Economic analysis of sustainable material flows for next-generation lithium ion batteries

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Introduction

Electric mobility is an essential aspect for reducing greenhouse gas emissions and driving sustainability in Europe (Kucukvar et al. 2022). The electric vehicles (EVs) global market is estimated to reach 125 million units before the next decade. Powering these EVs requires high-performance Li-ion Batteries (LIBs) that are safe, economical, long-lasting, and energy-dense, with a demand increasing from about 330 GWh in 2021 to 550 GWh in 2022 (International Energy Agency, 2023). Developing of cobalt-free electrodes will reduce environmental impacts associated with batteries materials, while avoiding reliance on critical raw materials, such as cobalt, will boost electrification of European transport system (Muralidharan et al., 2022).

The HYDRA project aims at developing high-performance and sustainable LIBs with the following properties: 750 Wh/L energy density, 5C of maximum charging rate and 15C of maximum discharging rate, a life time of 2000 deep cycles and an economic cost below 90 €/kWh (HYDRA, 2020). This work aims at analysis the value chains of raw materials used in traditional and next-generation LIBs in order to study the economic aspects of the Hydra battery manufacture.

Materials and methods

The economic trades associated with the LIBs value chain (considering material extraction, processing and refining, and battery manufacture) were analyzed by comparing two cells of conventional chemistries, such as NMC811 and LFP, and three next-generation cell's chemistries, hereafter referred to as "HYDRA 0", "HYDRA 1", and "HYDRA 2". The composition of the next-generation cells is reported in Table 1.

Table 1. Composition (%wt.) of blend materials in the positive and negative electrodes

Cell	Positive electrodes			Negative electrodes	
	LMNO	LFP	Binder solvent	Graphite	Silicon
HYDRA 0	100%	0%	NMP	100%	0%
HYDRA 1	98%	2%	water	92%	8%
HYDRA 2	98%	2%	water	88%	12%

Data about cells composition, materials and design of HYDRA cells were provided during the initial phase of the project. Additional information were taken from BATPAC excel sheet maintained by the US Department of Energy and combined with the Battery Manufacturing model, developed by SINTEF as an extension to the BattMo modelling framework in MATLAB. The resulting economic analysis provides information on materials distribution and cell costs, CAPEX, and OPEX. The economic analysis was based on the following aspects: investments, labor, energy and material costs. Data about plant size, production capacity and salaries were assumed.

Results and discussion

Mining reservoirs for LIBs raw materials are unevenly distributed across the World. Indeed, lithium is mainly extracted from brine pools in South America (Chile, Argentina and Bolivia) or mineral deposits in Australia and Canada; nickel is mined from sulfide and laterite ores in Canada, Indonesia and Russia; while manganese in Australia, Gabon and South Africa (U.S. Geological Survey, 2023).

LIBs material costs depends strongly on the cost of materials contained in the positive electrodes, e.g. cobalt, lithium, manganese and nickel. HYDRA cell materials, regardless of specific chemistries, have a cost of about 65 €/kWh, which is comparable to NMC811 cell materials. HYDRA 1 cells are slightly cheaper compared to HYDRA 0 because of the blending of LFP in the cathode. But HYDRA 2 cells are more expensive because of the addition of more silicon in the negative electrodes. It is crucial to include only the necessary amount of silicon, as underutilized silicon in the blend contributes to unnecessary costs.

CAPEX and OPEX were estimated from economic modelling of a theoretical Gigawatt-scale production line. The CAPEX is below 150 mln USD for NMC811, LFP and Hydra 0 cells, and it is reduces below 125 mln USD for HYDRA 1 and HYDRA 2 cells. OPEX instead is ranging between 500 and 600 mln USD for NMC811 and HYDRA cells, while it is limited at 400 mln USD for LFP cells. Thus, avoiding the use of the NMP solvent lowers the CAPEX of the HYDRA1 and HYDRA2 production lines. The OPEX is less affected.

Cost savings due to improvements in the production process are small on the per kWh basis and are outweighed by material cost effects. Nonetheless, it the production cost target of 90 € per kWh (HYDRA, 2020) is feasible within the HYDRA development paradigm.

Conclusions

These results highlight that materials are the primary driver of cell costs, emphasizing their significance in achieving cost-effective cells. Indeed the application of LFP active materials, which is cheaper than other cathodes materials, and the limitation of silicon content in the anodes, reduced the overall cost of HYDRA cells manufacturing. A significant breakthrough emerged in the form of aqueous processing of cathode materials, showcasing potential for cost reduction in the HYDRA system. By utilizing water-based solutions instead of traditional organic solvents, costs can be significantly reduced, impacting the affordability of battery cells. Eventually, by focusing on improving its efficiency, reproducibility, and stability at scale, the industry can fully exploit the cost reduction potential offered by water-based binder solutions.

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HYDRA

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