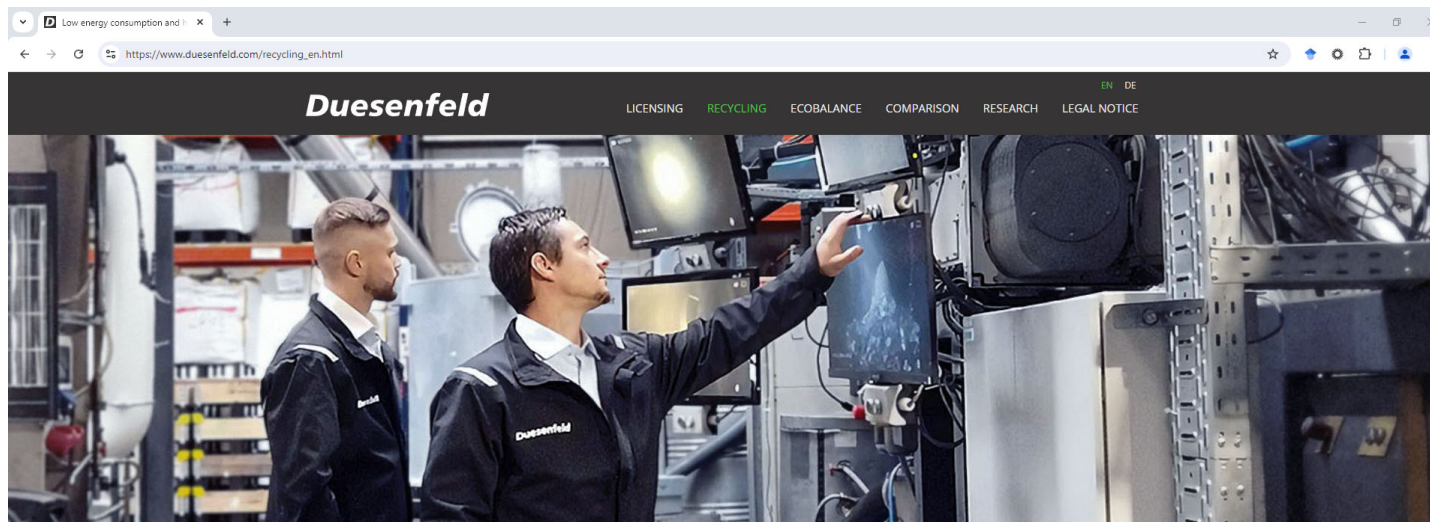


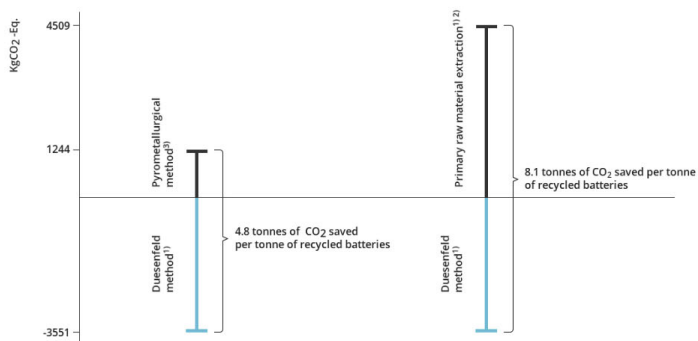


Ecofriendly Recycling of Lithium-Ion Batteries

Duesenfeld combines mechanical, thermodynamic and hydrometallurgical processes in a patented process. The process achieves the highest material recovery rates with low energy consumption. This is made possible by a process control with low temperatures, in which toxic hydrogen fluoride are not produced. Exhaust gas scrubbing is not necessary in the mechanical processing step. The fluorides are removed in a targeted and safe manner in hydrometallurgy.

Duesenfeld operates the only recycling process that, in addition to the usual metals, also supplies graphite, electrolytes and lithium for material recycling. Material recycling does not mean a declaration as a building material, e.g. for road construction, but all metals are recovered with high recovery rates in the form of high-quality secondary raw materials up to battery quality. The production of secondary raw materials with the Duesenfeld recycling process saves 8.1 tons of CO₂ per ton of recycled batteries compared to the primary extraction of the raw materials³⁾⁴⁾. Compared to conventional melting processes, the Duesenfeld process saves 4.8 tons of CO₂ per ton of recycled batteries³⁾⁵⁾, compared to mechanical processes with exhaust gas scrubbing, the saving is 1 ton of CO₂ per ton of recycled battery³⁾.

CO₂ savings in comparison with pyrometallurgical processes and primary production

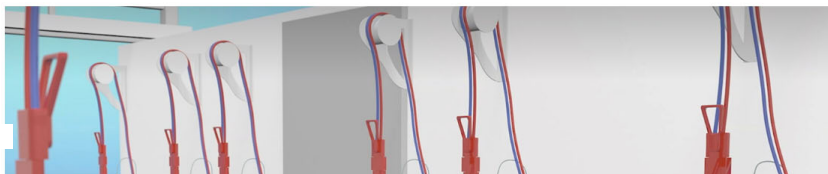


CO₂ saving in comparison^{3) 4) 5) 6)}

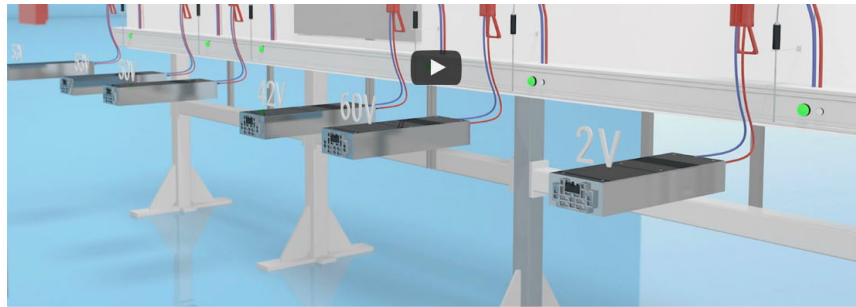
Electric mobility is Climate Friendly only with Duesenfeld Recycling

CO₂ savings from electric mobility to slow down global warming must not be nullified by inappropriate recycling of the batteries. With the environmentally friendly process from Duesenfeld, no CO₂ is produced during mechanical recycling, no toxic filter materials have to be deposited.

The Duesenfeld process achieves a more than twice as high material recovery rate for lithium-ion batteries as conventional recycling methods through mechanical processing. Supplemented by hydrometallurgical processes, almost complete recycling is possible. End-of-life batteries are usually classified as hazardous goods and transported in battery transport containers. The electrolyte is separated from the other substances by mechanical processing with modular recycling systems on site, the resulting products no longer require special hazardous goods transport containers. These intermediates are transported in standard containers, which makes it possible to transport 7 times the amount per truck. This reduction in the transport of dangerous goods saves a large part of the total recycling costs of the batteries.



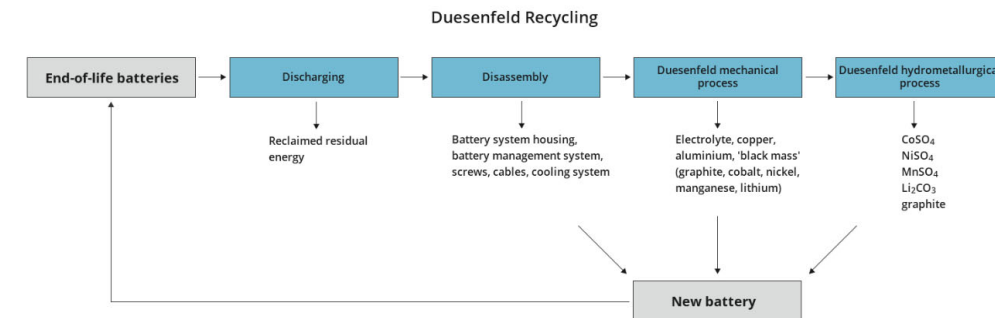
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Our focus is on recycling the batteries as completely as possible. Duesenfeld achieves a recycling rate of 72% in mechanical recycling, with the processing of the Duesenfeld Black® in Duesenfeld hydrometallurgy, the material recycling rate increases to 91%. Only the separator film and the high boiler portion of the electrolyte are not recovered at the moment. Duesenfeld thus goes far beyond the current requirements of the EU Battery Directive 2006/66/EC.

Innovative process chain for Recycling Lithium-Ion Batteries

The innovative Duesenfeld process chain was specially developed for lithium-ion batteries and is protected by extensive patents. Duesenfeld's unique combination of discharging, mechanical processing and hydrometallurgy, as well as the elimination of high-temperature processes, enables a comprehensive cycle closure of the battery materials. This makes Duesenfeld the technology leader in the field of lithium-ion battery recycling.



Recovery at Duesenfeld Recycling

Discharging

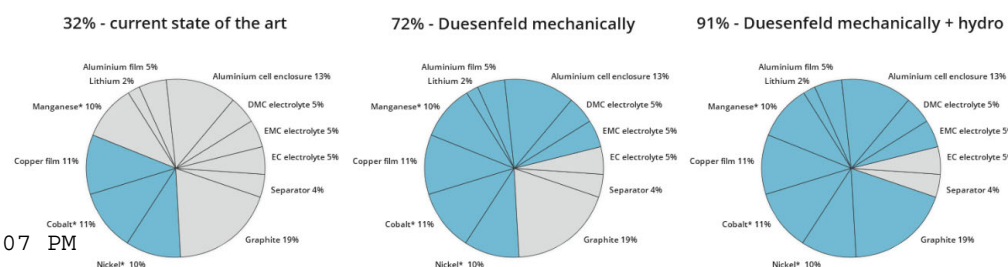
The recycling of lithium-ion batteries starts with the patented deep discharge of the batteries and the recovery of the energy. The deep discharge of the batteries using the Duesenfeld process ensures safe and efficient discharging of cells, modules or packs connected in series. The intelligent control software enables an automated deep discharge of the batteries independent of various factors such as the state of charge, the voltage, the age of the battery or the manufacturer. Due to the high linear discharge power, a large throughput and highest possible efficiency is achieved. The recovered electricity can be used to operate the recycling plant or fed into the grid.

The Duesenfeld discharging systems guarantee maximum safety and protection against incorrect operation through permanent software monitoring during the discharging process. For example, the connected lithium-ion batteries can be safely and easily replaced during operation through quick contacting.

Thanks to the patented technology, there is no further electrical risk involved in the subsequent process steps. At the same time, there is no need for high-voltage authorised personnel for the subsequent optional disassembly of lithium-ion battery packs.

Duesenfeld discharging of lithium-ion batteries ensures employee protection, process safety and high efficiency.

Recycling efficiency of a lithium-ion battery cell



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Comparison of recycling rates at battery cell level without battery housings, fastening systems, screw connections, cabling and Electronics

Mechanical Processing

The mechanical treatment of lithium-ion batteries is a demanding task due to the flammable electrolyte and dangerous ingredients. For safe reprocessing, Duesenfeld has developed and patented a process that eliminates the specific hazards in the process.

After discharge and disassembly, the batteries are comminuted under an inert gas atmosphere and the solvent of the electrolyte is recovered from the comminuted material by vacuum distillation. A low process temperature prevents the formation of toxic gases, so no exhaust gas scrubbing is necessary. The separated solvent has a very high purity level because the production of hydrogen fluoride from reaction products is avoided. The solvent is sent to the chemical industry for further processing.

The plant is also able to process dry electrode scraps from battery cell production. No retooling is necessary and the shredded material can be taken to the next stage of the sorting process without the need for drying time.

The shredded material is separated into different material fractions on the basis of physical properties such as grain size, density, magnetic and electrical properties, which are further processed metallurgically. The iron, copper and aluminium fractions are fed to established recycling routes. To process the so-called Duesenfeld Black®, which contains the electrode active materials and the conductive salt, Duesenfeld has developed a hydrometallurgical process. With this patented process, the metals cobalt, lithium, nickel and manganese as well as graphite are recovered from the Duesenfeld Black®.



Recovered electrolyte in the collecting tank

Hydrometallurgy

In most of the currently industrial hydrometallurgical processes for processing the black mass, only cobalt and nickel are recovered. Lithium, manganese and graphite are lost in these processes and are thus removed from the material cycle. Duesenfeld has developed and patented its own process, which enables a complete recirculation through the production of battery-quality raw materials of the electrode active materials.



A particular challenge in the hydrometallurgical processing of the Duesenfeld Black® is the fluorine-containing conductive salt, which can lead to the formation of hydrogen fluoride during wet chemical processing. By means of a patented, specific pretreatment step, Duesenfeld completely removes the fluoride before leaching, which reliably prevents the formation of hydrogen fluoride. After the fluoride removal, the metals are leached and thus separated from the graphite, lithium, cobalt, nickel and manganese are separated from each other by means of various extraction methods, purified and recovered in the form of salts. The salts serve as starting materials for the production of new cathode active materials.

³⁾ Screening LCA, Institute of Machine Tools and Production Technology IWF, Technical University of Braunschweig, LCA Duesenfeld Process, Prof. Dr Christoph Herrmann

⁴⁾ Wernet, G., Bauer, C., Steubing, B., Reinhard, J., Moreno-Ruiz, E., and Weidema, B., 2016. The ecoinvent database version 3 (part I): overview and methodology. The International Journal of Life Cycle Assessment, [online] 21(9), pp.1218-1230. Available at: <http://link.springer.com/10.1007/s11367-016-1087-8>, Version: Ecoinvent 3.6 cut-off

⁵⁾ Öko-Institut e.V. LCA LiBri, 2011, Development of a feasible recycling concept for the high-performance batteries of future electric vehicles - LiBri <https://www.oeko.de/uploads/oeko/oekodoc/1499/2011-068-de.pdf>

⁶⁾ Base: To ensure the comparability of the results were used for the calculations ³⁾ the same assumptions made as when calculating ⁵⁾, including lithium recovery and recycling battery housing. Generic battery composition according to the LCA Umbrella Group from the LiBri/LithoRec projects. Both recycling processes are CO-free2 rucksack (principle of first responsibility) calculated from primary raw material extraction.

