BASF - ANL Collaboration on NCM Cathode Materials

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Commission to Review the Effectiveness of the National Energy Laboratories

November 4, 2014
We combine economic success, social responsibility and environmental protection

Sales 2013: €73,973 million

EBIT 2013: €7,273 million

Employees (as of December 31, 2013): 112,206

6 Verbund sites and 376 other production sites

Our chemistry is used in almost all industries – Sales into automotive industry around 15% of total sales
# Chemistry-based innovations @ BASF

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<tr>
<th>Global needs</th>
<th>Key customer industries</th>
<th>Growth fields</th>
<th>Technology fields</th>
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<tbody>
<tr>
<td>Resources, Environment &amp; Climate</td>
<td>Transportation, Agriculture</td>
<td>Batteries for Mobility, Enzymes</td>
<td>Materials, Systems &amp; Nanotechnology</td>
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<td>Quality of Life</td>
<td>Consumer Goods, Electronics</td>
<td>Heat Management for Construction, Lightweight Composites</td>
<td>White Biotechnology</td>
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<td>Health &amp; Nutrition</td>
<td>Organic Electronics, Plant Biotechnology</td>
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<td>Water Solutions, Wind Energy</td>
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**BASF – The Chemical Company**

*BASF’s Comprehensive Battery Materials Portfolio*

- Global business unit established 2012
- Significant expansion of the scope of its battery materials technologies over the last two years
  - Start-up of own production sites
  - Licensing agreements
  - Multiple acquisitions
  - Investment into companies
- In-house R&D and strategic partnerships
Argonne National Laboratory

ANL and Inventors – Strong Reputation

Did you know?

> Argonne has broad battery portfolio of 150+ cathode, anode, electrolyte, coatings and additive technologies that are available for licensing.
> Argonne works with manufacturers to optimize their existing battery technologies or develop new technologies.

As a U.S. Department of Energy (DOE) National Laboratory, Argonne supports the development of advanced energy technologies for the benefit of the nation, its economy and economic competitiveness. Argonne’s research facilities are open to researchers, developers and manufacturers through various work or cooperative agreements.

As part of its research portfolio, Argonne operates the Joint Center for Energy Storage Research (JCESR), a major research partnership that integrates government, academic and industrial researchers from many disciplines to overcome critical scientific and technical barriers and create new breakthrough energy storage technologies. For more information, go to www.jcesr.org.

Argonne also directs DOE’s Energy Frontier Research Center for Energy Storage, the Center for Electrical Energy Storage (CEES), which was established to acquire a fundamental understanding of interfacial phenomena controlling electrochemical processes to improve the performance of electrochemical energy storage devices, notably lithium-ion batteries. For more information go to http://web.anl.gov/energy-storage-science/.

Work with Argonne

Argonne’s Technology Development & Commercialization (TDC) office oversees the laboratory’s development and progress of research projects with private sector firms.

Contact Argonne TDC at 800.627.2596 or partners@anl.gov to learn about Argonne’s patented technologies and how to tap into Argonne’s battery R&D resources.

BASF collaboration with ANL on patent protection and commercialization of ANL Technology.

“Argonne’s strength is that its battery research initiatives cover the broad space of discovery science through to technological implementation.”

— Michael Thackeray, Li-ion battery research pioneer

DOE’s investment in Argonne’s advanced battery research supports Obama administration goals to reduce American reliance on oil, decrease greenhouse gas emissions and create jobs, in this case through the development of a growing industry.

Argonne employs several of the field’s top scientists and is home to some of the world’s most sophisticated and unique scientific research facilities, including the Advanced Photon Source, the Advanced Leadership Computing Facility and the Materials Engineering Research Facility. These facilities allow scientists to gain not only an in-depth understanding of a battery material’s structure, but also to develop, bench test and scale-up innovative new materials for industrial investigation and potential commercialization.

Argonne is DOE’s primary National Laboratory for battery research. The Laboratory has a portfolio of more than 150 battery patents and inventions that are available for licensing. Argonne also operates DOE’s energy storage hub, the Joint Center for Energy Storage Research (JCESR), which is developing next generation batteries and other energy storage technologies that go beyond lithium-ion systems.

Argonne National Laboratory seeks solutions to pressing national problems in science and technology. The nation’s first national laboratory, Argonne conducts leading-edge basic and applied scientific research in virtually every scientific discipline. Argonne researchers work closely with researchers from hundreds of companies, universities, and federal, state and municipal agencies to help them solve their specific problems, advance America’s scientific leadership and prepare the nation for a better future. With employees from more than 60 nations, Argonne is managed by UChicago Argonne, LLC for the U.S. Department of Energy’s Office of Science.
Argonne Battery Technology

Patent Confirmed by U.S. Patent Office

January 29, 2014

The U.S. Department of Energy’s (DOE) Argonne National Laboratory is pleased to announce that after a careful reexamination of the relevant prior patents and publications, the U.S. Patent and Trademark Office (USPTO) has confirmed the novelty of U.S. Patent 6,677,082.

NMC cathode technology as described in this patent can be found in commercial consumer and vehicle lithium-ion batteries.

See more at:
http://www.anl.gov/technology
NCM Product Overview

Broad range of available compositions

1. State-of-the-art
   - **NCM 111**: \(\text{Li}_{1+x}(\text{Ni}_{0.33}\text{Co}_{0.33}\text{Mn}_{0.33})_{1-x}\text{O}_2\)
     - Discharge Capacity: 154 Ah/kg @ 0.1C
   - **NCM 523**: \(\text{Li}_{1+x}(\text{Ni}_{0.5}\text{Co}_{0.2}\text{Mn}_{0.3})_{1-x}\text{O}_2\)
     - Discharge Capacity: 164 Ah/kg @ 0.1C
   - **NCM 424**: \(\text{Li}_{1+x}(\text{Ni}_{0.4}\text{Co}_{0.2}\text{Mn}_{0.4})_{1-x}\text{O}_2\)
     - Discharge Capacity: 155 Ah/kg @ 0.1C

2. Hi Nickel
   - **NCM 622**
     - Discharge Capacity: 178 Ah/kg @ 0.1C
   - **NCM 811** and others
     - Discharge Capacity: >185 Ah/kg @ 0.1C

3. Mn rich
   - **HE-NCM**: Discharge Capacity: 260 Ah/kg @ 0.1C
   - **HV-Spinel**:
     - Discharge Capacity: 140 Ah/kg @ 1C

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**NCM COMPOSITION DIAGRAM**

- **High capacity region**
- **High stability region**
- **Lower cost region**

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November 4, 2014
BASF Battery Materials - Manufacturing

NCM plant – Elyria, Ohio

Electrolytes - Zachary, Louisiana and Suzhou, China

NCM & LFP Cathode Materials

- Fully operational production plants
- Suitable for NCM materials as well as for next generation high energy NCM

Electrolytes

- State-of-the-art manufacturing technology
- Global presence: North America and China

BASF Global Presence – includes R&D and Pilot Production in Ludwigshafen, Germany
BASF’s battery materials portfolio:
Driving Your Success

Solid IP position
- ANL license for NCM cathode materials
- Ovonic patents for NCM precursors
- LFP license from LiFePO4+C Licensing AG
- VC license from Mitsubishi Chemicals

Strong R&D
- R&D Centers in the US, Europe and Asia
- Strong development pipeline for cathode materials and electrolytes
- Global expert network to support BASF’s R&D

Broad portfolio
- NiMH Technology from Ovonic Batteries
- Formulated electrolytes
- NCM and LFP cathode materials
- Li-Sulfur development together with Sion Power

Global presence
- NCM production in Elyria, Ohio US
- LFP production in Germany
- Electrolyte production in Baton Rouge (US) and Suzhou (China)
- Customer application centers in the US, Germany, China and Japan

BASF’s Battery Materials: Customer centric
High Energy Cathode Materials

Overview about next generation cathode materials

HE NCM
Marked capacity increase at slightly lower voltage “High Energy”

HV Spinel
Marked voltage increase at slightly lower capacity “High Voltage”

Performance benefit calculated in a model cell

<table>
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<th>Gravimetric energy density [Wh/kg]</th>
<th>Volumetric energy density [Wh/l]</th>
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<tbody>
<tr>
<td>NCM-111</td>
<td>219</td>
<td>606</td>
</tr>
<tr>
<td>HE-NCM</td>
<td>+15%</td>
<td>+5%</td>
</tr>
<tr>
<td>HV spinel</td>
<td>+8%</td>
<td>+8%</td>
</tr>
</tbody>
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Discharge profiles HE-NCM vs. NCM-111

Discharge profiles HV spinel vs. NCM-111

\[ E = Q \times U \]

November 4, 2014
BASF Battery Materials

Global footprint

NCM production

LFP production
LFP production in Ludwigshafen and Weimar, Germany (3.0 kt)

Application labs, research centers

Amagasaki, Japan. Further application labs in the US, China and Germany
Research centers in the US and Germany

Electrolyte production

Production capacity in Suzhou, China. Further capacity in Louisiana

NCM production plant in Elyria, US (2.4 kt)
BASF Collaboration with ANL
Multiple Fields including Battery and Agricultural

- BASF is proud licensee of ANL NCM Cathode Technology
- Active development of next generation NCM Materials
- Capital Investment for Commercialization
  - Elyria, Ohio factory for NCM Calcination
  - Acquisition of Ovonic Precursor
- Patent Collaboration
Thank you