Sustainability in Device Design

Considerations and approaches to increased sustainability in the lifecycle of products

Will Davies • October 2024

Sustainability is the hottest of topics right now, presenting an enormously complex web of hurdles for every government, organisation, and individual to overcome. This is no less true for the global healthcare industry, which has a net carbon footprint of 2.2 gigatonnes CO2e - equivalent to a large country.

In this article, Will Davies explores what approaches can be taken by device manufacturers and designers to reduce or even negate the impact of their products and services.

What is Sustainable Design?

A sustainable design, regardless of the application, will seek to incorporate environmentally-preferable outcomes, such as:

- Lower energy and water consumption through the entire lifecycle – from manufacture to daily use to end of life.
- Minimise impact on climate change by reducing greenhouse gas emissions or mitigating them through carbon neutralising activities.

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- Limit resource consumption through minimal-waste manufacturing, a preference for renewable resources, and an emphasis on recycled materials.
- Reduce or eliminate waste by minimising consumption, reusing when possible, and recycling when necessary.
- Minimise impact on the local ecosystem and look for ways to incorporate biomimicry principles where possible (such as cradle-to-cradle resource use);
- Give preference to non-toxic materials and those that will contribute to the health and wellbeing of humanity.
- Emphasis upon quality and durability over price.

Benefits of adopting sustainable design principles:

Environmental concerns are currently at the top of the consumer, political and corporate agenda, including in the medical and pharmaceutical sectors. Manufacturers are increasingly using Corporate Social Responsibility (CSR) and Life Cycle Assessment (LCA) tools to measure and reduce their impacts. By being able to demonstrate quantifiable improvements in environmental responsibility, they can differentiate themselves in the market and gain competitive advantage. After all, consumers vote with their wallets: US Sales of products with a sustainability claim on-pack grew by 29% between 2013 and 2018[1].

Adopting more sustainable manufacturing principles often leads to increased efficiency – for instance in raw material use or power demand – which means lower manufacturing costs.

The drive to a national carbon-neutral future (the UK aims to be net-zero by 2050) makes the introduction of a carbon levy highly likely. Even without legislation, key buyers are likely to impose their own standards. For instance, the NHS in England is intending to reduce all emissions it is in control of and influences – i.e. those of its suppliers – to zero by 2045[2]. Hence by considering sustainability in our designs and business activities now, manufacturers and providers can stay ahead of any such future regulation and qualification.

Sustainable design principles:

1. Durability, Reliability and Repairability

Physical durability of a product is one of the key contributors to its sustainability. The longer a product is in service for, the fewer resources are consumed in the manufacture and disposal of replacement products. This argument is more complicated when considering products that consume resources during the use phase (such as a vehicles), as efficiency gains of the replacement product may offset the manufacture-related emissions. However, within Shore's field of medical device design, in most cases it is the embodied energy of the product that is the most significant factor.

[1] Harvard business Review: 'Actually, consumers do buy sustainable products'
[2] NHS England: 'Delivering a net zero NHS', July 2022.

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The familiar mantra ‘Reduce – Reuse – Recycle’ should be regarded as a hierarchy, not a trio of equally-weighted options. Enhanced product durability helps to satisfy the two most preferential – reduction and reuse of resources. There are three key design attributes that enforce this:

Emotional Durability promotes the physical durability of a product by increasing the emotional value of a product to the user. This strengthens the relationship with the user, who in turn will take greater care to extend its life and delay replacement. This can be promoted through great industrial, user experience (UX), and engineering design.

Reliability of a product is a quantifiable measure of its resistance to failure. This is in slight contrast to durability, which is typically regarded as more of a qualifiable measure of its ability to endure, or its permanence.

Repairability is a very desirable attribute when it comes to sustainable products; when reliability fails, repairability steps in to ensure continued durability.

A bicycle is the ultimate embodiment of all these concepts:

- The simplicity and engineering rigour of a bicycle makes it reliable;
- When a part fails it is repairable, which makes it durable;
- The utility of a bicycle to its owner, its perceived beauty and character, the way it ages and its modifiability

2. Resource Reduction

Reduction of resource consumption is a key sustainability goal for each of the product lifecycle phases:

1. **Manufacture:** the less material used, the less energy and fewer emissions associated with that material production. Recycled material content is generally better than virgin; reused content is best.

2. **Transport:** the smaller and lighter a product, the lower its emissions when the product is transported, which can be a very significant component of a product’s footprint.

3. **Use:** naturally, anything that reduces the power consumption requirements of a product is welcome, although the nature of a product’s power source can add complication (e.g. batteries). The same can be said for any other resource consumption during use, for instance water or replaceable filters.

4. **End of life:** waste disposal has severe environmental implications and all efforts to avoid landfill should be taken. Less resource consumed equals less waste. Waste-to-energy

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and material recycling are better but largely out of the designer's control. Component reuse is best, and may be controlled if the product ecosystem is defined from the outset.

The Smol Products multipurpose spray is a great example of resource reduction. Instead of shipping endless single-use spray bottles filled mainly with water, the user gets a single reusable spray bottle which they fill with tap water and a small refill tablet. What's more, it all arrives in the post as a subscription service so there are no supermarket round-trip emissions associated.

3. Behavioural Change

Whilst improvements in individual product-related efficiencies can be significant, product designers also have the potential to effect major change through systemic and behavioural change within society through the successful design and introduction of new product and system categories.

A great example is that of city bike and scooter hire schemes, such as London's Santander Bikes or Lime scooters. These provide the same primary function of private ownership – i.e. transport – but without all the associated burdens such as storage, insurance, and maintenance. The key sustainability benefit here is far greater usage efficiency per unit of product resource. Further secondary or potential benefits include reduced air pollution and congestion, and improvements to health and well-being; all benefits brought about by fundamental systemic change, which should be adopted and encouraged by politicians and society alike. Such schemes really embody the Product-as-a-Service model, whereby it is only really the Service that the user is interested in. This model could easily be applicable to a huge range of other markets, including that of drug delivery.

4. The Circular Economy

The Circular Economy represents the gold standard of sustainability with regard to a product's lifecycle, combining all three of the previous principles. It differentiates between renewable and finite material streams and establishes loops to return these materials either to nature or into new products indefinitely, minimising waste, resource use, and negative external effects.

The Circular Economy requires organisations to adopt systemic change, demanding the collection and remanufacture of products, in contrast to the typical 'fire-and-forget' model where end-of-life is not the original manufacturer's main concern.

The circular economy system lends itself well to Product-as-a-Service business models, in which the consumer is buying the product's contents or function, but the hardware itself is just a delivery vehicle that remains the property of the

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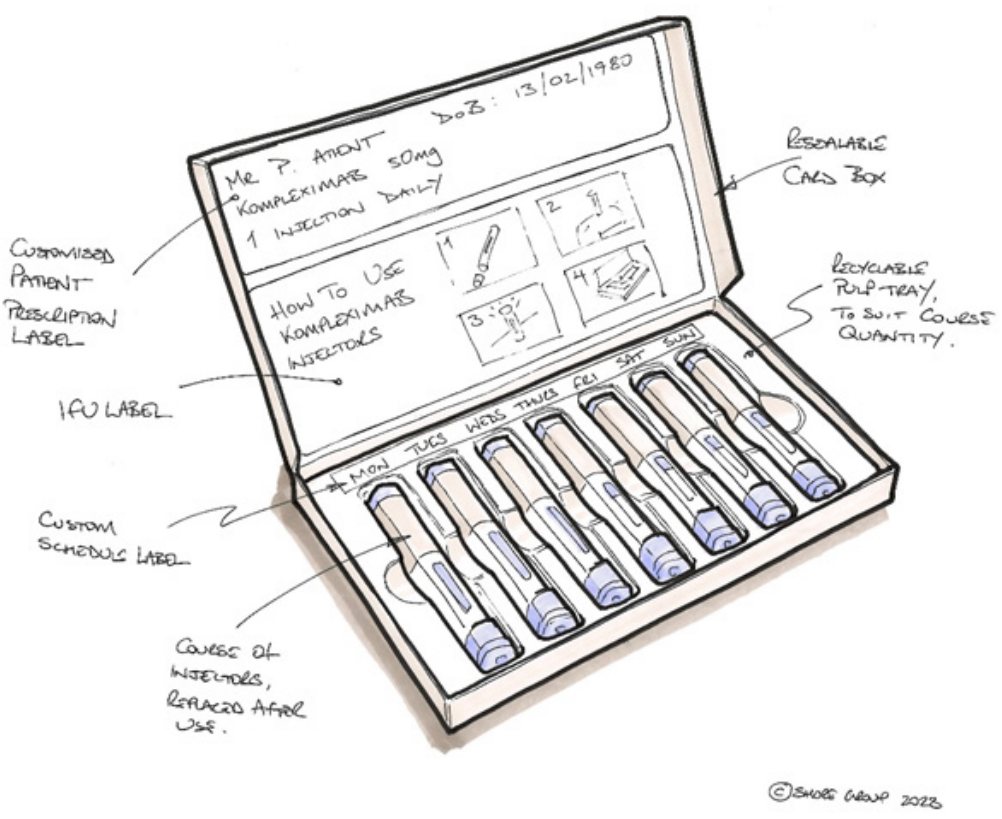
manufacturer. This permits the design of products with much smaller production volumes, the amortised cost-savings of which can be directed towards higher product quality, robustness, and design for disassembly and remanufacture. The model also facilitates continuous product upgrades, as new software or components can be installed during the remanufacture process. See this white paper for more details about how such a system might work in the context of pharmaceutical devices.

Achieving true circularity is somewhat aspirational as most organisations will find it difficult to transition to such models overnight. However, products can still be designed from the outset with many circular economy principles embedded – such as reusable modular components – thus facilitating smoother or more gradual future transitions. Forthcoming advances in regulation and recovery technologies may facilitate the recovery of device components that are currently problematic, such as contaminated needles or vials.



Packaging concept for circular auto-injector model, detailed in a previous paper exploring the subject.

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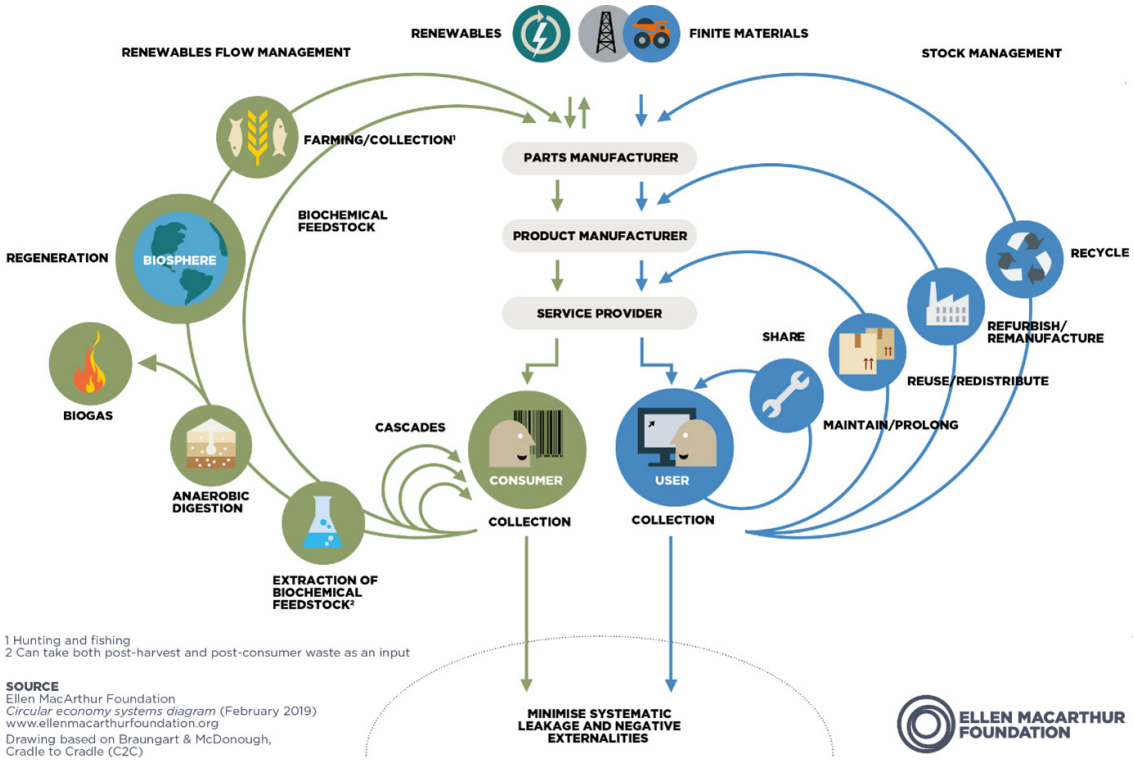

The Circular Economy butterfly diagram, courtesy of the Ellen MacArthur Foundation.

A key enabling technology for the circular economy is that of Digital Product Passports. Still in a nascent stage, DPPs provide access to a 'digital twin' of a product; not just a particular model, size, or trim, but the individual product itself. The digital twin can contain a wealth of information, such as component materials, manufacturing data, ownership history and so on. As it is digital, there is no limit to the volume or detail of information contained, and the scope of opportunity may grow well beyond that currently envisaged. The digital twin data can be accessed by the end user or reprocessing facility by scanning a QR or bar code on the product, or via RFID/NFC tags, facilitating the easy and accurate recycling and remanufacture of components and products.

EU legislation is now embracing and enforcing the use of DPPs in certain industries; initially batteries in 2026/7, but extending to vehicles, textiles, electronics, furniture, and construction by 2030. Medical and pharmaceutical products are likely to join this growing list before too long as well; rather than a burdensome hurdle to overcome, this technology offers a wealth of opportunity within the industry, and so it should be embraced and used to maximum advantage for all stakeholders at every stage of the product's lifecycle.

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Technical Considerations

1. Manufacture

Certain considerations can be given to the design and manufacture of a product that will improve its sustainability. Many of these are common sense, and will also reduce cost and increase production efficiency.

- Any product should comprise a minimum necessary quantity of material, as every gram of material represents an embodied value of carbon, energy and natural resource.
- The design and manufacture of the part also affects the embodied energy; for instance a complex part requiring a larger press and a long cycle time will use more energy during manufacture than a part of the same volume on a smaller press/shorter cycle. A large press uses more energy to operate and also takes up a larger footprint on the factory floor, reducing space efficiency.
- The use of family and multi-cavity tools should be encouraged, and parts designed accordingly, to reduce the number of presses required; one large press is generally more efficient than two smaller ones.
- The use of over-moulding should be considered carefully, as the two dissimilar materials cannot easily be separated for recycling. Where used for product protection/durability (e.g. bumpers) this can be worthwhile – but think of the volume of toothbrushes with overmoulded handles that head for landfill because they cannot be readily recycled.
- Also important is to consider any post-process operations required for a part – each process necessarily requires additional time, floor space and energy. Some processes require the use of chemicals that may risk harm to the environment, for example anodising, which necessitates a protracted treatment process of the waste degraded sulphuric acid and aluminium hydroxide. However, this may be offset by resulting enhancements to emotional or physical durability; these relationships are very hard to quantify but should be considered, and low-impact alternatives used where possible.
- Gas-Assisted Injection Moulding is a technology with a number of potential sustainability benefits. GAIM injects nitrogen gas into the core of the part as it cools, which may permit, amongst other things, lower part mass, increased dimensional stability, and faster cycle times.
- Induction moulding is a significant evolution of traditional injection moulding that promises sustainability benefits through vastly reduced power consumption – only the very surface of the tool is heated using induction, instead of the whole steel mass of the mould. This also allows very fine surface temperature control, permitting much better surface finish quality and the elimination of common blemish marks such as weld lines.

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2. Assembly and Disassembly

Assembly of a product also constitutes part of that product's embodied energy. The faster and more efficiently that product can be assembled, the less power is consumed by the assembly plant per product. Similarly, any powered processes used in a product's assembly contributes to its embodied energy, for instance ultrasonic welding; however, such processes may save significant time or increase a product's reliability.

Snap-fits make product assembly very rapid but can make parts hard to separate unless special features are designed in – although if only being separated for recycling, then it doesn't matter if the parts become damaged. Of course, two parts of the same material snapped together do not need to be separated for recycling, unless they contain further, different parts such as PCBs. Physical and emotional durability of the product should be considered here, as snaps alone may not provide appropriate quality in these respects, and may prevent repairability. Permanent joining or the trapping of dissimilar parts should be avoided so that all materials can be separated.

Product assembly and disassembly should be considered together – it should generally be assumed that the product will be recycled or even remanufactured at end-of-life, and design effort should be made to encourage this, especially as recycling processes and technology continue to develop. An example of this being considered is embodied in the YpsoMate On autoinjector, which has a small electronic module fixed to one end. After use, this is easily twisted off the device body for separation into different waste streams, with design language to encourage this.

YpsoMate On autoinjector, with separable electronic communication module

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Just as the designer might design assembly jigs, so disassembly jigs can also be designed, which would facilitate component separation or the safe removal of hazardous or contaminated parts. Regulation can also change – what may not be acceptable for reuse today may tomorrow be recoverable and, perhaps with appropriate treatment, deemed suitable for remanufacture.

A developing technology is that of Active Disassembly[3]. This uses 'smart materials' (e.g. memory alloys) to allow self-disassembly of a product at end of life, when subjected to the right environmental conditions such as heat or pressure. This enables rapid separation and recovery of components and materials for reuse or recycling. This is yet to hit the mainstream, but increasing demand may see it mature rapidly.

3. Packaging

Packaging has an important role in the sustainability of products. Its primary function is protection of the product from manufacture through to use, and in doing so effectively reduces resource use from the return and remanufacture of damaged products. Shore engineer Bex Jones recently wrote this detailed piece on medical device sustainable packaging – part of a trilogy on the topic – but here are a few general considerations.

The smaller the packaged product, the more units can be transported or stored at once, thereby reducing the transport-related emissions per product, which may be a significant component of the overall footprint.

There are many established recycling streams for packaging materials, and designers may take advantage of these. However, many of these are not universal, and so commonly-recycled materials should be prioritised. Paper, card, and pulp-based packaging materials are often favourable, being both biodegradable and recyclable, structural, printable and so on. Furthermore, bodies such as the Forestry Stewardship Council help promote renewability. There are of course circumstances when such materials are unfavourable, such as when air-tightness is required for preservation of the contents, although these barriers can sometimes be overcome with the correct treatment.

Premium yet sustainable product packaging, constructed of card outer with formed pulp inner tray.

[3] Pressure-sensitive fasteners for active disassembly | The International Journal of Advanced Manufacturing Technology (springer.com)

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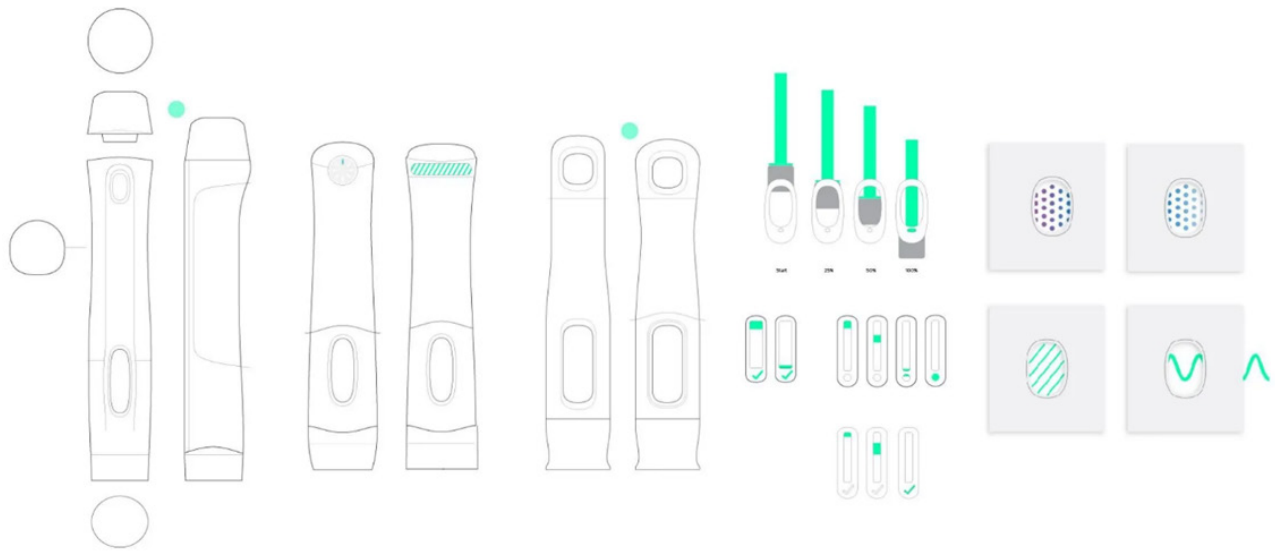
Packaging can also be returnable & reusable, and as such may form an intrinsic part of a circular economy system. There are growing movements to develop and promote return and reuse packaging services at both consumer and industrial levels, such as Terracycle's Loop scheme.

A new technology, pioneered by companies such as Polytag, is that of printing UV-visible QR codes onto product labels. These are invisible to the naked eye but can be machine-read at end of life to facilitate automated separation for recycling or re-use streams.

4. Electronics

Electronics are so universal in today's world of connected and smart products that it's easy to overlook how impactful the inclusion of electronic components can be. A simple PCB may have an emissions footprint up to 20 times greater than the equivalent mass of plastic, with further negative effects such as increased marine eutrophication.

Sometimes, a purely mechanical solution may provide a preferential alternative to electronics; for example, drive systems or visual indicators, such as that employed by the YpsoMate Large Volume autoinjector.



Design considerations for the mechanically-driven visual indicator on the Ypsomate Large Volume Autoinjector

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However, the inclusion of electronics into a product should be considered in the wider context. For instance, a connected inhaler aims to create better medication adherence and efficacy, which in turn avoids much greater downstream emissions associated with hospital visits. Similarly, the Mode Diagnostics bowel health test kit is a great example of a simple electronic diagnostic device that has the potential to significantly reduce emissions associated with clinical treatment by facilitating early diagnosis through a simple home test procedure.

For multi-use devices, rechargeable is preferable to disposable cells; this reduces the risk of electronic waste going into landfill, and also the emissions associated with battery manufacture. USB-charging is now very familiar to consumers.

Electronic modules may be very strong contenders for inclusion into a circular economy product strategy. Such a module could readily be recharged, reset, updated, and reassembled into a remanufactured product for multiple lifetimes, which would vastly reduce its impact.

Mode Diagnostics in-home bowel health test kit facilitates early diagnosis, which reduces downstream emissions related to disease management.

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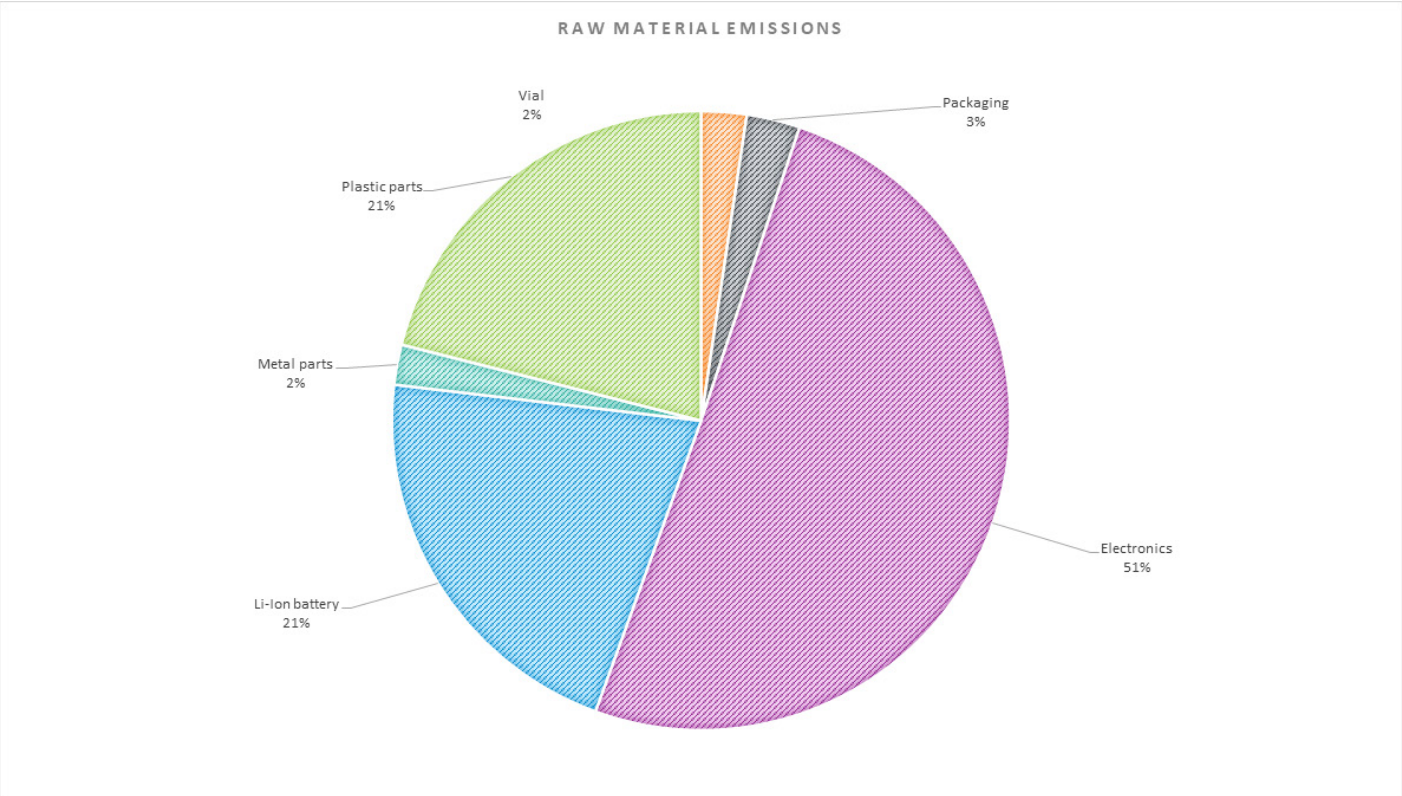

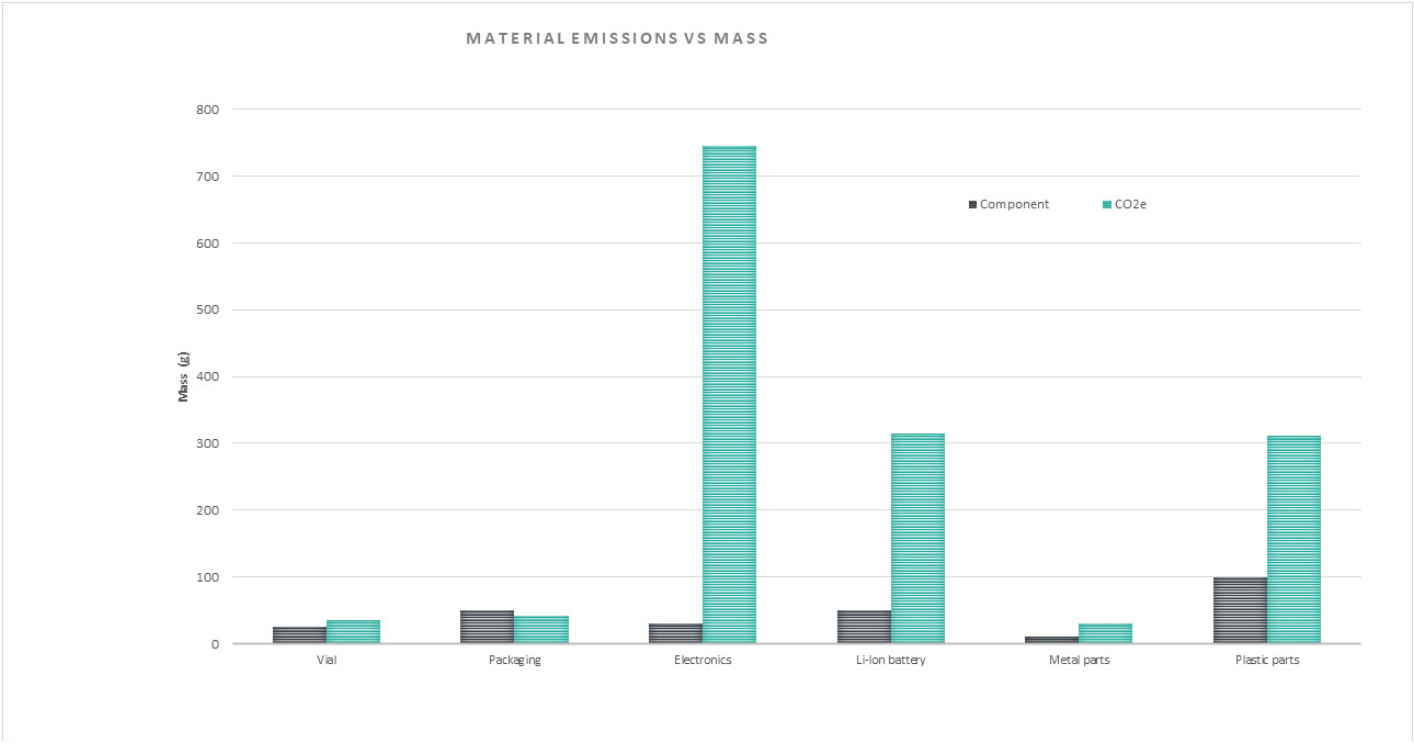

Raw material manufacturing emissions studies of a hypothetical connected injection device by component mass, demonstrating the relative impact of electronics. Conversion data from UK Gov 2022.

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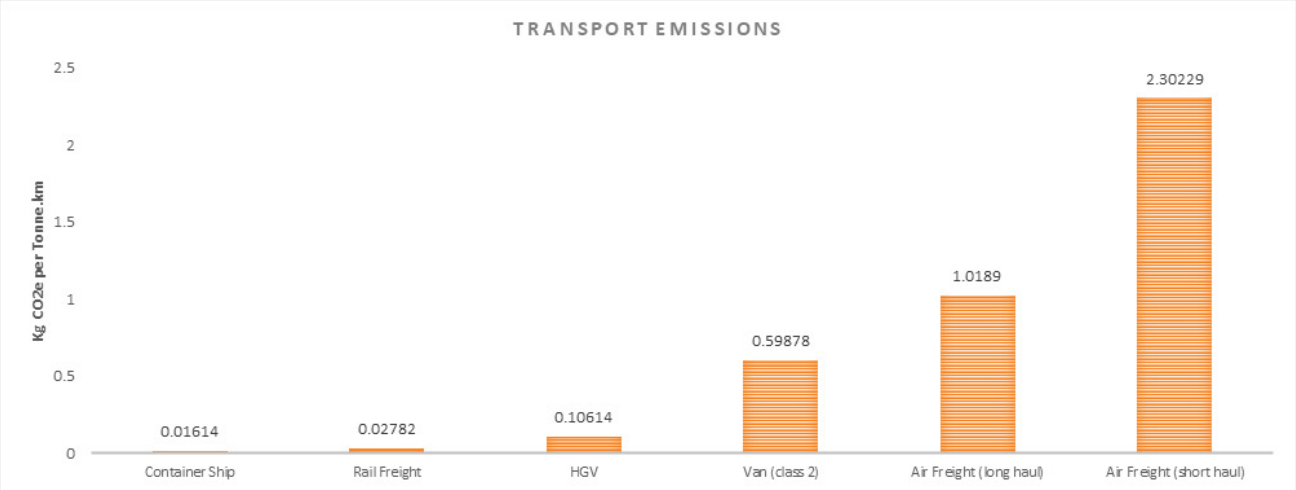
5. Transport

The method and distance in which a product is transported from factory to point of use can have a significant impact upon its emissions footprint. Factors to consider include:

- **Volume of product packaging:** the more densely packaged a product is, the more units can be packed into a single carton or shipping container and so transported by a single vehicle, ship or aircraft.
- **Product weight:** the lighter a product, the less energy is required to move it, and hence lower emissions. In many cases however, low weight should be balanced with durability.
- **Mode of transport:** there is a clear hierarchy in emissions for different transport types, as illustrated in the chart below[4] - a short-haul flight is fully 150 times worse than container shipping.
- **Environmental conditions:** Cold-chain shipping drastically increases transport emissions, through increased unit volume due to insulated packaging, and refrigeration power demand. If a product needs refrigerated transport and storage, then consider whether manufacture at a site close to point of use (which may mean regional manufacturing sites) and/or just-in-time manufacture might lead to lower emissions. Such products could be modular, with the bulk of the product manufactured centrally and the refrigerated component manufactured within the different market regions for final assembly.
- **Last-mile emissions** associated with a product can be significant and are often overlooked. These are the emissions arising from the consumer travelling to buy the product, e.g. driving a fossil-fuel-powered car to a shop to buy the product. Business models can help address this – for instance, home delivery services have lower emissions as the travel is shared with multiple products. Effecting behavioural change is another approach.



[4] Selected UK Gov 2022 CO2e conversion figures for freighting goods.

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Materials

1. Conventional Materials

Considered material selection has a big part to play in a product's footprint. The designer must weigh up factors such as cost, mass, mechanical properties, recyclability and so on. Where durability of a product is a key part of its sustainability, then strength and toughness may be favoured over low density, for example. Conventional materials still have a major role to play in the increased sustainability of products, alongside new material technologies such as those containing recycled content or additive manufacturing.

Significant carbon (and cost) savings may be made by replacing metal components, where appropriate, with an alternative such as glass-reinforced nylon. Although such fibre-reinforced materials are not typically recyclable, this downside is offset by a large reduction in embodied carbon in the raw material, and also lower product weight leading to reduced transport emissions.

Many conventional materials are highly recyclable; Polypropylene is a good example of a material that can be readily recycled again and again without any degradation in mechanical properties, whilst providing excellent toughness, strength, and surface finish. However, this does of course rely on effective recycling systems, which are typically out of the control of the designers – unless in a closed-loop system.

In general, many conventional plastics have reasonable potential sustainability value; compared to metals they require relatively low energy to produce and transport, have intrinsic recyclability, and their embodied energy can be recaptured using waste-to-energy schemes.

Issues with plastics such as ocean-littering and micro-plastic particles are very pertinent but should not be conflated with greenhouse gas emissions. Reduction in plastic use (especially for packaging), promotion of re-use, and increased recyclability are steps that designers can take to help address these issues.

When choosing metals, several things should be considered for sustainability, including:

- Energy intensity of ore extraction method;
- Density (relevant to transport emissions);
- Mechanical properties (relevant to product durability);
- Recyclability;
- Environmental impact of protective or decorative treatments.

Other materials may be assessed along similar lines. For instance, carbon fibre is extremely lightweight and strong so may contribute to a very durable product with low transport emissions, but is resource-intensive to produce and cannot be readily recycled.

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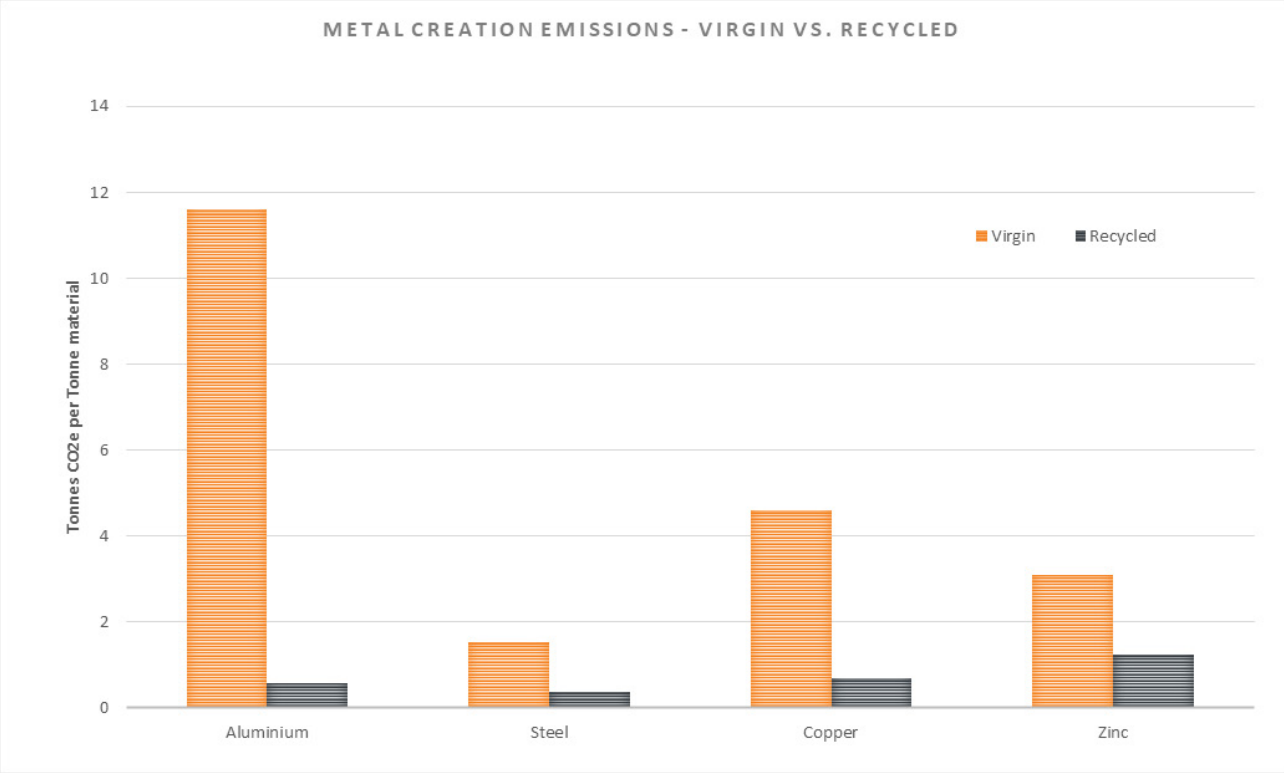
2. Recycled, Recycled Content, and Recyclables

In general, recycling requires far less energy, water and other resources than creating virgin material. This is particularly true for metals, especially those extracted from the ore using electrolysis (e.g. Aluminium), but also for plastics.

Metal recycling is now sufficiently developed such that mechanical properties can be fairly well defined in the recyclate, although typically of lower quality than a virgin grade.

For recycled polymers, there is an important distinction between two types. Post-Consumer Recyclate (PCR) is material typically recovered from packaging (etc.), often through municipal schemes; this is controlled fairly loosely and usually results in downgraded material properties (down-cycling). Post-Industrial Recyclate (PIR) uses much more tightly controlled material streams directly from industry and so produces specific, reliable grades of recycled polymer that can be considered and specified as alternatives to virgin polymers in premium devices.

PIR engineering polymers are available in grades of ABS, HIPS, PP, PA, POM and HDPE (amongst others), saving significant carbon emissions over the creation of virgin polymers. Non-traditional grades are also becoming increasingly available as alternatives. Many of these may be cheaper than virgin material.



Carbon dioxide equivalent emissions for the creation of virgin vs. recycled metals. Data from IEA.org.

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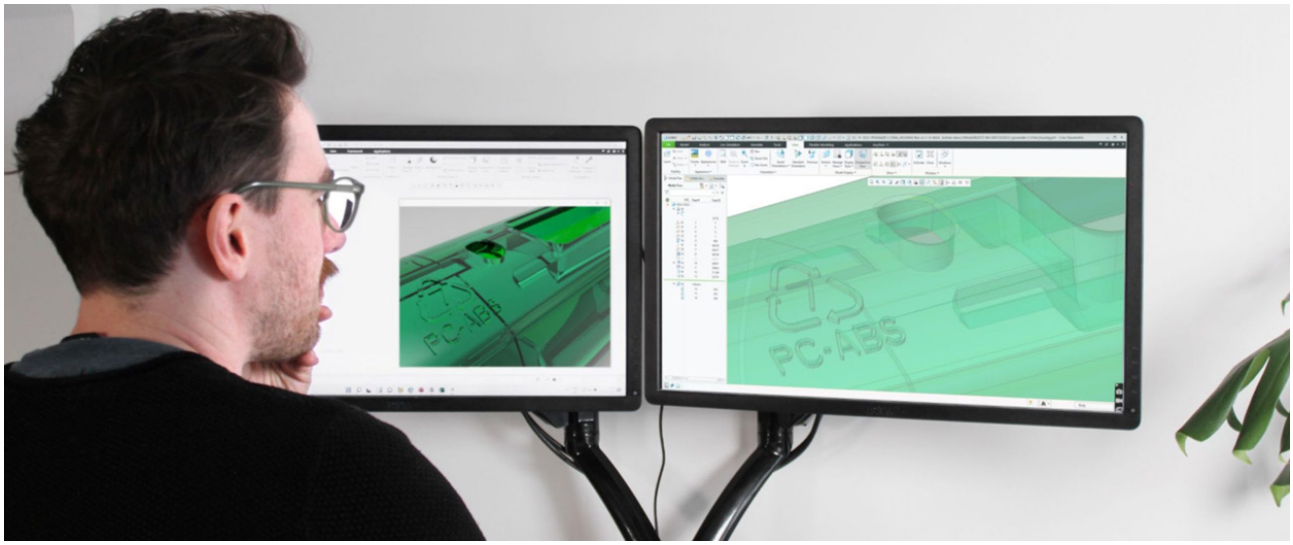

The Resin Identification Code symbol is insufficiently accurate for industrial recyclers to use for grade identification, but still helps guide consumers to separate waste into broad streams.

3. Biopolymers, Biodegradable, and Compostable

Bio-based plastics are derived either directly from crops such as sugar cane, corn, or castor oil, or indirectly from biomass derived from agriculture or forestry (e.g. cellulose). Examples include Polylactic Acid (PLA), Bio-derived Polyethylene, and bio-derived nylons (e.g. PA11 & PA410).

Use of these sustainable feedstocks reduces the dependency on oil for the production of plastics. However, consideration should be given to the efficiency of the agricultural process used to provide the feedstock – for instance whether it is an agricultural byproduct or a dedicated crop. Some feedstocks require vast amounts of water for their production, or the use of toxic chemicals for processing, such as bleaching.

Biopolymers are often but not necessarily biodegradable (or recyclable), and consideration should be given to end-of-life when specifying a biopolymer. Biodegradability is defined as “The degradation of a polymer material to its base compounds, within a reasonable amount of time, due to biological processes”. By contrast, Compostability is “The degradation of a material into humus, water and other non-toxic compounds at a similar rate to organic material”. Compostable materials should only be specified where composting at end-of-life can be assured, otherwise the resultant biomass goes to waste and produces methane.

Biodegradable materials are commonly used in medical applications, e.g. for drug release and tissue engineering; these are generally bio-based polymers such as PLA, PHB, PHA, PBS and PCL.

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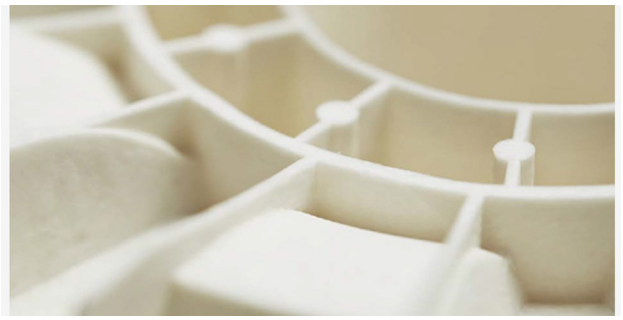
Oxo-biodegradable (OBD) materials are standard polymers with the addition of a pro-oxidant and a reaction-rate modifier. These additions make them susceptible to microbial attack, which ultimately breaks the polymer down into CO2, water, and biomass. The degradation speed can be controlled, varying between weeks and years. Examples are PE, PP, PS and PET.

For all bio-degradable materials, the thicker it is, the slower the process; hence bio-degradable products are typically only film and sheet-based.

A great development in the world of sustainable bio-degradable materials is that of Paper Injection Moulding (PIM), in which Japanese company Niisha is a leader and with whom Shore is lucky to have developed a strong partnership, sharing mutual expertise. PIM provides a genuine alternative to plastic injection-moulding, facilitating complex geometries, thin walls, and low component weights, whilst also being highly sustainable. PIM is biodegradable within 3 to 6 months, is non-toxic, and some grades are flushable. It has a distinctive surface texture that can provide a premium feel. It is also heat-resistant and takes adhesive well, for example for labels. Nissha calculate that its CO2e footprint is 28% that of PP; when integrated into a product, its low density may contribute to further emissions reductions, namely through transport (see above). It therefore lends itself extremely well to complex or premium packaging solutions such as device trays, and offers strong opportunities for components in single-use devices and circular economy applications.

Nissha is pioneering PIM's application in medical devices. PIM trays have been used for medical device packaging for some time, and recently Nissha announced that they have developed a concept prototype for a self-injection pen cap. Although a successful demonstration of the technology's capabilities, further process optimisation is ongoing to achieve even better surface quality and mechanical performance.



An example PIM component, demonstrating the level of detail and structure the process is capable of. Photo courtesy Nissha.

Nissha have developed a prototype auto-injector cap made of PIM in lieu of plastic, demonstrating the technology's potential for sustainable mechanical applications. Photo courtesy Nissha.

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There are many levers that we can pull to increase a product's sustainability. The ultimate route to net zero is for manufacturers to adopt circular economy models, which – particularly in the pharmaceutical industry – is a long and complex road likely to require regulatory change as well as business model reinvention. However, we designers have the tools that will allow us to be instrumental in developing products and services that will transition smoothly to circularity, and have a significantly reduced environmental impact in the meantime. The imperative is clear, and constantly-evolving design, manufacturing and material technologies and methodologies can be implemented today to bring the ultimate goal closer step by step.

Ypsomed SmartPilot reusable smart insulin pen

If you would like to discuss sustainability in relation to your business, products, or a design project, we'd love to hear from you. Please get in touch at:

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