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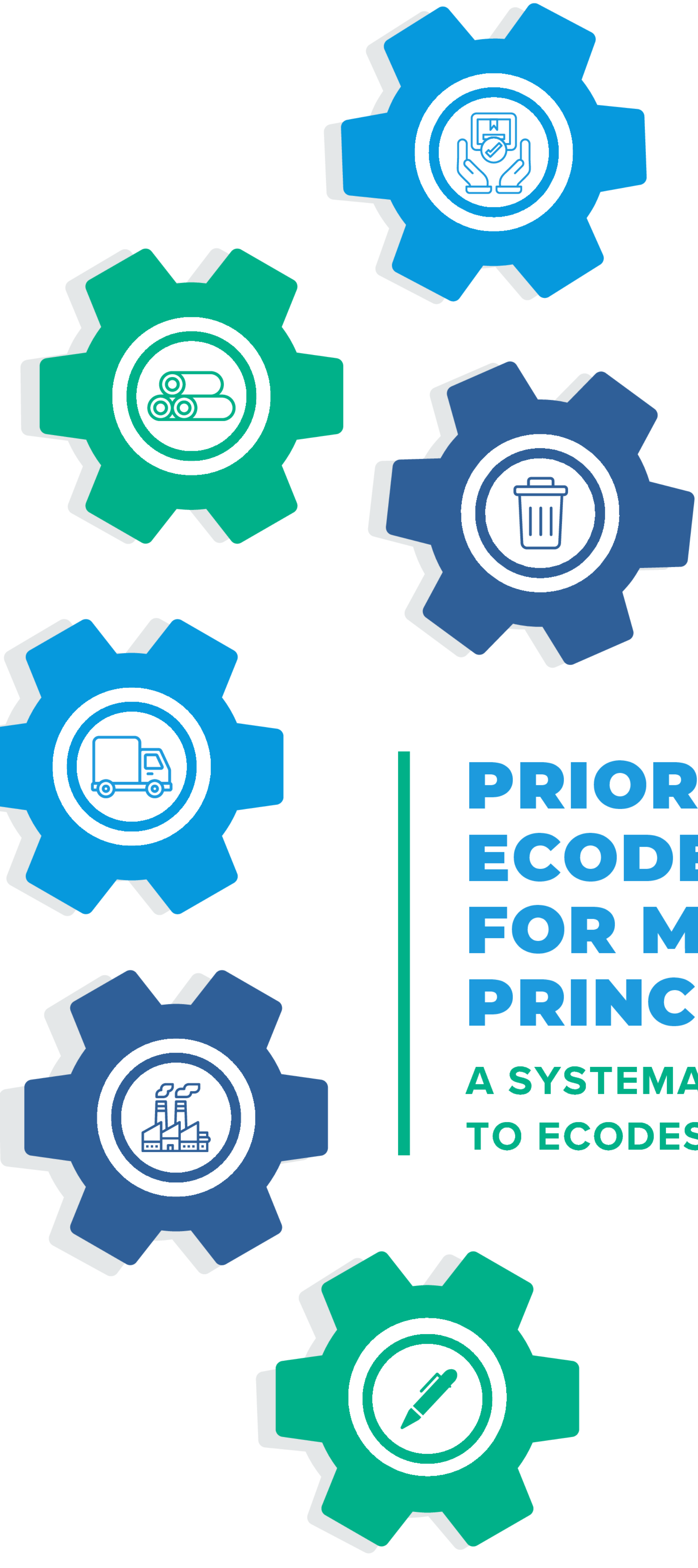

PRIORITISING ECODESIGN FOR MACHINERY PRINCIPLES:

A SYSTEMATIC APPROACH TO ECODESIGN

Enabling Net Zero
Pharma Products

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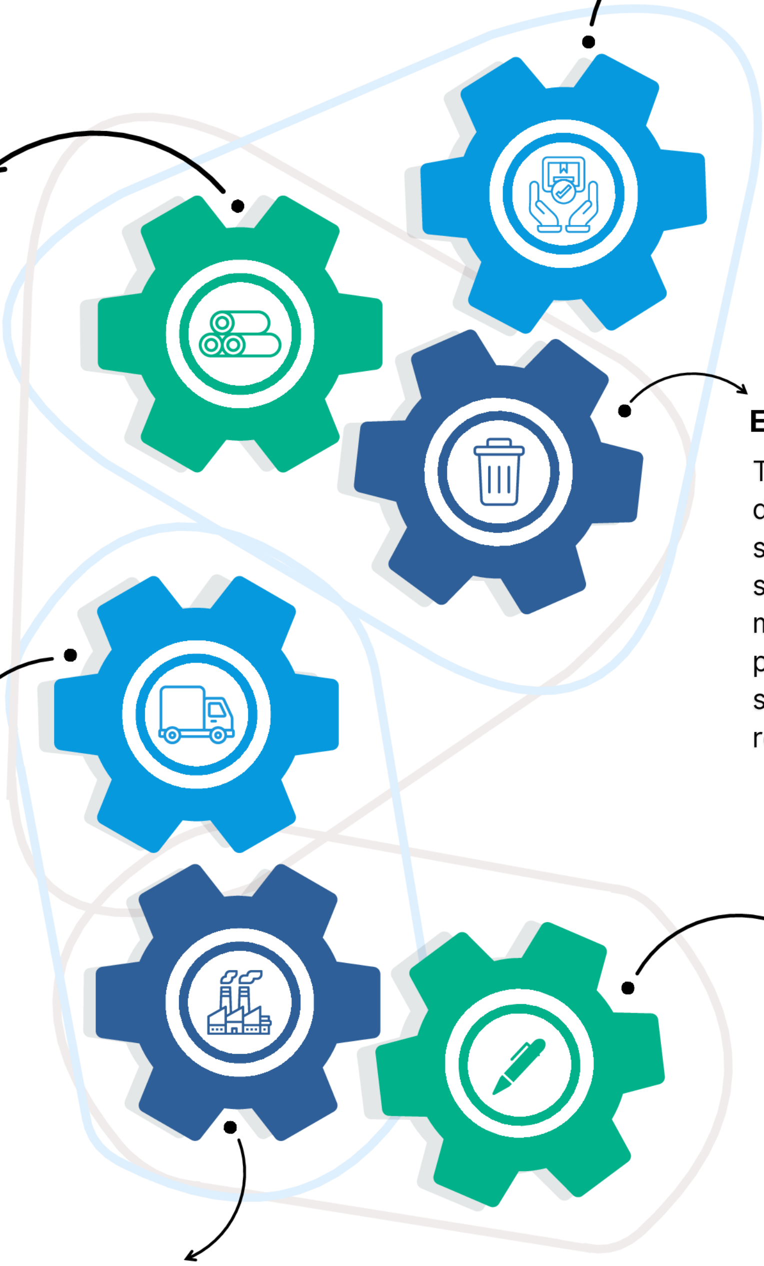


Product Use

Increase the expected lifetime of a device either through reuse, repair or remanufacture, and consider the potential energy use of an active product.

Raw Materials

The full life-cycle of materials must be considered, from the source and extraction, to the production and end-of-use processes.

End of Use

Think about end-of-use disposal at the design stage and in material selection, considering methods of recycling and possible take-back schemes to facilitate responsible disposal.

Distribution

Reduce packaging materials, increase packing density, design reusable transport containers, and explore sustainable transport.

Design Development

The true goal for eco-design is to design for circularity, focusing wider ecosystem, looking for ways to reuse materials via new processes, new value chains and regeneration pathways.

Production

Reduce energy consumption during manufacture and aim to re-use waste or by-products where possible.

OUR CORE ECODESIGN PRINCIPLES

1 Introduction

Ecodesign is often discussed at the level of individual products – for instance, a single prefilled autoinjector. However, behind every device sits a vast ecosystem of custom-built machinery that makes production possible.

These machines are constantly evolving to drive innovation across supply chains yet remain one of the most overlooked parts of the system to decarbonize. Their footprints may appear small in isolation, but at scale they represent a major, under-explored opportunity for impact.

Carbon footprint analysis shows that 8.8% of total emissions arise from member companies' assembly and packaging processes. This is a meaningful share - similar in scale to end-of-life emissions - and, crucially, it sits within our direct control.

In fact, this figure likely understates the true impact of machinery: the Alliance baseline includes only a small subset of machines, whereas industry Scope 3.2 data shows that machinery and site construction can account for anywhere from 1–3% of total emissions in some companies, up to 5–10%, and even 15–20% in others.

Machinery influences emissions in multiple ways: the embodied carbon of the equipment itself, the scrap it generates, and the energy required to operate it. These impacts depend heavily on utilisation.

A machine running at high throughput over many years has a relatively low per-unit footprint; but for low-runner products or equipment that never reaches expected volumes, the impact becomes disproportionately high.

Taken together, these insights highlight a clear opportunity: machinery design and performance are significant levers for decarbonisation.

At the same time, the majority of emissions still originate from the design, materials, use phase, and transportation of the autoinjector.

Meaningful reduction therefore requires optimising both the product and the production system for a low-carbon footprint. Key strategies for product optimisation are outlined in the whitepaper Prioritising Ecodesign Principles.

1 Introduction, cont.

Product Carbon Footprint – Prefilled Autoinjector Device

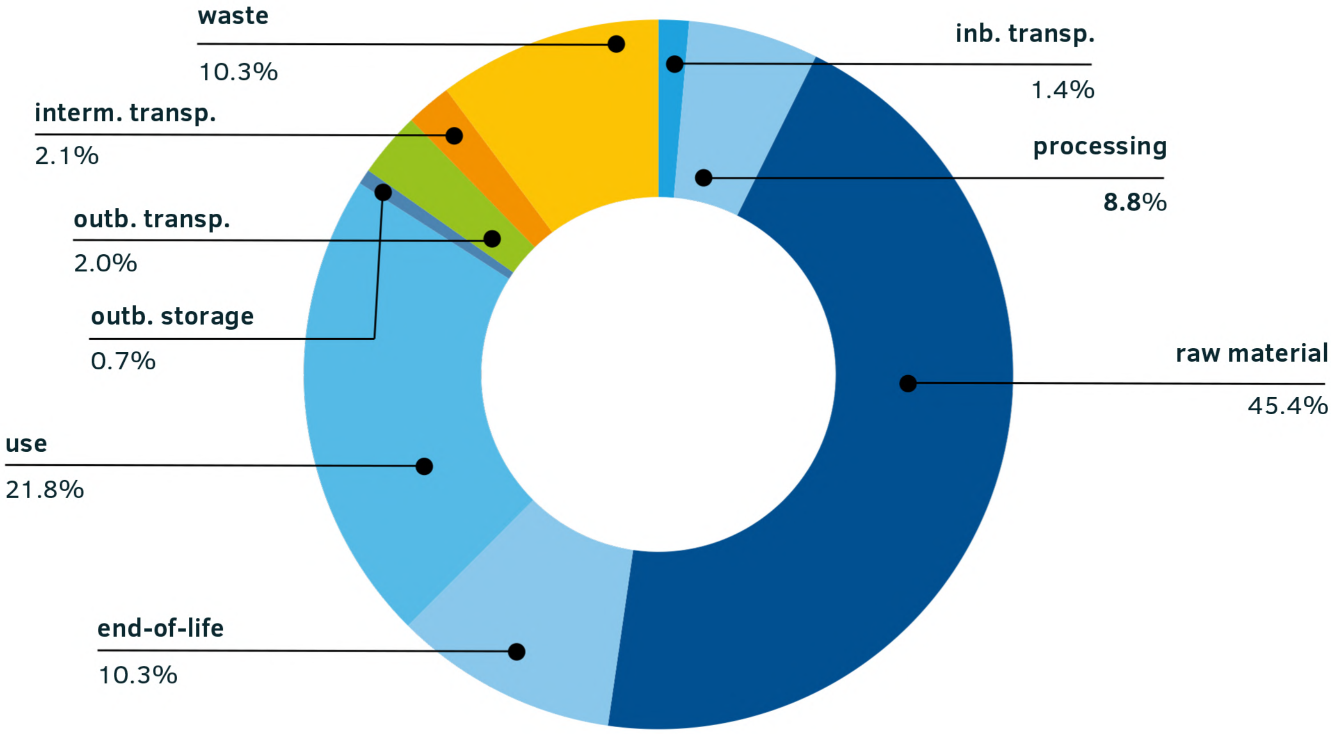


Figure 1: Product Carbon Footprint for a Prefilled Autoinjector Device - an example calculation for a 1ml autoinjector

1.1 Ranking Ecodesign Principles

There is no one-size-fits-all approach to Ecodesign.

Careful evaluation of options is required throughout the development process to determine which strategies will deliver the greatest impact across the entire product lifecycle.

Additionally, the relevance of specific Ecodesign principles depends on the machine's function, its application, the resources available, and project timelines. Some strategies may call for large-scale system overhauls, while others can be quickly implemented on existing equipment to yield immediate sustainability gains.

Life Cycle Assessments

> **One of the most effective tools for guiding these decisions is a life cycle assessment (LCA), which quantifies both direct and indirect carbon emissions across all stages of a machine's life and highlights the biggest contributors to the carbon footprint. This enables targeted interventions and smarter design choices.**

This whitepaper, which is grounded in an LCA, ranks twelve Ecodesign principles based on the combined impact of the principle on the product carbon footprint and the overall ease of implementation.

A visualization of this analysis is presented in **Figure 2**, with the four 'priority' Ecodesign principles represented in green.

These include:

- **Renewable energy sources**
- **Production efficiency (machinery efficiency, reduction of waste)**
- **Increase Lifetime Through Design for Repair / Maintenance**
- **Footprint Reduction Through Carbon Reduced Aluminium, Steel, and Stainless Steel**

1.1 Ranking Ecodesign Principles, cont.

Priority and Supporting Ecodesign Principles

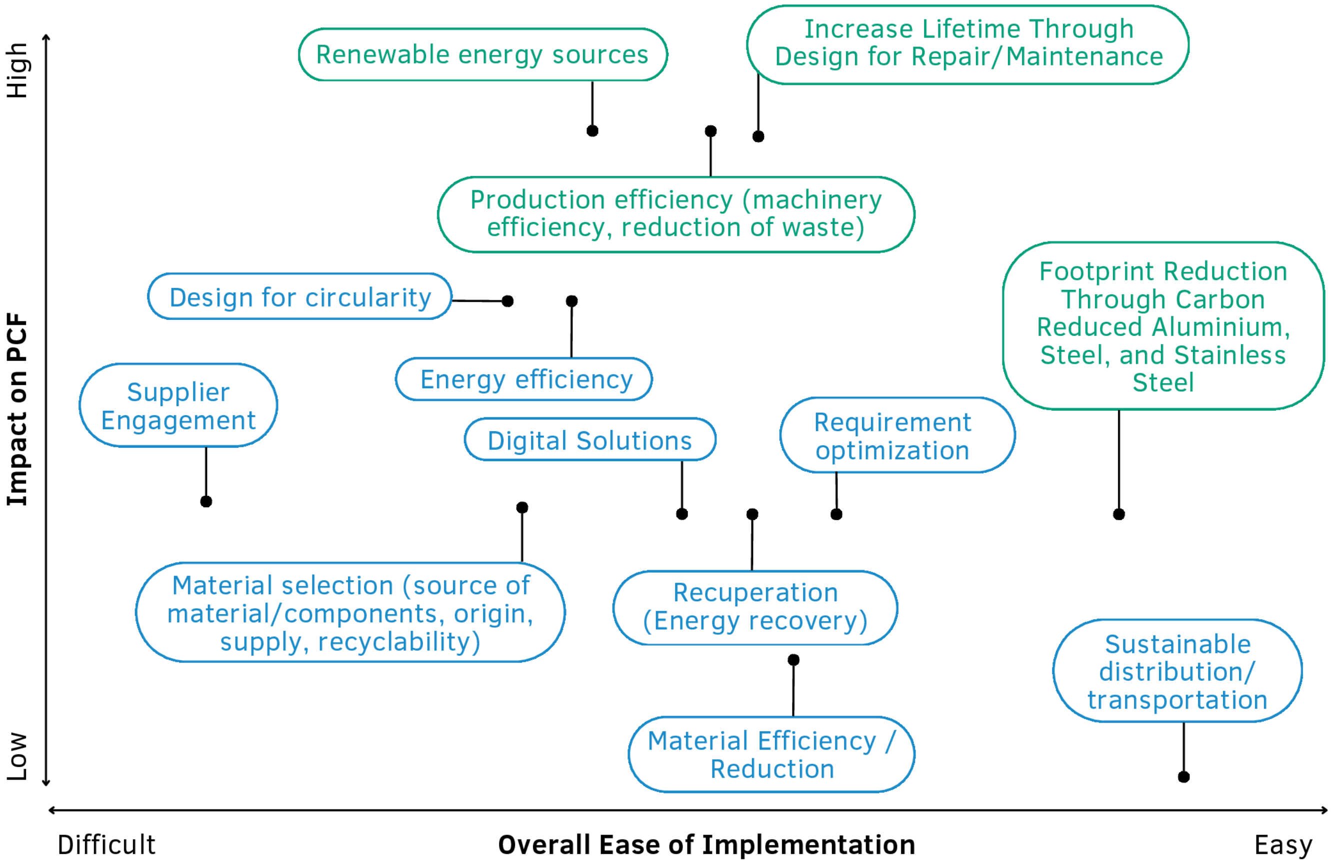


Figure 2: Visualization of Priority and Supporting Ecodesign Principles

The remaining eight supporting principles (represented in blue) are still highly relevant and should be considered on an individual basis. However, these approaches often involve more complex implementation or deliver a smaller return in terms of carbon footprint reduction.

As such, they are best considered once the priority principles have been fully integrated into the design and manufacturing process.

Taken together, these insights provide a structured foundation for selecting the most effective interventions.

With the overall framework established, the next step is to explore each principle in more detail, beginning with the four priority areas that offer the strongest combination of carbon-reduction potential and practical feasibility.

2 Priority Ecodesign Principles

The following **four** Ecodesign principles emerged as the highest priorities, reflecting both their significant potential to reduce the carbon footprint of automated disposable injector devices and their comparatively straightforward implementation.

1. **Increase Lifetime Through Design for Repair and Maintenance**
2. **Increase Production Efficiency**
3. **Optimize for Renewable and Low-Emission Energy Sources**
4. **Prioritize Low-Emission Raw Materials**

2.1 Increase Lifetime Through Design for Repair and Maintenance

Extending the lifespan and usage phase of a machine can dramatically reduce its overall carbon footprint. While a longer operational life means more energy is consumed over time – making energy-efficient design essential – it also spreads the significant emissions from the manufacturing of the machine (primarily associated with the raw materials used) across many more processed items. This results in a significantly lower environmental impact per unit produced, making durability a powerful lever for sustainability.

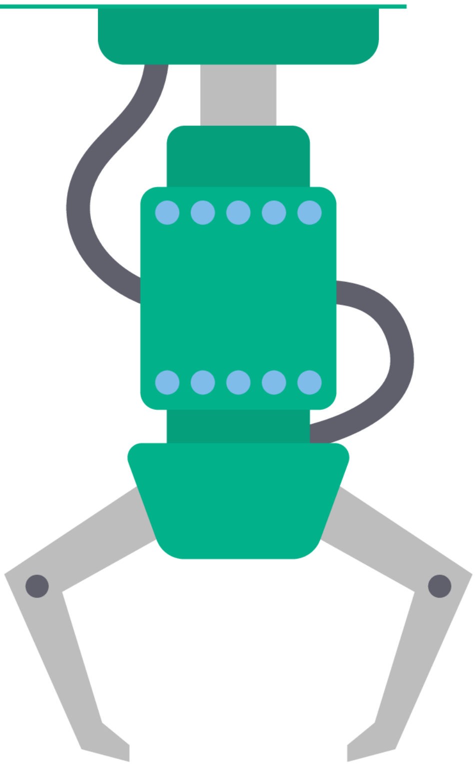
To ensure a long and productive service life, machines must be designed for easy, cost-effective repair and maintenance. This means making wear-prone or defective components readily accessible and easy to replace – minimizing downtime and extending operational efficiency.

Utilizing these tactics will help ensure that the lifetime of a machine can be increased as much as possible, ultimately delivering reduced emissions per product produced.

Key strategies for enabling repairability and long service life include:

Design for simplicity	Fewer parts and modules make repairing and maintaining the machines easier.
Avoid permanent joins	Minimizing the use of gluing or welding helps prevent damage during disassembly and supports easier part replacement.
Embrace modular design	Structuring machines with accessible, interchangeable modules (e.g. battery units) enables quick testing, repairs, upgrades, or reuse across different products.
Provide support services	Offering repair programs, part exchanges, and clear maintenance documentation empowers users to extend equipment life.
Reduce tool dependency	Designing for maintenance without specialized tools and enabling on-site servicing helps minimize downtime and transport-related emissions.

2.2 Increase Production Efficiency



The efficiency of a machine at the customer's site plays a pivotal role in shaping its carbon footprint. Every bit of material wasted during processing represents emissions without value - lost resources that still carry an environmental cost. By maximizing material use efficiency, manufacturers can significantly reduce these avoidable emissions.

Over a machine's 15–20-year lifespan, even small gains (e.g. every gram saved, every percentage point of increased efficiency) compound into meaningful environmental impact. Smarter material use is not simply good practice – it is a powerful lever for long term sustainability.

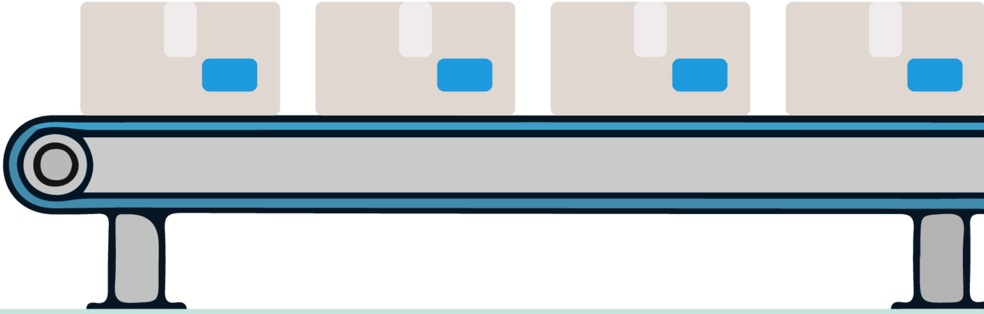
As materials move through the production line, each processing step adds energy, resources, and emissions, thus steadily increasing their value. This journey up the "value hill" means that the further a product progresses, the more carbon becomes embedded within it.

As a result, waste generated at the end of the line carries a heavier environmental cost than waste generated at the beginning. Minimizing these late-stage losses is therefore critical to reducing overall emissions and preserving the value created throughout the process.

Key strategies for increasing energy efficiency include:

☎ Implement control stations	Control stations can support material use efficiency by enabling precise, real-time control of machine operation.
Use shift registers	These enable precise sequencing and coordination of machine actions, reducing unnecessary movements, errors, and resulting material waste.

Together, these proactive strategies prevent unnecessary processing of waste and avoid end-of-life treatment for defective items, ultimately reducing emissions while preserving added value.



2.2 Increase Production Efficiency, cont.

The ‘Value Hill’

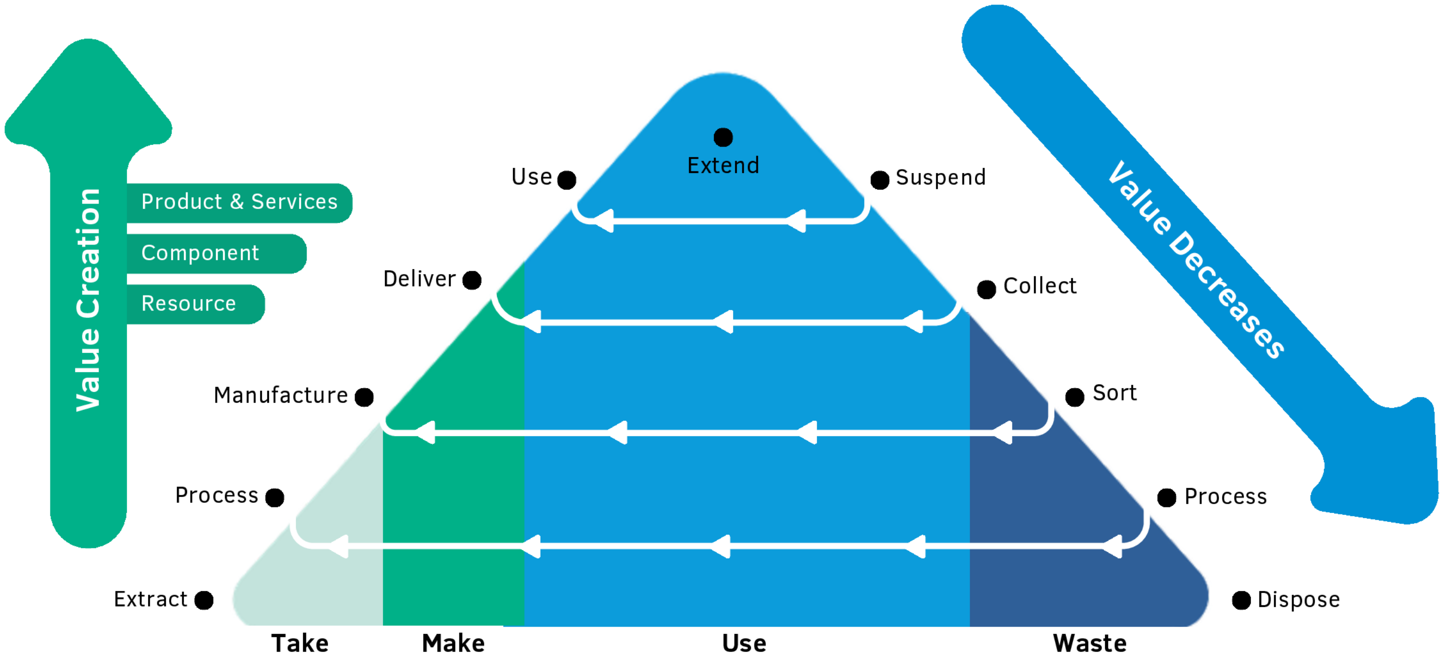


Figure 3: The “Value Hill”

2.3 Optimize for Renewable and Low-Emission Energy Sources

The type of energy used during a machine's operation presents a key opportunity for optimization. By switching to renewable sources, emissions from electricity and compressed air generation can be significantly reduced.

Renewable energy has lower carbon emissions per kilowatt-hour in comparison to non-renewable sources, therefore when multiplied by the amount of energy consumed over the long machine usage period, it creates a significant opportunity for CO_2 savings.

Plastic made from recycled materials **reduces carbon emissions by 42%** compared to conventional plastic production

The grid emission factor of the energy used by customers operating the machine is often not within the control of the equipment manufacturers. However, by raising customer awareness and highlighting the potential savings, this measure can still be effectively implemented.

2.3 Optimize for Renewable and Low-Emission Energy Sources, cont.

Key strategies to renewable energy and low-emission sources include:

Support customer transition to green power	Provide tools or documentation to help customers understand operational energy use and the emissions savings available when switching to renewable electricity.
Decarbonize in-house manufacturing energy	Prioritize energy-efficiency improvements in machinery production processes, then electrify processes and procure electricity from certified renewable or low-emission sources.

These strategies ensure that both machine operation and manufacturing processes make full use of low-carbon energy sources, amplifying emissions reductions across the entire product lifecycle.

2.4 Prioritize Low-Emission Raw Materials

When selecting materials, it is essential to consider their entire lifecycle - from the sourcing and extraction of raw materials to production and end-of-use.

The aim should be to prioritize materials with a low environmental footprint, characterized by reduced carbon intensity, minimal water consumption, lower waste generation, and fewer by-products.

In pharmaceutical machinery, materials like **steel, stainless steel,** and **aluminium** often make up a significant portion of the total mass.

As such, they offer a key opportunity to drive down emissions and enhance sustainability across the product lifecycle.

Of every 1,000 kg of scrap steel made into new steel, over **1,400 kg of iron ore, 740 kg of coal** and **120 kg of limestone** are saved.

2.4 Prioritize Low-Emission Raw Materials, cont.

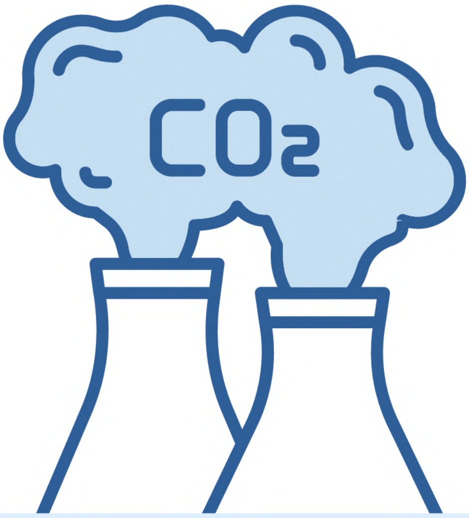
Key strategies to renewable energy and low-emission sources include:

Use recycled or secondary (waste) materials	Wherever possible, source materials from secondary sources (e.g. scrap steel or recycled plastics).
Prioritize sustainable suppliers	Engage with suppliers to understand how their sustainability strategies are employed (e.g. using renewable energy in extraction and processing of raw materials, or utilizing recycled water sources).
Source locally	Purchasing from local suppliers helps avoid the high carbon footprint of transportation methods (especially air freight)

It is important to note that potential savings from purchasing CO_2-reduced raw materials are currently difficult to quantify, as only a few suppliers can determine the environmental impact of their materials.

Additionally, not all alloys, semi-finished product dimensions, etc., are available in CO_2-reduced versions.

However, investing in these strategies can support the broader transition to lower-emissions materials over time.



3 Supporting Ecodesign Principles

While the priority Ecodesign principles deliver the greatest carbon-reduction potential and should be addressed first, this set of supporting principles can further strengthen the sustainability performance of machinery used in the production of automated disposable injector devices.

These measures reflect a more advanced level of optimisation and innovation, addressing areas such as digital integration, transportation logistics, and supplier collaboration.

While their individual impact may be modest, collectively they contribute to a more *holistic* and *resilient* sustainability strategy.

By layering these measures on top of the priority principles, manufacturers can push the boundaries of what is possible in low-carbon machinery design and move closer to achieving net-zero goals.

3.1 Material Efficiency and Reduction

To use raw materials more efficiently, it is important to understand the size and shape of components before manufacturing begins. This helps minimize scrap and off-cut waste. For example, designing parts so that their finished geometry closely matches the dimensions of the raw material's bounding box can greatly reduce unused material. Additive manufacturing technologies go a step further by building components layer by layer, using only the material required for the final shape and keeping waste to an absolute minimum.

In moving applications, lightweight construction plays a key role in extending machine lifespan and reducing energy consumption. By reducing moving mass, wear and tear are significantly minimized, along with the machine's susceptibility to damage. This not only reduces the financial costs and environmental impacts associated with producing new machines but also enhances operational efficiency and simplifies maintenance.

3.2 Energy Efficiency

Energy efficiency is a cornerstone of sustainable mechanical design. It shapes how machines perform not just during peak operation, but also in standby mode. Innovations such as advanced drive systems and water-based sealing (which replace energy-intensive heat adhesives) are already making a measurable difference.

Additive manufacturing takes this further by enabling lightweight, streamlined components - like grippers with built-in air or vacuum functions - which replace complex assemblies with single, optimised parts. This results in reduced energy consumption, lower transmission losses, and smarter, more sustainable machines from the inside out.

Selecting the right technology for the task is fundamental for effective Ecodesign. It does not just drive down operational costs but also plays a critical role in reducing environmental impact. For example, choosing between electric and pneumatic drive systems based on specific performance needs can lead to substantial energy savings.

Tools like condition monitoring and predictive maintenance further enhance efficiency by preventing unnecessary energy use and extending the lifespan of machinery. Even simple actions, such as powering down components during standby, can contribute meaningfully to overall energy reduction.

Yet, despite these advancements, machines will always require energy to function. That is why maximising efficiency and minimising consumption remain non-negotiable priorities. The goal is not just to build machines that work, it is to build machines that work smarter, for longer, and with less environmental impact.

> **The goal is not just to build machines that work, it is to build machines that work *smarter*, for *longer*, and with *less environmental impact*.**

3.3 Digital Solutions

Digital technologies such as artificial intelligence (AI) and machine learning are becoming powerful enablers of sustainability in mechanical engineering. By analysing production data, operational conditions, and usage patterns, these tools uncover insights that can guide smarter design decisions and continuous improvement. They help engineers move from reactive to proactive - designing with foresight rather than hindsight.

During machine operation, real-time energy monitoring empowers customers to pinpoint energy-intensive processes and optimise performance. Features such as predictive maintenance, remote diagnostics, and augmented collaboration not only boost equipment efficiency but also reduce downtime and extend machine lifespan. Together, these digital solutions turn data into measurable environmental gains.

3.4 Energy Recuperation

In machinery, electrical energy is converted into kinetic energy to enable movement and handling. Energy recovery systems capture the kinetic energy generated by moving parts or gravitational forces and convert it back into usable electricity. This reclaimed energy can then be redirected to other components, reducing overall consumption.

Intermediate energy storage plays a key role in this, acting as a buffer that activates energy sharing between drives. For example, energy produced when one motor brakes can be immediately reused by another motor accelerating - creating a more efficient, interconnected system. It is an innovative way to turn momentum into meaningful savings.

3.5 Sustainable Transportation and Distribution

Although transportation of components and materials makes up only a small share of a machine's total cradle-to-grave carbon footprint, it still presents a valuable opportunity for improvement. Every decision in the supply chain counts.

To minimize transport-related emissions, avoid air freight whenever possible due to its high carbon intensity. Instead, sourcing materials and components locally and opting for lower-emission transport methods like rail or sea freight can make a meaningful difference - especially when scaled across global operations.

3.6 Requirement Optimisation

In custom-engineered machinery, tailoring designs to meet specific customer requirements is standard practice, but it can come at a sustainability cost. Features such custom color coatings, additional components, or the blanket use of electric drives to avoid pneumatics can all increase emissions during design, specification, and manufacturing.

Whilst optimizing these requirements can reduce environmental impact, the feasibility and effectiveness of such changes depend heavily on the specific use case – and in any case may offer only modest gains in the overall carbon footprint.

3.7 Supplier Engagement

Supplier engagement is a powerful catalyst for sustainable transformation across the value chain. By collaborating to ensure that components and raw materials come from lower-impact sources and are produced in line with environmentally conscious practices, companies can significantly reduce their Scope 3 emissions and drive broader industry change.

This collaborative approach extends the impact of a company's sustainability strategy far beyond its own operations. It empowers suppliers to innovate, align with climate goals, and adopt more sustainable practices - creating a ripple effect throughout the supply chain.

In this way, supplier engagement becomes more than just a procurement strategy; it becomes a *pillar* of long-term, systemic emissions reduction.

3.8 Design for Circularity

At the heart of Ecodesign lies a shift in mindset - from the traditional linear model of "take, make, use, waste" to a circular approach where materials are kept in use for as long as possible. This means designing products, components, and systems with the intention that nothing becomes waste.

Instead, every material is seen as a valuable resource that can be recovered, reused, or repurposed in downstream applications.

Circularity is not just a sustainability buzzword – it is a design *imperative* that redefines how we think about value, longevity, and environmental responsibility.

3.8 Design for Circularity, cont.

To support this shift, the 9 R strategies offer a practical framework for keeping materials and components in the loop (see Figure 4). These strategies - ranging from “Refuse” and “Reduce” to “Recycle” and “Recover” - are ranked by how well they preserve the value added in at the earlier stages of production.

By integrating these principles from the very beginning of the concept phase, engineers can embed circular thinking into every aspect of machinery design, from individual parts to entire systems.

The result is smarter, more sustainable equipment this is built not just for performance, but for long-term environmental stewardship.

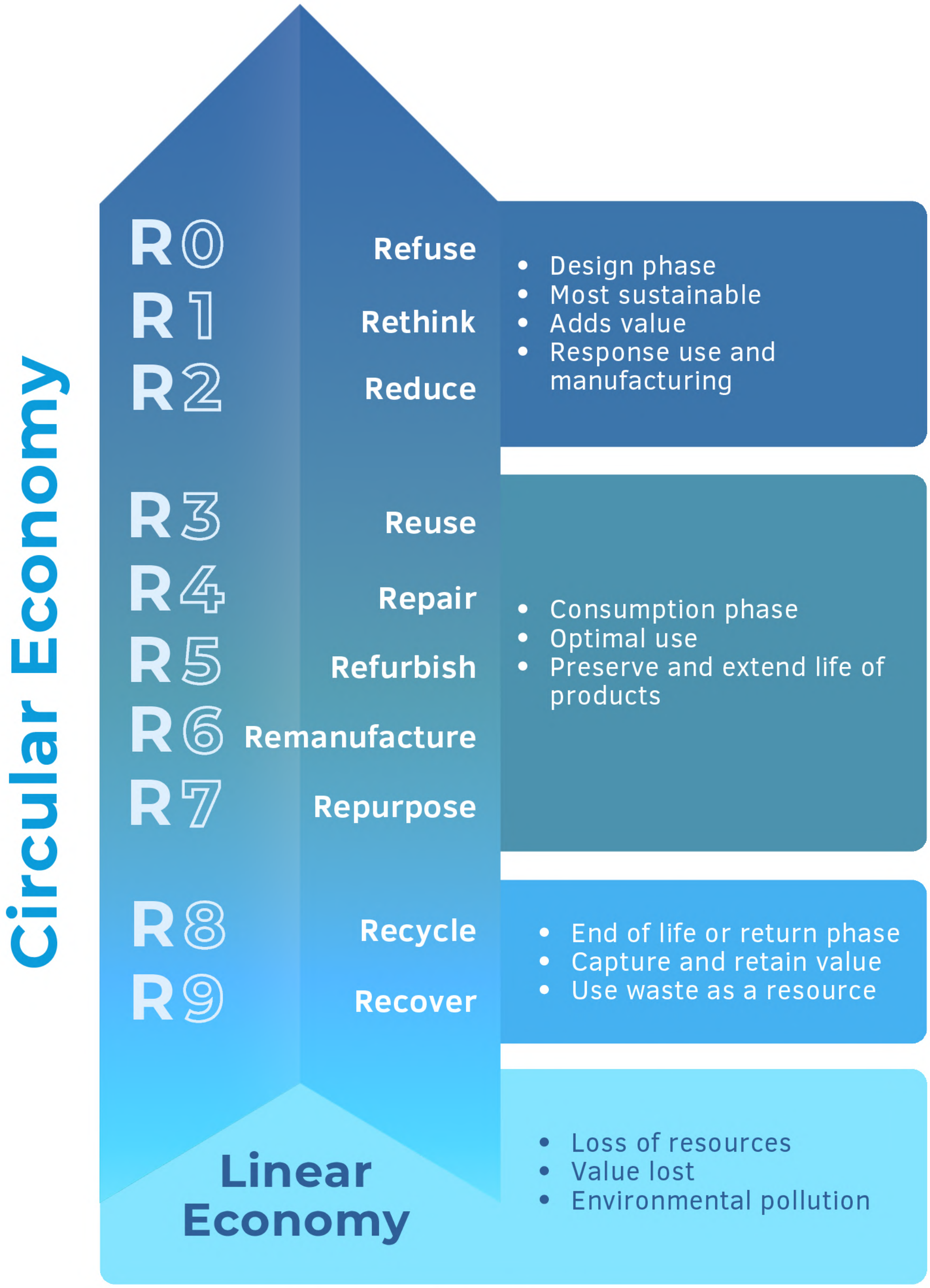


Figure 4: The ‘9 R’ Strategies for the Circular Economy

4.0 Conclusion

Ecodesign for machinery demands a flexible, context-specific approach that considers the unique function, lifecycle, and constraints of each machine. While this whitepaper focuses on incremental improvements rather than large-scale redesigns, it emphasizes the importance of identifying and prioritizing the measures that deliver the greatest impact.

Sustainable design is rarely achieved through a single breakthrough; it is an iterative process of balancing trade-offs, refining decisions, and continually evaluating lifecycle impacts. Progress in Ecodesign depends not only technical innovation but also a shift in mindset to seeing environmental performance as a core design criterion, not an afterthought.

Collaboration across the value chain is essential for achieving lasting improvements.

What is the Alliance to Zero?

The Alliance to Zero is driving the pharmaceutical industry's transition to net-zero emissions by uniting stakeholders across the entire value chain - from component suppliers to packaging and device manufacturers.

For more information, connect with the Alliance to Zero **here**.

The work of the Alliance to Zero demonstrates the *power of collective action* by bringing together suppliers, manufacturers, and end users to reduce emissions at every stage.

By adopting a holistic and collaborative approach, the industry can move beyond isolated efficiency gains toward systemic sustainability - building machinery that not only performs reliably but also supports a more resilient, low-carbon future.

5.0 Your Actions for This Procurement Cycle

To accelerate credible eco-design, buyers must start asking the right questions, at the right time.

We call on procurement teams, specifiers, and device manufacturers to embed energy performance, material efficiency, and lifecycle footprint requirements at the design brief stage.

Because when sustainability expectations are clear before a machine is built, suppliers can innovate, optimise, and invest in lower-impact solution.

By making environmental performance a standard part of every purchasing conversation, we can shift the market toward machinery that is efficient, future-proof, and aligned with net-zero ambitions.

> **When sustainability expectations are clear before a machine is built, suppliers can innovate, optimise, and invest in lower-impact solution.**

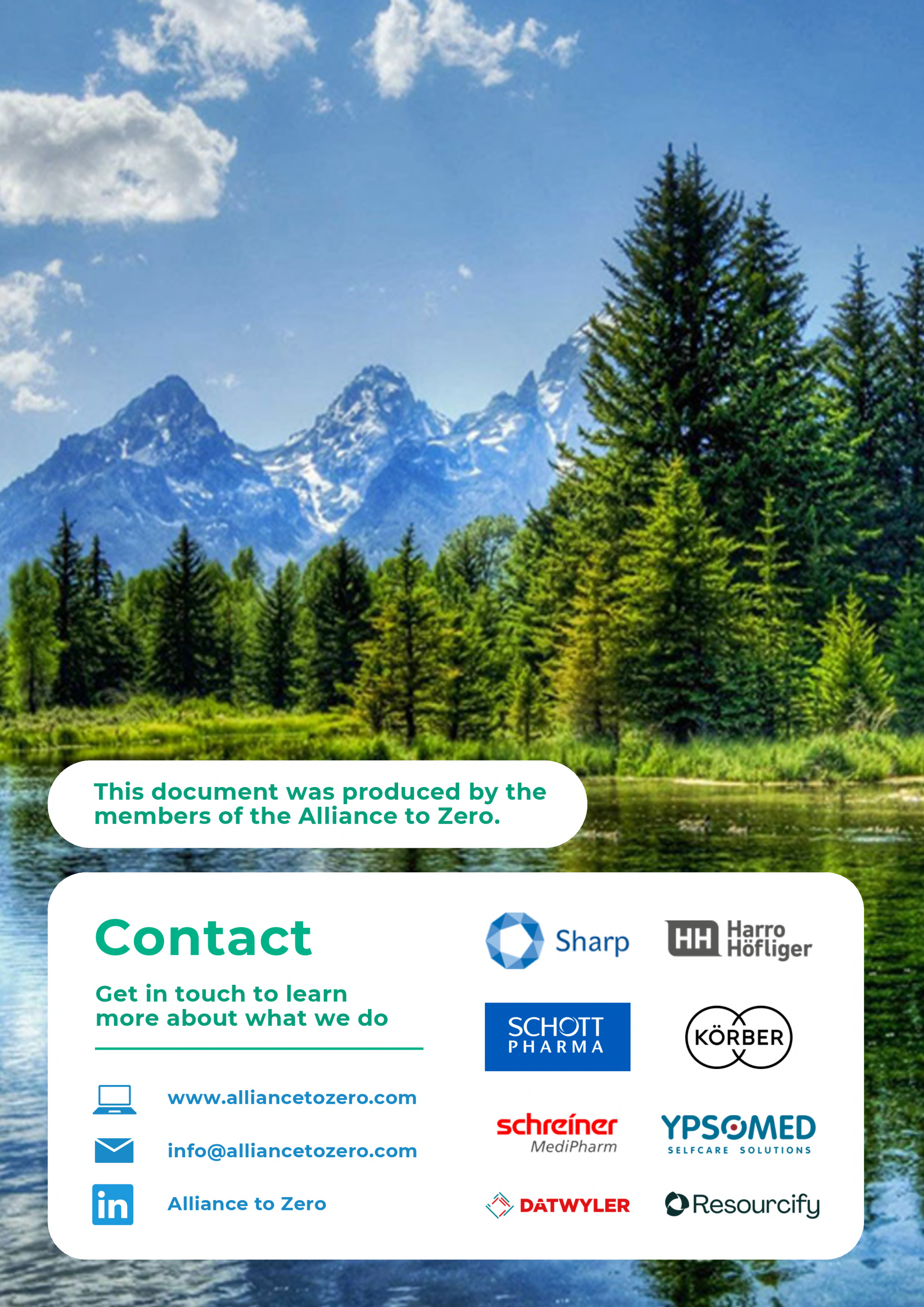
Sources

1. **Master Circular Business with the Value Hill (2016).** Available: https://www.circle-economy.com/resources/master-circular-business-with-the-value-hill

2. **World Steel, Raw Materials (2025).** Available: https://worldsteel.org/other-topics/raw-materials/

3. **Assessing the environmental footprint of recycled plastic pellets: A life-cycle assessment perspective (2023)**. Available: https://doi.org/10.1016/j.eti.2023.103289

4. **R-Strategies for a Circular Economy (2023).** Available: https://www.circularise.com/blogs/r-strategies-for-a-circular-economy



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