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Carbon footprint assessment of KREBS® pumps: A comparative carbon footprint

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Industrial pumps play a crucial role in mining and resource industries, yet their energy consumption significantly contributes to greenhouse gas (GHG) emissions. This whitepaper presents a comparative product carbon footprint (PCF) of the KREBS pump range using the Life Cycle Assessment (LCA) methodology. Conducted in compliance with the ISO 14067 PCF standard, the analysis evaluates emissions across the product lifecycle, including manufacturing, operation, and end-of-life. Findings indicate that KREBS pumps achieve a 4.8% to 9.7% reduction in global warming potential (GWP) per cubic metre of slurry pumped, primarily due to enhanced energy efficiency facilitated by patented wear ring technology. While production and transportation contribute minimally to overall emissions, the operational phase dominates the carbon footprint. Based on the PCF report prepared by FLSmidth A/S Denmark (FLS) and reviewed by an independent third party, the whitepaper underscores the significance of efficiency improvements in industrial pumping applications.

Keywords:
Carbon Footprint Study, Product Carbon Footprint,
Life Cycle Assessment (LCA),
Industrial Pumps, Slurry Pumps, Energy Efficiency

Introduction

Mining is known to cause high environmental and social impacts due to its extractive nature and the fact that resources and reserves are primarily located in developing or emerging economies. However, the industry is also crucial to the net-zero transition, supplying the critical minerals, including copper, lithium, nickel, cobalt, and rare-earth elements, necessary for electric vehicles and renewable energy. Demand for these minerals is expected to increase significantly, yet must be met amid decreasing ore grades and growing pressure, through the concept of 'responsible investing' depicted in environmental, social, and governance (ESG) principles, to support sustainable development goals.

The industry is also known for its high greenhouse gas (GHG) emissions due to the use of heavy machinery and the energy-intensive nature of mining operations. The entire sector is estimated to consume 12 EJ of final energy, or 3.5% of total final energy globally (Engeco, 2021). The GHG emissions associated with primary mineral and metal production were equivalent to about 10% of the total global energy-related GHG emissions in 2018 (Azadi, Northey, Ali, &Edraki, 2020). Meanwhile, mining operations are using more energy to produce the same quantity of some metals (due to the declining ore grades mentioned above); the growing global demand for metals and minerals further compounds this challenge.

There are many feasible options to reduce mining's GHG emissions. Broadly, they can be split into four sections **(Figure 1)**:

- Reducing fugitive emissions.
- Increasing resource recovery.
- Reducing energy use and changing energy production.
- Biological solutions focused on offsetting and sequestering the CO2e released during mineralextraction and processing.

To implement such options effectively, the mining industry and regulators must accurately and transparently account for GHG emissions to implement mitigation strategies. Detailed lifecycle analyses are conducted to evaluate the environmental impact of machinery used in the mining and beneficiation process on climate change. This is accomplished by measuring the machinery's lifecycle GHG footprint . Furthermore, some companies have endeavoured to identify business activities that fall within the scope of the European Union (EU) taxonomy to develop a reporting framework that aligns with the relevant criteria. Evaluating the alignment of an eligible activity with the EU taxonomy begins with demonstrating that the activity contributes significant lifecycle GHG savings compared to the most effective alternative solution.

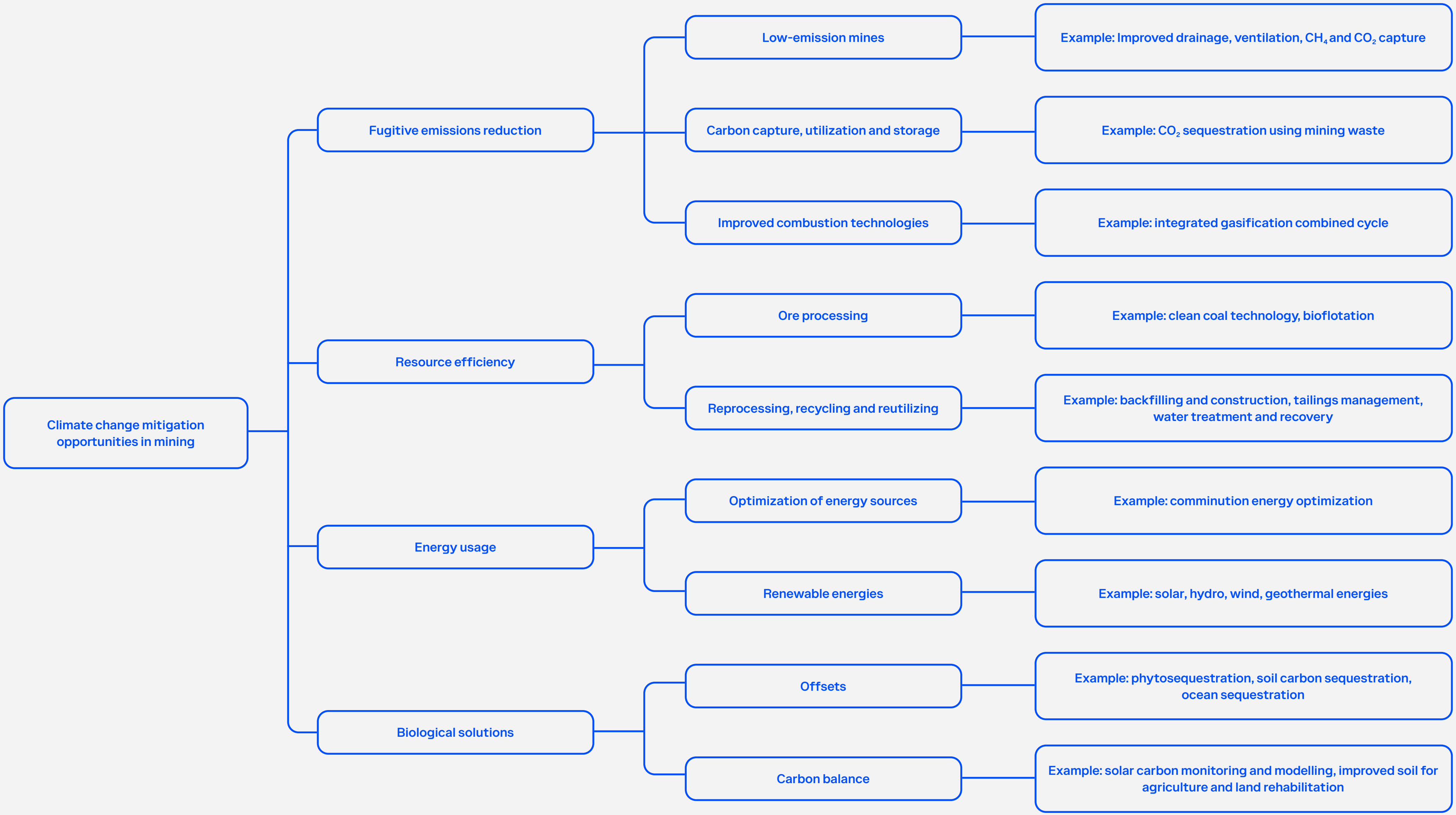


Figure 1: Pathways for climate change impact mitigation in mining (Azadi, Northey, Ali, & Edraki, 2020)

Transport of slurries and fluids in mining operations

Extracting ores from the earth's crust involves moving vast tonnages of material, as the typical ore body contains only a few percent of the metal-bearing minerals. The mined material must often be moved multiple times: first into a processing plant, then through various steps that separate the valuable minerals from waste, and finally, this waste (or tailings) is returned to the environment, often at some distance from the plant. The bulk of this processing and transport is undertaken with the material in slurry form.

A slurry pump is a device that adds energy to slurry to facilitate its movement across the various processing stages. These pumps are critical in mining and resource processing operations and are characterised by an end-suction design with energy imparted by a rotating impeller. Centrifugal pumps in hard rock mining range from 20 kW with 200 mm impellers to 4000 kW with 2 m impellers across pipelines from 50 mm to 750 mm (Visintainer, Matoušek, Pullum, & Sellgren, 2023).

An indicative mine flowsheet is shown in Figure 2, illustrating where a KREBS pump might fit. For example, in the MissionZero Mine flowsheet for copper extraction, ore arrives by conveyor, is mixed with water, and is loaded into grinding mills. The resulting slurry, a mix of water, coarse gravel, and fine sand, is recirculated through cyclone separators. Coarse solids return to the mills , while fine solids go to flotation cells where the valuable minerals are recovered as a concentrate. Both flotation concentrate and tailings remain a slurry, with concentrates processed for shipment and tailings thickened and pumped to storage areas. Slurry characteristics vary significantly through this process due to changes in particle size, density, concentration, temperature, viscosity, and chemical composition.

Pumps' energy consumption contributes substantially to their lifecycle carbon footprint, making energy-efficiency improvements a key factor in reducing environmental impact. As industries move towards more sustainable operations, Life Cycle Assessment (LCA) has become an essential tool for quantifying the carbon footprint of industrial equipment and identifying opportunities for emissions reductions.

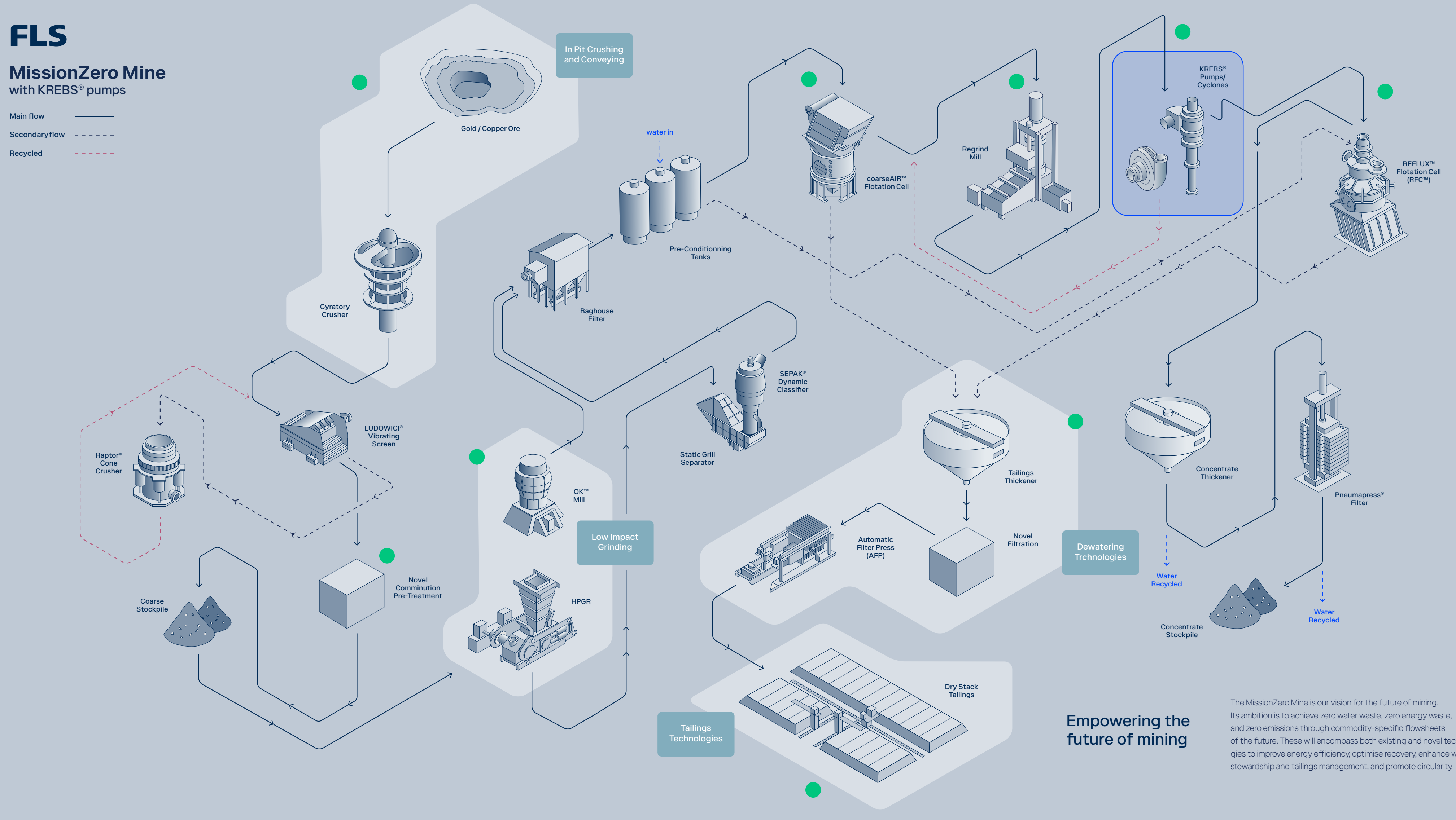
This study evaluates the carbon footprint of the KREBS pump range, developed by FLS, and compares it to the best-performing alternative pump technology available on the market. The analysis follows the ISO 14067 standard and employs a Life Cycle Impact Assessment (LCIA) approach to measure global warming potential (GWP) over the entire product lifecycle, from raw material extraction and manufacturing to operation and end-of-life disposal (Warmerdam & Vedel Hjuler, 2024).

This paper aims to:

1. Compare the GHG emissions of KREBS pumps against the best-performing alternative.
2. Identify key factors contributing to emissions reductions, particularly in the operational phase.
3. Assess the broader implications for pump design and industrial energy efficiency.

It begins by describing the KREBS pump design. LCA methodology is then discussed before concluding with a discussion of results, quantifying the environmental benefits of KREBS pumps and providing insights into how innovative pump technology can reduce the carbon footprint of mining and industrial operations.

Figure 2: The MissionZero Mine with KREBS® pumps circled blue (FLS, 2025)



Empowering the future of mining

The MissionZero Mine is our vision for the future of mining. Its ambition is to achieve zero water waste, zero energy waste, and zero emissions through commodity-specific flowsheets of the future. These will encompass both existing and novel technologies to improve energy efficiency, optimise recovery, enhance water stewardship and tailings management, and promote circularity.

Krebs pump design

As mentioned, slurry pumps are crucial in transporting slurries containing solid particles; however, they are subject to substantial wear on the flow passages, leading to material degradation and significantly reducing pump lifespan. This, in turn, results in considerable production losses. To address this challenge, particularly in the mining industry, there is a growing demand for slurry pump designs that maximise efficiency, minimise wear, and ensure long operational lifetimes (Peng, Fan, Zhou, Huang, & Ma, 2021).

Primary Causes of Pump Wear

Centrifugal slurry pumps' hydraulic efficiency and wear resistance are influenced by multiple factors. A deeper understanding of these parameters enhances component longevity and lowers operational costs in slurry transport. An optimised pump component design minimises flow instability and mitigates the impact of solid particles (Tarodiya & Gandhi, 2017).

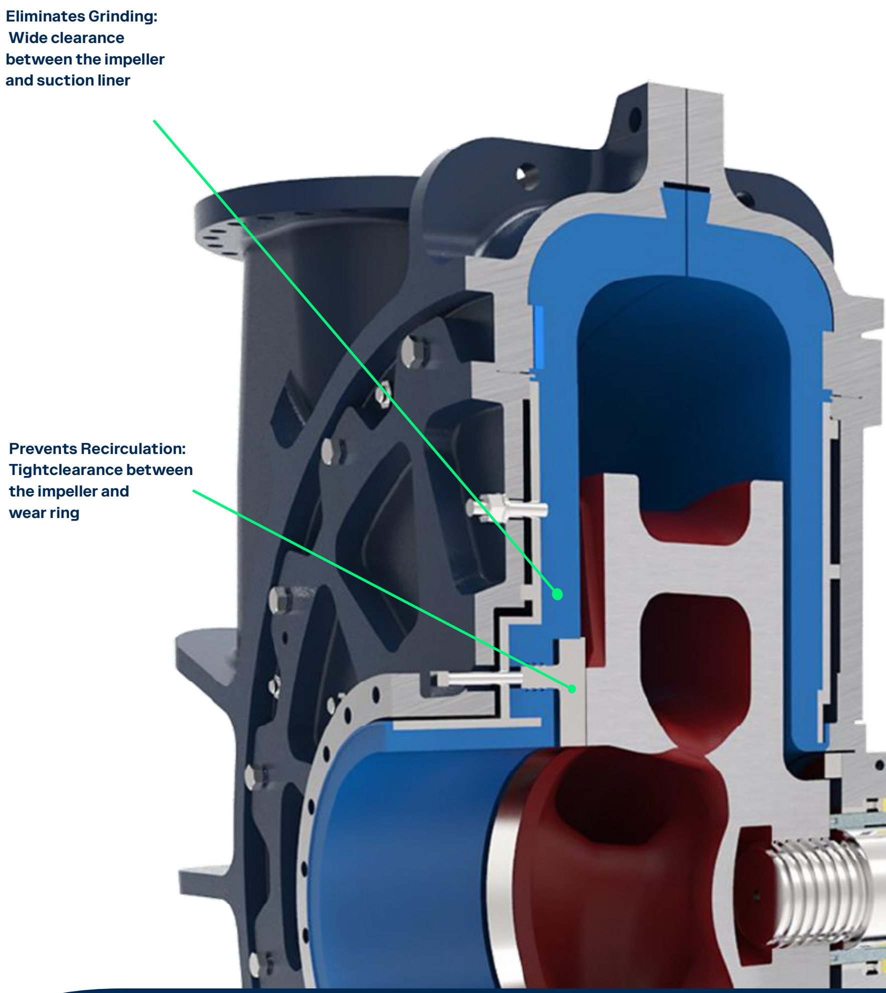
Fluids want to move from high to low pressure. Centrifugal slurry pumps take advantage of this principle. The impeller's rotation throws fluid to the outer walls of the casing, creating a low-pressure zone at the impeller's eye. This low-pressure zone is filled with higher-pressure fluid from the suction side, usually a sump, while the higher-pressure fluid at the walls moves to lower pressure regions of the discharge pipe. However, fluid at the walls will sometimes move back toward the eye via the clearance between the impeller and suction-side casing wall. This unwanted phenomenon is called recirculation. Recirculation within the casing detrimentally impacts pump efficiency; it may also affect
flow patterns in the clearance between the impeller and the suction-side liner, producing secondary gouging there. The localised wear can be severe (Visintainer, Matoušek, Pullum, & Sellgren, 2023, S. 437).

FLS sought to solve this problem by creating a patented suction-side sealing system with an adjustable wear ring. The wear ring closes the suction-side clearance at the impeller eye rather than along the entire diameter of the impeller, stopping recirculation while maintaining a large enough gap between the impeller and suction liner to avoid grinding of solids (Figure 3). This translates to significant improvements in pump performance:

- 1.5 times increase in the wear life of all wet-end parts.
- 5-10% decrease in power consumption for the same flow and head compared to a competitor by eliminating the grinding of solids.
- Adjustments to the wear ring are safe and easy to make while the pump runs.

Combined, these benefits mean the wear ring technology is best in class for addressing suction-side recirculation in slurry pumping applications (Haines, 2025), leading to significant reductions in
electricity consumption and associated GHG emissions and providing the lowest total costs of Eliminates Grinding: Wide
clearance between the impeller and suction liner
Prevents Recirculation: Tight clearance between the impeller and wear ring
5 ownership of any pump on the market. Given that use accounts for most of a pump's carbon footprint, improving efficiency at this stage offers substantial sustainability benefits.

Figure 3: KREBS pump wear ring design. Source: FLS



Methodology

Generally, an LCA analyses the entire lifecycle of the system or product under study and covers a wide range of impacts for which it attempts to provide a quantitative assessment. It focuses mainly on environmental impacts, although social and economic effects can also be included. It is a critical assessment tool, as evidenced by its significant role in environmental regulation in many parts of the world, its ISO standardisation, and the sharp increase in its use in recent decades by companies in all sectors and worldwide.

The LCA study that this whitepaper is based on aimed to quantify the carbon footprint of KREBS pumps and compare it to the best-performing alternative pump technology (Warmerdam & Vedel Hjuler, 2024). The analysis followed the ISO 14067 Product Carbon Footprint (PCF) standard and the LCA standards 14040 and 14044, which provide guidelines for assessing a product's GWP over its entire lifecycle. It was prepared using the Sphera Life Cycle Assessment for Experts software, formerly GaBi Professional, incorporating the latest available datasets at the time (version 2023.2). Prof. Michael Hauschild of Hauschild Consult reviewed the study, following the technical screening criteria of the EU taxonomy.

A PCF requires a clear definition of its goal, which sets the study's context and guides the scope definition. This includes the following (Hauschild, Rosenbaum, & Olsen, 2018):

- Defining the functional unit that quantifies the function or service assessed and determines the reference flow for data collection.
- Scoping the product system.
- Identifying relevant activities and processes.
- Selecting impact parameters.
- Specifying the environmental effects to be assessed.
- Establishing boundaries and defining the geographical, temporal, and technological scope.

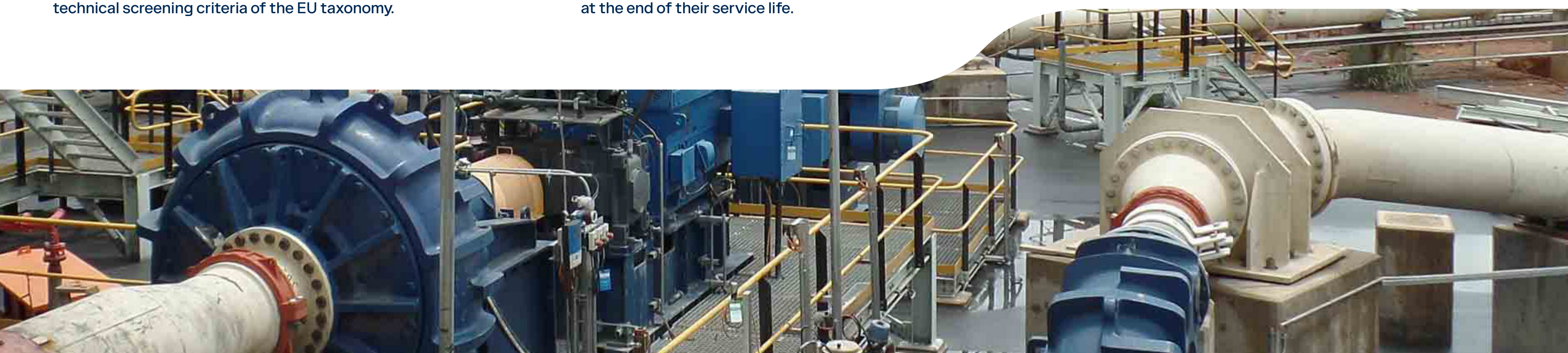
System Boundaries and Functional Unit The goal and scope definitions are crucial, as they shape data collection, system modelling, and ultimately, the validity of the study's conclusions and recommendations. The recent LCA considered the full lifecycle of the pumps, including:

1. Production: raw material extraction, component manufacturing, and assembly.
2. Transport: shipping of components to assembly sites and distribution to end-users.
3. Use: energy consumption during pump operation (the primary driver of carbon emissions).
4. End-of-life: disposal and recycling of pump components at the end of their service life.

To ensure comparability, the study defines the functional unit as follows:

> **Pumping one cubic metre of slurry with a specific gravity (SG) of 1.6 tonnes/m^3 to a total dynamic head of 35 metres.**

This functional unit reflects typical operating conditions in mining applications and enables a standardised comparison between KREBS pumps and alternative technologies. The results are expected to be reflected across the standard range of operating conditions for KREBS pumps.



Data collection and assumptions

Primary data for KREBS pumps, including material composition, energy consumption, and wear part replacement rates, were sourced from FLS's internal engineering records and real -world performance 6 studies. Secondary data, such as electricity grid emissions and material production impacts, were obtained from the Sphera LCA database and the International Energy Agency (IEA). The assessment assumed a global electricity mix, with sensitivity analyses conducted to evaluate the impact of varying grid decarbonisation scenarios.

Comparison to alternative technologies

Benchmarking KREBS pumps against competing technologies can be challenging due to the limited availability of competitor data. However, independent performance studies from real -world mining applications support the theoretical efficiency advantage. These studies demonstrate energy savings ranging from 5.3% to 34.1%, depending on slurry composition and operating conditions. The highest efficiency gains were observed in highly abrasive applications, where the wear ring significantly reduces material degradation and energy losses.

Impact Assessment And Sensitivity Analysis

The study employs the ISO 14067 Global Warming Potential 100 years (GWP 100) methodology to evaluate the carbon footprint. Given that energy consumption during use is the dominant factor in lifecycle emissions, the analysis focused on comparing electricity efficiency improvements between KREBS pumps and their alternatives. Sensitivity analyses were conducted to examine the following:

- Variations in steel production emissions.
- Differences in wear part replacement rates.
- The influence of electricity grid decarbonisation on overall results.

Results and discussion

Carbon Footprint Reduction Potential

The PCF indicates that using KREBS pumps leads to a 4.8% to 9.7% reduction in global warming potential (GWP 100) per cubic metre of slurry pumped, compared to the best performing alternative. This reduction translates to 0.0049 to 0.012 kg CO_2-equivalent per m^3 of slurry. While this may appear small on a unit basis, the cumulative effect over the lifetime of a single pump is substantial. For instance, a small KREBS pump (UMD 150x125) pumping 36 million m^3 of slurry saves 175 tonne CO_2-equivalent over its lifespan, highlighting the long-term carbon footprint benefits.

Lifecycle stage contributions

A contribution analysis reveals that use dominates the carbon footprint, accounting for over 95% of total emissions. This underscores the significance of energy efficiency in reducing GHG emissions. In contrast, the production, transport, and end-of-life phases contribute less than 5%, confirming that material selection and logistics play a minor role in overall emissions.

Lifecycle Stage	Contribution to Total GWP (%)
Production <1	<1
Transport <1	<1
Use 96-98	96-98
Wear Part Replacement 1-3	1-3
End-of-Life	0,01

Table 1: Lifecycle stage contributions (Warmerdam & Vedel Hjuler, 2024)

Sensitivity Analysis

The stability of the results was determined using a sensitivity analysis. Sensitivity analysis is a so-called post-optimal calculation: a subsequent investigation following the solution to the optimisation problem. In the sensitivity analysis, the variables of the initial problem are varied to determine the extent to which they can be changed without the change affecting the essential properties of the solution. Since it is not possible to modify all data simultaneously in a problem analysis, only one variable is changed while keeping all others constant ('ceteris paribus') (Drusche, 2023).

To evaluate the robustness of the results, several sensitivity analyses were conducted:

1. Impact of steel production. Doubling the emissions factor for steel production had a negligible effect on the overall footprint, reinforcing the dominance of the use phase.
2. Wear part replacement frequency. Assuming more frequent wear part replacements for the KREBSpumps (reducing lifetime from 4,500 hours to 1,000 hours) had a minimal impact on total emissions.
3. Electricity grid decarbonisation. In scenarios where electricity generation shifts towards lowercarbonsources (e.g., Sweden's energy mix), the carbon savings from KREBS pumps were still at least 3%, confirming their efficiency benefits across various energy contexts.

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