SPECIALTY CARBONS FOR THE POSITIVE ELECTRODE OF LITHIUM-ION BATTERIES

C-NERGY™
TIMCAL Carbon Black

C-NERGY™
TIMCAL Graphite
WHO ARE WE?

IMERYS Graphite & Carbon has a strong tradition and history in carbon manufacturing. Its first manufacturing operation was founded in 1908. Today, IMERYS Graphite & Carbon facilities produce and market a large variety of synthetic and natural graphite powders, conductive carbon blacks and water-based dispersions of consistent high quality.

Adhering to a philosophy of Total Quality Management and continuous process improvement, all Imerys Graphite & Carbon manufacturing plants comply with ISO 9001:2008. IMERYS Graphite & Carbon is committed to produce highly specialized graphite and carbon materials for today’s and tomorrow’s customers needs.

IMERYS Graphite & Carbon belongs to IMERYS, the world leader in mineral-based specialties for industry.

WHERE ARE WE LOCATED?

With headquarters located in Switzerland, IMERYS Graphite & Carbon has an international presence with production facilities and commercial offices located in key markets around the globe. The Group’s industrial and commercial activities are managed by an experienced multinational team of more than 430 employees from many countries on three continents.

For the updated list of commercial offices and distributors please visit www.imerys-graphite-and-carbon.com

What is our mission?

To promote our economic, social and cultural advancement with enthusiasm, efficiency and dynamism by offering value, reliability and quality to ensure the lasting success of our customers.

What is our vision?

To be the worldwide leader and to be recognized as the reference for innovative capability in the field of carbon powder-based solutions.
Product characteristics vs. application benefits

1. VERY HIGH PURITY

**Product characteristics**
- The total Fe content for our conductive carbon blacks is less than 5 ppm
- The total Fe content for our graphite is less than 20 ppm
- C-NERGY™ grades have very low total metallic impurity content

**Application benefits**
- Increased battery safety
- Lower rejection ratio
- Fully compatible with most electrolyte systems

<table>
<thead>
<tr>
<th>PRODUCT</th>
<th>BET SURFACE AREA (m²/g)</th>
<th>ASH CONTENT (wt. %)</th>
<th>TOTAL FE (ppm)</th>
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<tr>
<td>Carbon black</td>
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<tr>
<td>SUPER P® Li</td>
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<td>C-NERGY™ SUPER C65</td>
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</table>

Typical value

2. EASE OF PROCESSABILITY

**Product characteristics**
- The BET surface area for our conductive carbon blacks is lower than competition
- Well-defined particle size distribution (PSD)
- Well-suited for lithium-ion battery processing environment

**Application benefits**
- No additional pre-dispersing unit is needed
- No dispersing aid is needed
- Very high loading is possible
- Cost savings on NMP and faster drying time when C-NERGY™ SUPER C45 is applied

3. HIGH ELECTRICAL CONDUCTIVITY

**Product characteristics**
- High structure, which can be seen from the high oil absorption number (OAN)
- High crystallinity
- Low dosage is sufficient to achieve the percolation threshold

**Application benefits**
- High energy density
- Improved power density
- Cost reduction thanks to lower dosage needed

4. GOOD COMPRESSIBILITY

**Product characteristics**
- Compressibility can be increased with the addition of fine graphite particles having high crystallinity and low spring back

**Application benefits**
- High energy density
- Improved power density
- Improved “flexibility” of the electrode
Percolation curves of C-NERGY™ SUPER C65 in different active materials

Electrical volume resistivity of dry powder mixtures consisting of either LiFePO₄ (LFP), LiNi₀.₃Mn₀.₃Co₀.₃O₂ (NMC), or LiCoO₂ (LCO) with various dosages of C-NERGY™ SUPER C65 conductive additive (measured at 450 kg/cm²). The percolation curves are specific for a particular carbon additive: active material pairing and must be determined experimentally. The measured percolation curves are useful for the development of electrode formulations containing suitable concentrations of conductive additives.

Percolation curves of different conductive additives in LiCoO₂

Electrical volume resistivity of dry powder mixtures consisting of LiCoO₂ with various dosages of different conductive additives (measured at 450 kg/cm²). C-NERGY™ conductive additives have complementary characteristics; carbon black starts percolating at lower concentration, while graphite enhances the compressibility, resulting in lower resistivity at high additive concentrations. Both C-NERGY™ SUPER C65 and SUPER C45 decrease the electrical resistivity of the powder mixtures to lower levels compared to acetylene black.
Percollation curves of C-NERGY™ conductive additives in LiFePO₄
Electrical volume resistivity of dry powder mixtures consisting of LiFePO₄ with various dosages of different C-NERGY™ conductive additives (measured at 450 kg/cm²). The percolation curves in LiFePO₄ are shifted to higher concentrations of conductive additive due to the higher resistivity of LiFePO₄ compared to LiCoO₂. At low additive concentration, mixing conductive carbon black with graphite allows for increased compressibility without significant loss of conductivity (synergistic effect).

![Percolation curves of C-NERGY™ conductive additives in LiFePO₄](image)

Electrical resistivity of LiFePO₄ with 6 wt. % C-NERGY™ conductive additives
Electrical volume resistivity vs. sample density of dry powder mixtures consisting of LiFePO₄ with 6 wt. % of different C-NERGY™ conductive additives. Conductive carbon black efficiently decreases the electrical resistivity at low additive concentrations, whereas graphite enhances the compressibility of the powder mixtures and improves the inter-particle contacts. A synergistic effect is observed when mixing conductive carbon black with graphite (giving simultaneously good compressibility and low electrical resistivity).

![Electrical resistivity of LiFePO₄ with 6 wt. % C-NERGY™ conductive additives](image)
Rheology of LiCoO\textsubscript{2} dispersions in NMP for different conductive additives

Rheology of LiCoO\textsubscript{2} (94 wt. %), PVDF (3 wt. %), and 3 wt. % of either C-NERGY\textsuperscript{TM} SUPER C45, C-NERGY\textsuperscript{TM} SUPER C65, or acetylene black dispersed in N-methyl pyrrolidone (NMP) for the same total mass of the dispersion.

The BET surface area of the conductive additive plays an important role on the rheology of the electrode dispersion. Electrode manufacturing requiring a lower amount of solvent and shorter drying time is possible when using C-NERGY\textsuperscript{TM} SUPER C45 thanks to the lower viscosity of its liquid dispersions. This enables additional costs savings and increased electrode productivity.

![Graph showing viscosity vs. shear rate for different conductive additives.](image)

**Thermal diffusivity of LiFePO\textsubscript{4} electrodes with 5 wt. % C-NERGY\textsuperscript{TM} conductive additives**

Thermal diffusivity of LiFePO\textsubscript{4} electrodes containing either C-NERGY\textsuperscript{TM} SUPER C65, C-NERGY\textsuperscript{TM} KS6L, or a 1:1 mixture (by weight) of SUPER C65 and KS6L (90 wt. % LiFePO\textsubscript{4}; total 5 wt. % conductive additives; 5 wt. % PVDF).

Small amounts of C-NERGY\textsuperscript{TM} KS6L significantly increase the thermal diffusivity of positive electrodes; this leads to an improved heat dissipation in the electrodes.

![Graph showing thermal diffusivity vs. type of conductive additive.](image)
MAKE YOUR BATTERY WORK AT ITS BEST WITH DEDICATED IMERYS GRAPHITE & CARBON ADDITIVES
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