Hydrogen</td>
<td></td>
<td>PEM in water</td>
<td>Graphite</td>
<td>Small portable (laptops, music players, mobile phones)</td>
</tr>
</tbody>
</table>
Fuel cells

Daimler-Chrysler Natrium

Chrysler Town & Country Natrium® Is Designed With A Clean, Safe Energy System

- Electric Drive Motor
- Lithium Ion Battery Pack
- DC/DC Converter
- Ballard Fuel Cell Engine
- Sodium Borohydride Fuel Tank
- Hydrogen On Demand™ 54 kW net hydrogen generator

Source: DaimlerChrysler
Fuel cells

Daimler-Chrysler Natrium
Fuel cells

Mercedes-Benz F-Cell B-Class
Photovoltaic cells
Photovoltaic cells

Cumulative installed PV capacity in EU 27 and in the world

Photovoltaic cells

Figure 3: Global annual PV market Outlook until 2013

Source: EPIA
Photovoltaic cells

Figure 4: Global annual PV market Outlook per Region (Policy-Driven scenario)

Source: EPIA
Photovoltaic cells
Photovoltaic cells
Photovoltaic cells

Figure 9: Production Capacity Outlook – Crystalline technologies vs. Thin Film
Photovoltaic cells
Quartz to solar cell system

Quartz feedstock
- Metallurgical grade Si from quartz
- Solar grade polysilicon
- Multicrystalline ingots

Cutting of ingots into blocks
- Slicing Si wafers from blocks
- Solar cell manufacture
- Module manufacture

Solar cell system
- Glass minerals
- Filler minerals
- Fluorochemicals
- Fused silica crucibles
- SiC wiresaw
Photovoltaic cells
Quartz to solar cell system
Metallurgical grade Si from quartz

Simcoa, Kemerton, Australia
Photovoltaic cells
Quartz to solar cell system
Solar grade polysilicon to ingots

Fused silica crucibles
Photovoltaic cells
Quartz to solar cell system
Cutting of Si ingots into blocks
Photovoltaic cells
Quartz to solar cell system
Slicing Si wafers from multicrystalline blocks

Silicon carbide wiresaw slurry
Photovoltaic cells
Quartz to solar cell system
Slicing Si wafers from multicrystalline blocks

Silicon carbide wiresaw
Photovoltaic cells
Quartz to solar cell system
Solar cell manufacture

Simplified cross section of crystalline silicon PV cell showing use of industrial minerals

Glazing or superstrate – glassmaking minerals
Backsheet – fluoropolymers
Encapsulation resin containing Si wafer – mineral fillers
Photovoltaic cells
Quartz to solar cell system

Solar cell manufacture

A Front Sheet Materials
DuPont® Teflon® films

B Photovoltaic Encapsulants
DuPont® PV1000 Series EVA resins
DuPont® PV5200 Series encapsulant sheets
DuPont® PV5300 Series encapsulant sheets

C Metallization Pastes
DuPont® Solamet® metallization pastes

D Thin Film Substrates
DuPont® Kapton® polyimide films
DuPont Teijin Films™

E Junction Box and Structural Support Materials
DuPont® Rynite® PET thermoplastic polyester resins

F Back Sheet Materials
DuPont® Tedlar® PVF films
DuPont Teijin Films™

G High Performance Seals for Cell Manufacturing Equipment
Kalrez® perfluoroelastomer parts from DuPont Performance Elastomers
Photovoltaic cells
Quartz to solar cell system
Solar cell modules & systems
Wind turbines

GLOBAL INSTALLED CAPACITY

- Total 28,190 MW in 2008
- Total 51,390 MW in 2012

1% Inshore
8% Offshore

BTM Consult ApS - March 2009
Wind turbines

ANNUAL WIND POWER DEVELOPMENT
Actual 1990-2008 and forecast 2009-2013

MW

60,000
50,000
40,000
30,000
20,000
10,000
0


Existing Europe USA Asia Rest of world

Wind turbines

GLOBAL WIND POWER FORECAST
Cumulative MW by end of 2007 and forecast 2013

Europe | USA | Asia | Rest of world
---|---|---|---
160,000 | 140,000 | 120,000 | 100,000
140,000 | 120,000 | 100,000 | 80,000
120,000 | 100,000 | 80,000 | 60,000
100,000 | 80,000 | 60,000 | 40,000
80,000 | 60,000 | 40,000 | 20,000
60,000 | 40,000 | 20,000 | 0
Wind turbines

SMC/fibreglass wind turbine blade – fibreglass minerals, eg. kaolin borates, alumina, lime, silica, soda ash; graphite

SMC/fibreglass nacelle – fibreglass minerals

SMC/fibreglass tower – fibreglass minerals

Motor; permanent magnets using Nd, Pr, Dy, Tb – rare earths
Wind turbines

Components of a horizontal axis wind turbine (gearbox, rotor shaft and brake assembly) being lifted into position

22.5 deg. 14x8 in. Nd wedge magnet; (2 tonnes RE/3MW wind turbine)
Wind turbines
Fibreglass blades

Glass content up to 70% of turbine blade

Owens-Corning 2020 est. = 140,000 MW = 1m. tonnes for fibreglass reinforcements (7 tonne/ MW)

Fibreglass trends & drivers:
• Weight efficient strength and stiffness
• Shorter cycle time and improved infusion process
• High surface quality of manufactured blades
• Cost reduction/cycle time
• Longer blades enable reduced cost per kilowatt hours
• Design of blades greater than 45m in length is becoming more critical
• High performance materials enable the manufacture of low weight blades greater than 45m
Wind turbines
Fibreglass blades

OCV™ Advantex® Unifilo® Continuous Filament Mat Provides strength, impact and corrosion resistance

OCV™ Advantex® Single-End Roving Provides tensile strength, modulus and corrosion resistance

OCV™ Advantex® Surfacings Veil Provides corrosion resistance and Aesthetic surface

OC boron-free and fluorine-free Advantex® glass composites ensure high strength-to-weight ratio, design flexibility, excellent fatigue and corrosion resistance, and reduced drag
Wind turbines
Sheet moulding compound components

SMC is a combination of chopped glass strands and filled polyester resin in the form of a sheet.

Mineral fillers, eg. talc, wollastonite, GCC etc.
## Summary & conclusions

**Applications and IMs**

<table>
<thead>
<tr>
<th>Application</th>
<th>Minerals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li-ion batteries</td>
<td>lithium minerals, fluorspar, graphite</td>
</tr>
<tr>
<td>Fuel cells</td>
<td>borates, graphite, lithium minerals, phosphates, rare earths, zircon</td>
</tr>
<tr>
<td>Photovoltaic cells</td>
<td>quartz, fused silica, silicon carbide, fluorspar, filler minerals</td>
</tr>
<tr>
<td>Wind turbines</td>
<td>fibreglass minerals, rare earths, graphite, filler minerals</td>
</tr>
</tbody>
</table>
Summary & conclusions
Supply concerns: rare earths shortage

Perceived gap in future demand vs. supply, compounded by Chinese RE export reduction
Summary & conclusions
Supply concerns: rare earths demand increase

<table>
<thead>
<tr>
<th>Application</th>
<th>Consumption tpa REO</th>
<th>Market growth 2011-14</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2008f</td>
<td>2014f</td>
</tr>
<tr>
<td>Catalysts</td>
<td>23,000</td>
<td>28-30,000</td>
</tr>
<tr>
<td>Glass</td>
<td>12,500</td>
<td>12-13,000</td>
</tr>
<tr>
<td>Polishing</td>
<td>15,000</td>
<td>19-21,000</td>
</tr>
<tr>
<td>Metal Alloys</td>
<td>22,500</td>
<td>45-47,000</td>
</tr>
<tr>
<td>Magnets</td>
<td>26,500</td>
<td>39-43,000</td>
</tr>
<tr>
<td>Phosphors &amp; Pigments</td>
<td>9,000</td>
<td>11-13,000</td>
</tr>
<tr>
<td>Ceramics</td>
<td>7,000</td>
<td>8-10,000</td>
</tr>
<tr>
<td>Other</td>
<td>8,500</td>
<td>10-12,000</td>
</tr>
<tr>
<td>Total/Range</td>
<td>124,000</td>
<td>170-190,000</td>
</tr>
</tbody>
</table>

Source: Dudley Kingsnorth, Industrial Minerals Co. of Australia.
Summary & conclusions
Supply concerns: lithium demand increase

LIB growth in e-cars
40% 2010-2020 = 40,000 t LCE
12% 2020-2030 = 125,000 t LCE

Patricio de Solminihac, SQM, Lithium Supply & Markets 2010
Summary & conclusions
Supply concerns: lithium developments rush

Jay Chmelauskas, Western Lithium, Lithium Supply & Markets 2010
Summary & conclusions
Supply concerns: lithium oversupply

Patricio de Solminihac, SQM, Lithium Supply & Markets 2010
Summary & conclusions
Supply concerns: graphite

Graphite 2nd largest input material by volume in Li-ion batteries, mainly for conductivity properties.

Estimated that about 3-7kg/battery is needed.

“The need for graphite will be about 1m. tpa”
George Hawley, leading graphite consultant
= double the world’s present production of natural flake graphite

Concerns over Chinese reduction in flake graphite supply/exports
Summary & conclusions

There will be healthy future demand for IMs in new energy systems

Demand tempered by end use technology, economic viability, recyclability

Consistent availability of specific grades (correct processing) is key to raw material supply

Certain minerals deemed “strategic” with associated supply concerns, eg. graphite, lithium, rare earths; supply/demand debate

Enhanced interest in new mineral sources, especially outside China

These minerals will see their prices increase

More investment/j-vs end users & raw materials; closer co-operation between end users and raw material developers in grade development

More activity by government and industry associations addressing “strategic” mineral issues, eg. EC critical list May 2010
Hope to see you in Miami
IM20 Congress 21-24 March

Details at our booth #538
Thank you for your attention