DECEMBER 14, 2022

THE CIRCULAR ECONOMY IN MEDICAL TECHNOLOGY

A CASE STUDY OF PHILIPS HEALTHCARE

710078542

ENGM023

Contents

Abstract

Healthcare and medical technology have a large environmental impact in both carbon emissions and waste generated. The circular economy offers several theoretical design strategies and business models to reduce the impact of a business, and these can and should be applied to the medical industry. This paper explores circular strategies and reviews the opportunities and challenges for the circular economy in the medical sector, then analyzes Philips Healthcare as a case study. The analysis of Philips offers generalizations for the wider industry and further recommendations for Philips's circularity efforts.

Introduction: Climate Impact of Healthcare

Healthcare, though not typically included in the sustainability conversation, has a large environmental impact: 4.4% of global carbon emissions come from the healthcare sector, many of which are from the supply chain (Health Care Without Harm and ARUP, 2021). For example, 62% of the emissions of the UK National Health Service (NHS) come from the supply chain, such as pharmaceuticals and medical equipment (Figure 1). Medical equipment alone is 10% (NHS England, 2022). Besides carbon emissions, healthcare generates large amounts of waste, some of which is biohazardous and must be incinerated or sterilized before disposal; estimates range between 8 and 13 kg per bed per day in the United States (Minoglou *et al.*, 2017; Practice Greenhealth, 2022). Thus, healthcare, and medical equipment specifically, are an important part in the overall environmental sustainability of society.

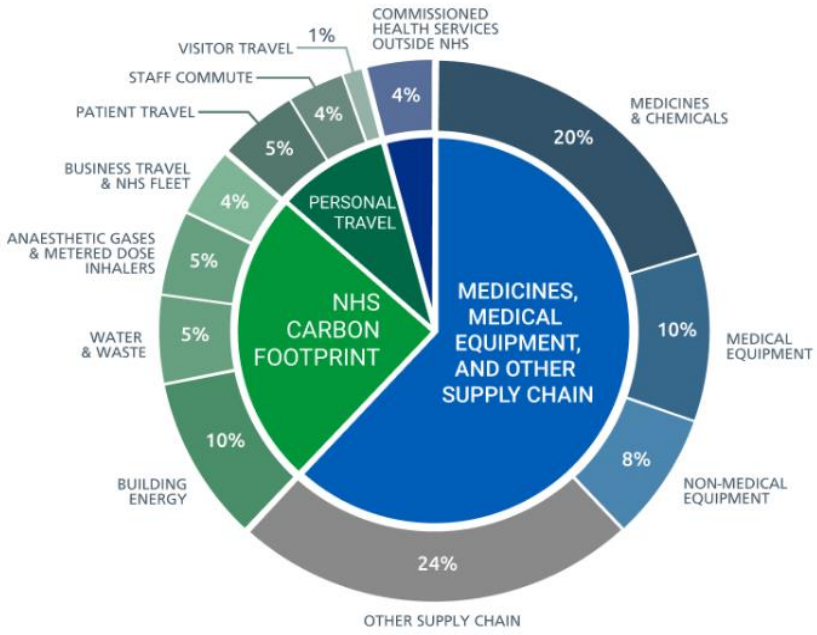

Figure 1: Proportion of carbon footprint of the NHS (Scopes 1-3) from 'Delivering a Net Zero NHS' (NHS England, 2022). A significant portion comes from medical equipment.

Theory of the circular economy

The circular economy (CE) offers theories and strategies to reduce environmental impact. CE is a nature-inspired concept where no resource is wasted, and multiple actors cooperate to fully utilize materials (Lovins *et al.*, 1999). As opposed to the current linear economy where resources are taken from the earth, made into products, used, and then wasted, a circular economy 'closes the loop' by reusing or recycling goods to eliminate waste and reduce the raw materials extracted from the environment (Ellen MacArthur Foundation, n.d.-a). As a leader in the CE concept, the Ellen MacArthur Foundation (n.d.-a) defines it as a system that does the following:

1. Eliminates waste and pollution
2. Circulates products and materials at their highest value
3. Regenerates nature

The 'butterfly diagram' (Figure 2) shows the ways that materials are recirculated. The preference is keeping materials in the inner loops of the diagram where the embodied production energy is highest for as long as possible (for example, shredding up and recycling a usable product and then manufacturing a new product with it is less efficient than reusing the product or repairing it). This is called the "inertia principle," a term coined by Walter Stahel (2010: 195):

> *"Do not repair what is not broken, do not remanufacture something that can be repaired, do not recycle a product that can be remanufactured. Replace or treat only the smallest possible part in order to maintain the existing economic value of the technical system."*

Additionally, keeping materials pure and uncontaminated may allow for "pure circles" of infinite recycling. Finally, cascading use of a material throughout the economy maximizes use and efficiency if the material quality degrades over time (for example, using shredded textiles as insulation when they are unusable) (Ellen MacArthur Foundation, 2013).

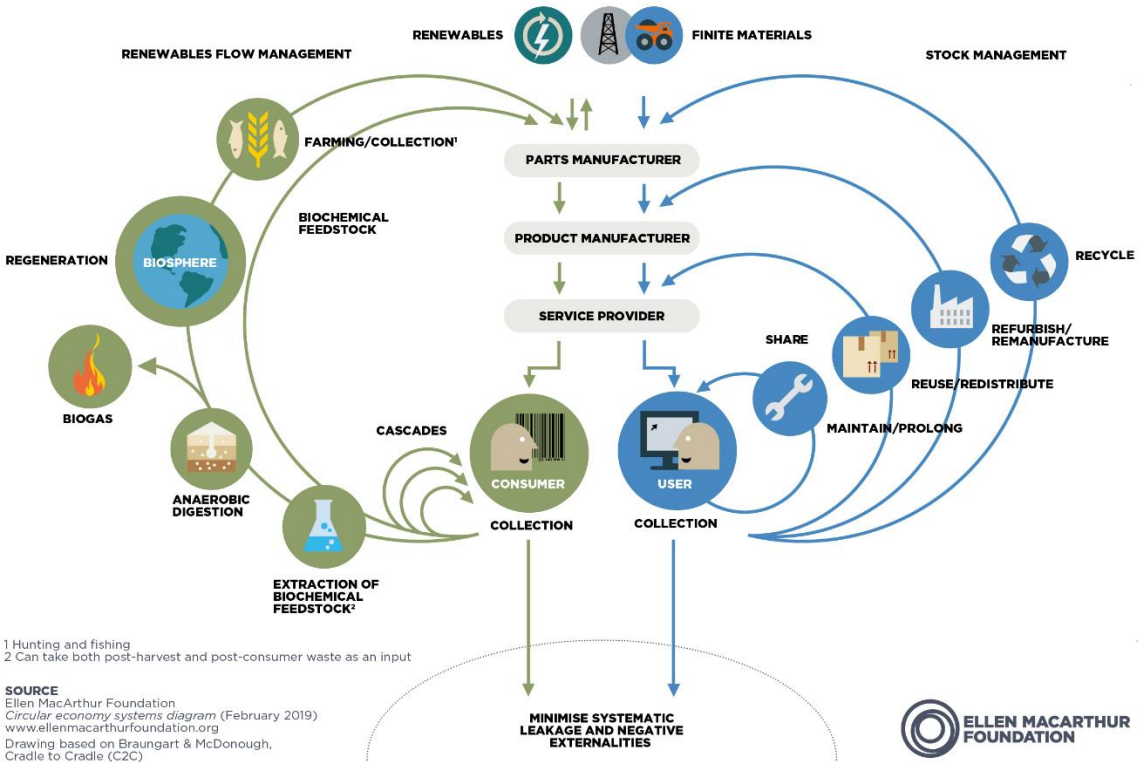

Figure 2: The 'butterfly diagram' illustrating material pathways in the circular economy (Ellen MacArthur Foundation, n.d.-a)

CE is something that must be designed in from the beginning of a process; wedging it in as an afterthought is rarely successful (Bocken *et al.*, 2016). There are numerous techniques that designers can use to make their system CE-ready, and the main categories are either design for material recovery (recycling) or design for maximal product lifetime (den Hollander *et al.*, 2017). Designing for recycling, besides choosing recyclable materials, includes design requirements such as ease of disassembly, minimizing the number of materials, avoiding composite materials, and labeling products and materials to ensure safe and non-toxic recycling (Leal *et al.*, 2020). Designing for lifetime includes design priorities to resist obsolescence: making products maintainable, repairable, upgradeable, reusable, and remanufacturable to increase their longevity (den Hollander *et al.*, 2017). Using whole system thinking to design the product sustainably from the start is critical.

Even if a product is circularly design, a specifically circular business model is needed to commercialize it because the majority of companies are optimized to profit in the current linear economy. Sustainable business models can capture the value that is often missed (e.g., waste materials), destroyed (e.g., negative environmental effects), or absent (e.g., undiscovered value via new partnerships or models) in a linear system (Evans, Fernando, *et al.*, 2017). Bocken et al. (2016) lists business models for extending use and closing loops:

1. Product-service system, where a business retains ownership of the product and sells the function or access to the product
2. Extending product value by recovering parts or entire products after they are initially used

3. Extending product life model where a product is designed for longevity, and maintenance or repair can be obtained from the manufacturer
4. Extending resource value by recovering materials from the product after they are used
5. Industrial symbiosis where wastes from processes are sold to other businesses

A business model of particular interest is the product-service system (PSS) in which the business sells access or use of the product rather than the product itself. This system reverses the ownership of a product back to the business and makes it responsible for service and upkeep (Evans, Vladimirova, *et al.*, 2017), and in doing so changes the incentives of both the business and the consumer for the better. It incentivizes the business to create a product that lasts longer so it can sell more use or access time per product, allows the business to optimally maintain that product for longevity, and further lets the business extract value once the product is obsolete by harvesting it for parts or recycling it. It also incentivizes the customer to only use the amount they need, which may save them money in the long term (Bocken *et al.*, 2016). Circular business models and design strategies are summarized in Figure 3.

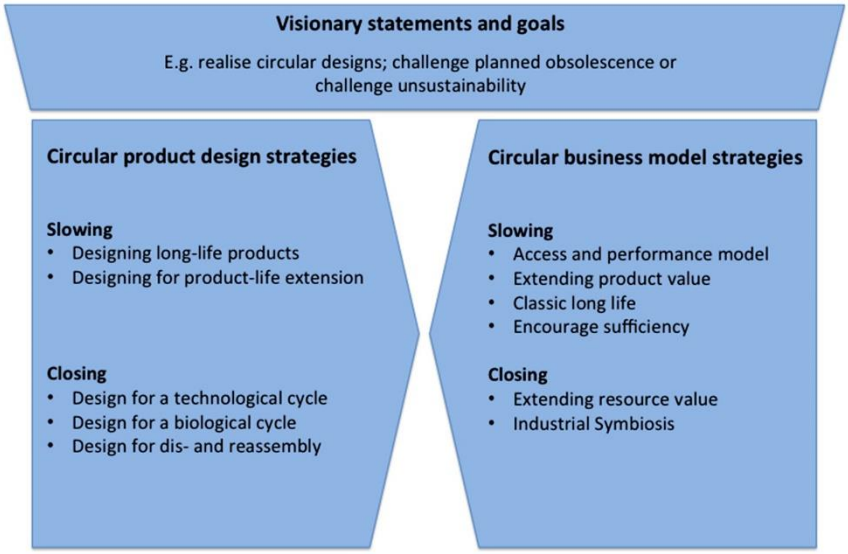

Figure 3: Design strategies and business models for the circular economy (Bocken et al., 2016)

All stakeholders can benefit from the CE. Businesses will gain a reduced material bill, better reputation, and customer loyalty, and consumers gain more efficiency, reduced waste, and reduced cost. The planet benefits from less material waste and reduced consumption of finite resources. The Ellen MacArthur foundation estimates that an implementation of the circular economy could save 520 to 630 billion USD per year globally (Ellen MacArthur Foundations, 2013).

However, CE does have challenges. Additional logistics and relationships are needed. For example, if a product is designed for remanufacturing, it must be returned to the original manufacturer at the end of each cycle, which requires reverse logistics systems and some incentive or requirement for the user to return it (den Hollander *et al.*, 2017). Further, tight business-to-business relationships are needed for symbiosis, especially if certain circular functions, such as recycling or repair, are not among the business's competencies. These partnerships can have high transaction costs in time and effort (Lahti *et al.*, 2018). If the circular economy was easy, everyone would already be doing it.

Nevertheless, medical technology could benefit from the adoption of CE principles. In 2020, reprocessing single-use devices in hospitals saved 400 million USD and diverted 11.9 million pounds of waste (Association of Medical Device Reprocessors, 2020); this can and should be expanded with intentional circular design. The leader in circular healthcare in large corporations is Philips Healthcare, and their practices will be analyzed as a case study after reviewing the literature on circular medical technology and its challenges.

Literature Review: Circular medical technology

Challenges to circularity in medical devices

There are major barriers to the circular economy within medical devices. First, patient safety is paramount, and all equipment used must be sterile. Some devices have higher hygiene criticality[1] than others, leading to more intensive requirements for cleanliness and the perception of more difficulty to reuse (Centers for Disease Control and Prevention, 2016). A study of industry opinions found that reprocessing difficulty was the major barrier to reuse (Kandasamy *et al.*, 2022). There were two deaths in the US in 2015 due to reprocessed and incorrectly sterilized duodenoscopes (Drues, 2015). Incidents like this can reduce trust in reprocessed devices, and generally single-use devices are perceived as safer (Macneill *et al.*, 2020). Though "there is no compelling evidence that [single-use devices] reduce healthcare acquired infections," that has not stopped the vast shift away from mostly reusable devices prior to plastic and towards single-use devices purely due to the perception of safety (Macneill et al., 2020: 2091).

Additionally, handling contaminated equipment which is classified as a biohazard is difficult as it must be decontaminated (US Environmental Protection Agency, 2022). Up to 90% of waste from the operating room is typically treated as a biohazard, even if it is not actually contaminated, and biohazard waste is usually incinerated (Lee and Mears, 2012). This is a type of unnecessary obsolescence of products due to concern for safety (Kane *et al.*, 2018). Concern for safety, liability, and profits also leads to designed obsolescence after a single use of a device by some companies (Kane *et al.*, 2018; Macneill *et al.*, 2020).

Finally, the regulatory landscape is generally unfavorable to CE initiatives. For example, NHS Scotland usually does not purchase reused equipment due to liability concerts (Dawson *et al.*, 2022). Regulatory bodies like the US Food and Drug Administration have made it more difficult for reprocessors by ending premarket approvals for them but not for original equipment manufacturers. Devices labeled as multi-use must provide evidence verifying the safe reusability, whereas there is no regulatory burden for single-use devices; thus single-use becomes the default (Macneill *et al.*, 2020). Even seemingly simple switches like including recycled content have a higher regulatory expectation. Medical devices cannot use post-consumer recycled plastic because of the need for complete traceability for the required Device History Record; though non-virgin plastic is not specifically disallowed, it would be extremely difficult to meet requirements without it (Healthcare Plastics Recycling Council, 2021). Sterility, the

[1] Hygiene criticality is the importance of disinfection for that medical device before it is used (e.g., a syringe must be more sterile than a stethoscope) (Centers for Disease Control and Prevention, 2016)

perception of sterility, biohazard waste, and regulatory hurdles are all barriers to the circularity of medical equipment.

Circular design and business models for healthcare

Medical equipment is only beginning to be considered for circular design due to the challenges explored above. Given the challenges and potential benefits, Kane *et al*. (2018) developed a matrix to recommend the best circular design practices depending on the financial value and hygiene criticality of the medical device. For devices that are valuable and do not demand high sterility, such as imaging machines, patient monitors, and medical furniture, remanufacturing is a realistic and profitable strategy for sustainability. For devices that are inexpensive and low criticality like compression sleeves, designing for recycling is recommended as it may be more economically and financially expensive to recover the product in another way. In the inexpensive but highly critical category, devices like syringes and bandages which will be contaminated during use should be designed out of the care pathway if possible by inventing alternative methods to achieve the same result; alternatively, they may be designed to be sterilized and recycled since the energy and money to sterilize them and reprocess may be prohibitively high. Finally, expensive and highly critical devices like hearing aids and surgical staplers should be designed for reprocessing in a healthcare-friendly way by considering the sterilization needs. The devices could be designed more modularly, with durable parts to be reused and patient-contacting parts to be single-use. Built-in indicators of device performance and quality should be added to increase trust and ensure safety after multiple use-sterilization cycles. Additionally, the devices could be certified not for an infinite number of cycles but for a fixed number of uses to facilitate regulatory validation (Kane *et al.*, 2018). This matrix provides a useful generalization of design approaches depending on the device and its use.

Guzzo *et al*. (2020) places nine existing medical circular business models (CBMs) on the criticality-value axes in Figure 4. They are connected to the relevant CE principles in Table 1. Though only existing CBMs are shown, it is useful to see successful approaches specific to the device category.

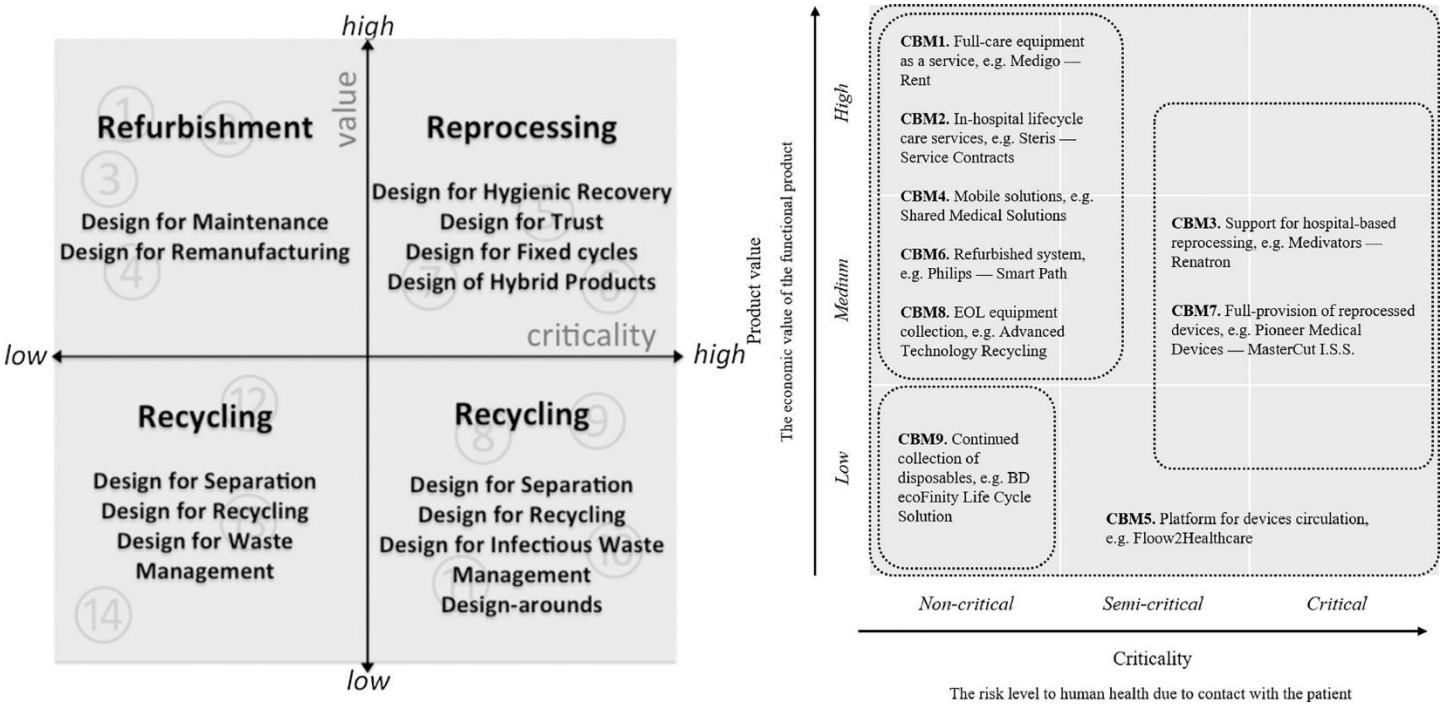

Figure 4 (left): Suggested circularity approach depending on hygiene criticality and device cost (Kane et al.*, 2018);*
Figure 5 (right): Circular business models on the criticality - product value axis (Guzzo et al.*, 2020)*

	Model description from Guzzo *et al*. (2020)	***Connection to CE principles***
CBM1	Full care equipment as a service; continuously providing access to equipment, support, maintenance	*PSS – product service system. Prolonging product life, optimization, dematerialization*
CBM2	In-hospital lifecycle care services; service for predictive maintenance, providing spare parts or consumables	*Prolonging product life, potentially extending product value by using parts harvested*
CBM3	Support for hospital-based reprocessing; consumables and equipment for sterilization and processing to take place at the hospital	*Prolonging product life, cycling again*
CBM4	Mobile solutions; travelling and setting up mobile medical equipment in various hospitals for short periods of time	*Dematerialization, optimization, sharing*
CBM5	Platform for device circulation; buy/sell or share/rent programs for facilitating transfer	*Sharing, optimization*
CBM6	Selling refurbished systems; hospitals can by secondhand equipment	*Prolonging product life, cycling again*
CBM7	Full reprocessing of single-use devices – service provider takes on risk of doing all the reprocessing and provides them to the hospital	*Prolonging product life, cycling again*

CBM8	End of life equipment collection for parts harvesting and recycling	*Extended product value, extended resource value*
CBM9	Collection of disposables and recycling any high-quality materials	*Extended resource value*

Table 1: Existing circular business models in medical technology

Present state of circularity in medical technology

The present state of circularity in medical technology is limited. Currently, only equipment in the top left quadrant of Kane *et al*.'s (2018) matrix such as large and expensive imagine machines are regularly refurbished and resold. Some manufacturers are trying out PSS with low-criticality, low-tech, high-volume devices (bottom left quadrant) such as pulse oximeters by selling access to devices and filling orders with refurbished devices first (Scalia and Benedettini, 2022). Additionally, hospitals often, against the labelling of the devices, reuse some single-use devices such as surgical tools for the cost savings. They often turn to third party reprocessors to handle sterilization (Klein, 2005). Because it is not the original manufacturers doing the reprocessing, third party reprocessors have to reverse-engineer the device (Scalia and Benedettini, 2022). This demonstrates the market need for more circular (and cheaper) medical devices.

Case Study: Philips Healthcare

Overview and environmental goals

Philips Healthcare (PH), a multinational corporation based in the Netherlands, is a pioneer in circular medical technology. In 2021, its total sales were worth 17.2 billion EUR, and it put 73,500 tonnes of product on the market (Philips, 2022a). Its healthcare products cover several areas such as patient monitoring (cardiograms, Holter monitors, neonatal and maternal monitoring), large imaging (CT, MR, mammography, fluoroscopy, x-ray, and C arms), treatment (ventilators, respiratory drug delivery, breast pumps), and small consumables (cannulas, masks, maternal accessories) (Philips, 2022b).

PH has established their general environmental attitude through emissions goals[2] in line with science-based targets[3]. Though they are carbon neutral in their operations as of 2020 in part due to offsets, they plan to get 75% of their electricity from renewables by 2025. They are also working with their suppliers to decrease their emissions (Philips, 2022c). More relevant to this discussion are their circularity goals. By 2025, they aim to generate 25% of their revenue from circular products and service, and in 2021 they achieved 16%. They also aim to "close the loop" on all professional medical equipment by 2025 by either refurbishing and reselling or recycling. In 2021, about 3,000 systems were returned, and 8% of products globally (6,000 tonnes) were collected, reused, or recycled (Philips, 2022a). Finally, they are adopting

[2] "Global health technology company Royal Philips commits to reduce absolute scope 1 and scope 2 [greenhouse gas] emissions 75% by 2025 and 90% by 2040 from a 2015 base year. Royal Philips also commits to reduce absolute scope 3 [greenhouse gas] emissions from purchased goods and services, business travel, downstream transportation & distribution and use of sold products 42% by 2030 from a 2020 base year" (Science Based Targets, 2022).

[3] Science-based targets are emissions targets that are certified to align with the global goal of less than 2°C warming for the company's industrial sector based on the Intergovernmental Panel on Climate Change (The Carbon Trust, 2019)

circular practices at their offices, manufacturing sites, warehouses, and R&D facilities, and as of 2021 sent zero (<0.1%) waste to landfill[4] (Philips, 2022a).

EcoDesign

PH has embraced the idea of eco-design (or EcoDesign as they term it) to design out environmental impacts of their products, and circularity is part of their design requirements. By using lifecycle assessment (LCA), they can quantify the impacts of the entire lifecycle of the product and identify high-impact stages to address. Specific efforts include improving the energy efficiency of products during the use phase because, as seen in the LCA results in Figure 6, their products are environmentally intensive to use (Philips, n.d.-a). PH includes recycled materials in their products; however, an exact figure is not readily available, indicating it is probably not a high proportion. They are applying design for recycling principles, including creating "recycling passports" so that materials are properly identified and disassembled safely (Philips, n.d.-b). Additionally, they use labeling that indicates when a product has been EcoDesigned with significant reductions in impact (Philips, n.d.-a). Dematerialization is in progress, as increasing use of software allows for completely virtual and remote product upgrades and predictive maintenance; they also are moving to be more compatible with existing technologies to reduce redundancies, such as the ability to plug in a patient monitor to a handheld device rather than requiring its own specific screen (Philips, n.d.-a). Overall, Philips is incorporating several aspects of circular design into their process.

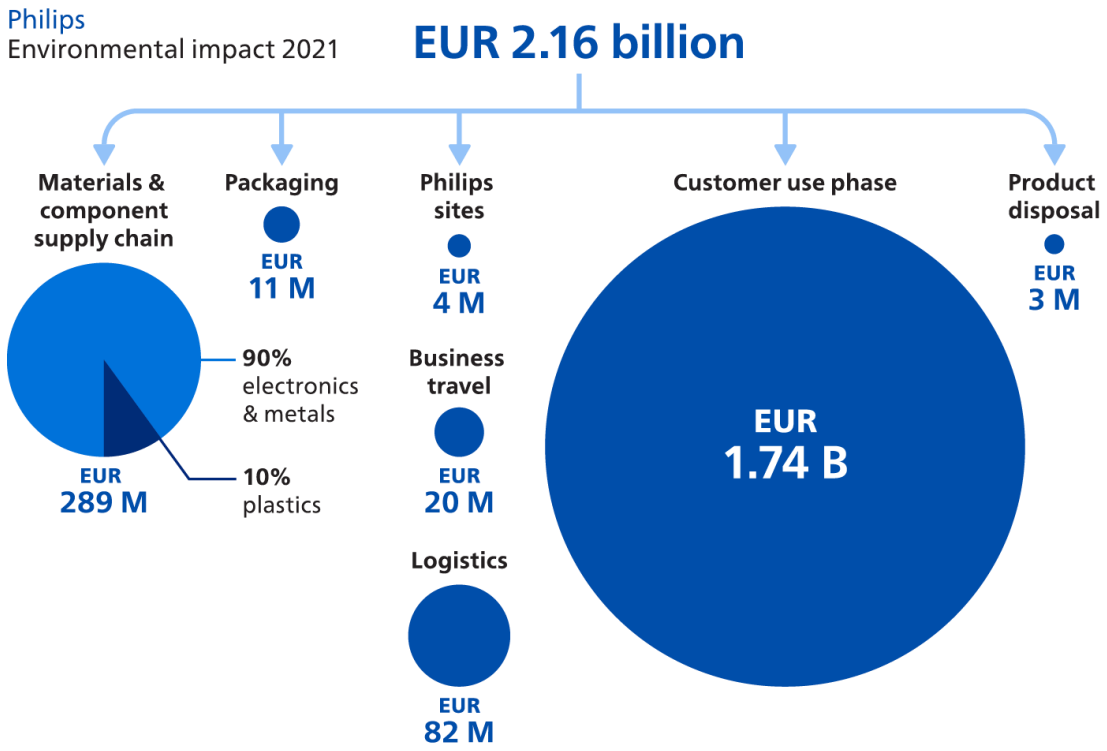

Figure 6: Lifecycle assessment results for all Philips's operations and products (Philips, n.d.-a)

[4] Incineration and waste-to-energy are included as waste destinations (Philips, 2022a)

Circular business models

EcoDesign alone does not make a circular product without the business models to support it. PH has deployed three circular business models for some of their products: refurbishment, product-service systems, and partial leasing, all with the goal of extended product use. They have emulated the Ellen MacArthur butterfly diagram as seen in Figure 7 with their own.

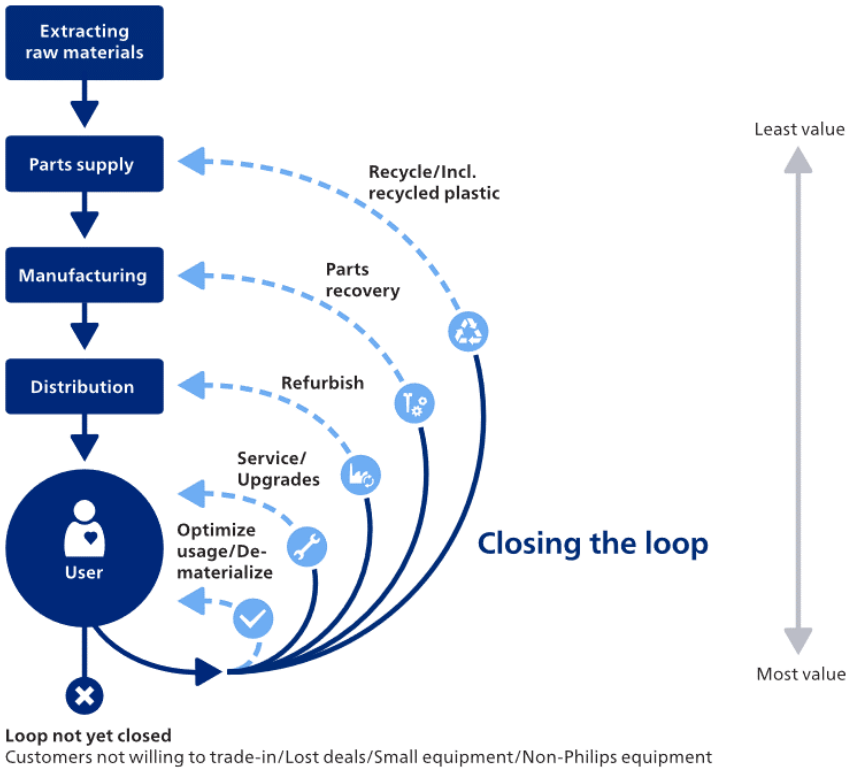

Figure 7: Philips's circular models (Philips, 2022a)

First, PH utilizes CBM6 regularly by taking back, refurbishing, and reselling large and expensive imagine systems at a lower cost. As an example, the refurbished interventional x-ray is typically sold for 60-85% of the new cost. As 80% of the market does not need the newest x-rays to properly care for patients, this helps PH to keep market share and maintain customer relations while also reducing waste: the lifespan of the x-ray is typically increased by 5-10 years with refurbishment (Jensen *et al.*, 2019). This corresponds to the CE principles of extending product life and value and aligns with the recommended approach for large and low criticality equipment according to Kane *et al.*'s matrix.

Second, PH deploys a partial leasing business model for the Lumea hair remover, allowing them to retain some ownership and control of the product. Customers can "try then buy" the device, paying a monthly fee until the device is paid off (12 months) or until they wish to return it. This lets Philips a) potentially re-lease the shaver after any required maintenance and b) prevent the shaver from ending up in the landfill at the end of its life by harvesting parts and recycling (Philips, 2022d). This is an example of partial CBM6 by re-leasing used devices, and partial CBM1 by selling access to the device for the first 12 months until full ownership. Prolonging product life and value are the CE principles at play.

Third, PSS, or CBM1, is deployed for the portable ultrasound as a subscription service. A monthly subscription gives healthcare providers use of the ultrasound while Philips maintains ownership and responsibility for maintenance. Providers pay a flat fee for basic use and can pay-per-use for more specialized features, allowing them to try new tools without committing to the expense of a new model (Philips, n.d.-c). For budget-tight hospitals, this improves specialized patient care and provides a flexible and predictable expense due to the price cap. Monitoring the usage of the equipment encourages efficiency as hospitals are incentivized to use only what they need, and they have flexibility to modify usage and equipment as needed (British Journal of Cardiology, 2015); this corresponds to the inner loops of the butterfly diagram to share or redistribute products. PSS simplifies the maintenance and takeback process for Philips as well because of the retention of ownership, working towards their goal of closing the loop. This is an excellent example of a sustainability solution being a win-win for customers, the company, and the environment.

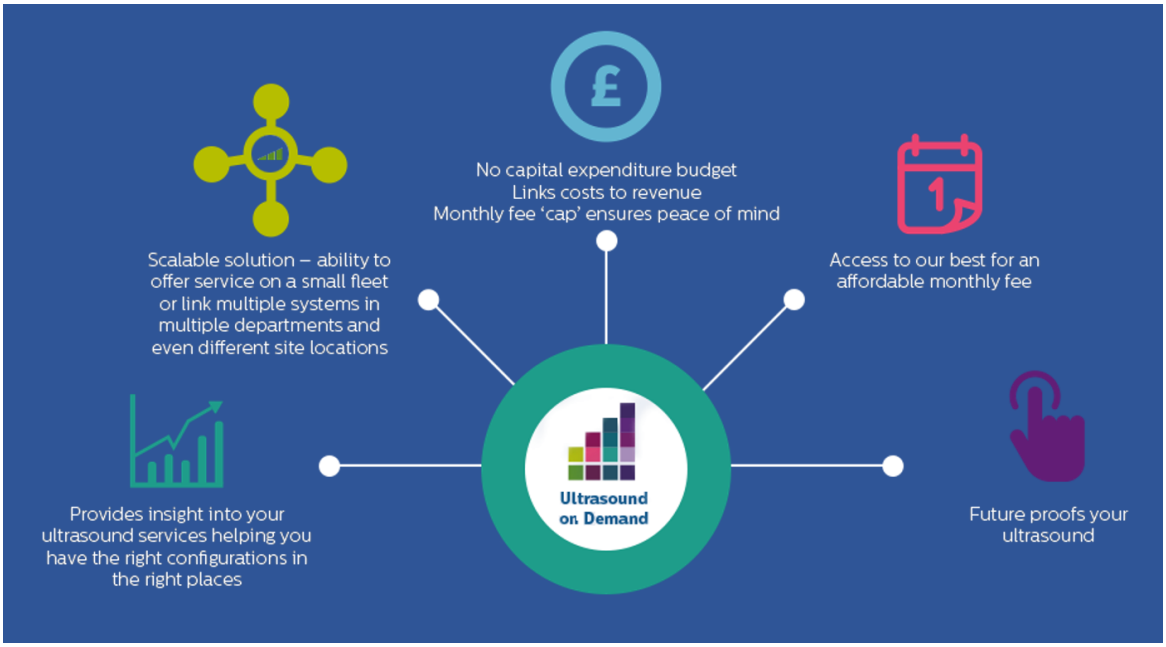

Figure 8: Philips's Ultrasound on Demand selling points (Philips, n.d.-c)

Discussion

Generalizations for the industry from Philips

PH is attempting circularity in a way that few other medical technology companies are based on my experience in the industry, and their prolonged engagement and support for external initiatives like the Ellen MacArthur foundation suggests it is a good faith effort rather than a publicity stunt. Other companies in the medical technology industry need to commit to a circular transformation as well. A simple place to start is requiring LCAs as part of design processes and reviews as there is no way to design for sustainability without knowing the product impact. PH has undertaken a mindset shift towards circularity throughout the company and employee base with training, dedicated support hubs, and leadership from CEO Frans van Houten who first included CE in the business strategy in 2012 (Ellen MacArthur Foundation, n.d.-b). Other companies, from small businesses to transnational corporations,

need a similar culture shift. As more companies work towards CE, collaborations will become easier, and change may accelerate.

Recommendations for Phillips

Though PH is a leader in the industry, their CE program is far from finished. Although they have goals to close the loop on all professional medical equipment, there is no equivalent goal for smaller, consumer-facing devices. Admittedly, this would be a more difficult task as those devices may be dispersed in consumers' homes rather than centralized at the hospital, increasing the effort needed to take them back without shifts in ownership or incentives. Transitioning to further PSS use could solve unlock more circularity for smaller devices. PH also could engage further with designing *from* recycling (Leal *et al.*, 2020) and using more post-consumer recycled materials as allowed by regulations. Finally, following the common idea that the most sustainable product is the one not bought or manufactured, the most sustainable healthcare is prevention. PH should engage in the preventative health space and find innovative solutions that are both profitable and preemptive.

Wider changes needed

Industry alone cannot solve the many challenges of sustainability in healthcare and medical technology. If the barriers discussed above are to be overcome, leadership is needed from regulatory bodies to create more pathways for circular devices. Perceptions of single use equating to safety also need to be confronted with more research and open discussion between healthcare providers, patients, and regulators. Finally, in 2020 the UK NHS was the first health system to commit to net zero (NHS England, 2022), which in my personal experience has had ripple effects throughout the international industry as manufacturers create sustainability plans to comply with a major customer's demands. More health systems should use their purchasing power to demand faster sustainable and circular change from the medical technology industry. According to a Kearney analysis, 70% of medical technology companies have not yet set a science-based target to align with 1.5°C[5] or even an emissions reduction goal (Blazic *et al.*, 2022). Though emissions reductions are not the same as circularity goals, they are much more well-known and becoming mainstream, so it can be extrapolated that the number of healthcare technology companies with circularity goals is even lower.

Conclusion

Circularity is much needed in the healthcare industry, especially medical equipment, in the global effort to decarbonize and stay within the finite limits of the Earth's resources. There are many circular design strategies and business models that can be applied to extend product use and material recovery, and the healthcare-specific requirement of patient safety plays a large role in determining which strategies are environmentally and economically feasible. Philips Healthcare is leading the CE effort in the global medical corporation arena with goals to close the loop on all professional medical equipment and generate 25% of revenue from circular products by 2025. These are ambitious by industry standards, and these efforts will expand the recognition and potentially the adoption of CE principles by other

[5] 1.5 C of increase in global temperatures, widely regarded as a 'safe' amount of warming and codified in the Paris Agreement

companies. Even though the goals are ambitious compared to its peers, PH still has a long way to go to – fully 75% even after 2025 – achieve full circularity. Continued efforts from both PH and the wider regulatory, healthcare provider, and patient community are necessary to create an economy and healthcare system that are truly healthy for people and the planet.

References

Association of Medical Device Reprocessors (2020) *2020 Annual AMDR Member Survey Results*. Available at: < https://amdr.org/wp-content/uploads/2022/01/2020_reprocessing_infographic_update_12-23.pdf>.

Blazic, E., Wise, M., and Rowe, E. (26/08/2022) Are healthcare companies making progress against their climate ambitions? *Kearney*. Accessed: 11th December 2022 <https://www.kearney.com/health/article/-/insights/are-healthcare-companies-making-progress-against-their-climate-ambitions. >.

Bocken, N. M. P., de Pauw, I., Bakker, C., and van der Grinten, B. (2016) Product design and business model strategies for a circular economy. *Journal of Industrial and Production Engineering* 33(5): 308–320.

British Journal of Cardiology (08/2015) 'Ultrasound on demand' − how will it work in the UK?. *British Journal of Cardiology*. Accessed: 12th December 2022 <https://bjcardio.co.uk/2015/08/ultrasound-on-demand-%E2%88%92-how-will-it-work-in-the-uk/. >.

Centers for Disease Control and Prevention (2016) A Rational Approach to Disinfection & Sterilization Guidelines. Accessed: 13th December 2022 <https://www.cdc.gov/infectioncontrol/guidelines/disinfection/rational-approach.html. >.

Dawson, T. A., Hopkinson, P., Charnley, F., Pencheon, D., Zils, M., Eatherley, D., Burton, K., and Gopfert, A. (2022) *Accelerating the transition towards a net zero NHS: Delivering a sustainable and resilient UK healthcare sector*.

den Hollander, M. C., Bakker, C. A., and Hultink, E. J. (2017) Product Design in a Circular Economy: Development of a Typology of Key Concepts and Terms. *Journal of Industrial Ecology* 21(3): 517–525.

Drues, M. (30/04/2015) Can We Design Medical Devices To Be Reprocessed Without Killing People? *Med Device Online*. Accessed: 3rd November 2022 <https://www.meddeviceonline.com/doc/can-we-design-medical-devices-to-be-reprocessed-without-killing-people-0001. >.

Ellen MacArthur Foundation (n.d.-a) What is a circular economy? Accessed: 10th December 2022 <https://ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview. >.

Ellen MacArthur Foundation (n.d.-b) Pioneering circularity in the healthcare industry: Royal Philips. Accessed: 10th December 2022 <https://ellenmacarthurfoundation.org/circular-examples/pioneering-circularity-in-the-healthcare-industry-royal-philips. >.

Ellen MacArthur Foundations (2013) *Towards the circular economy Vol. 1*. Available at: < https://ellenmacarthurfoundation.org/towards-the-circular-economy-vol-1-an-economic-and-business-rationale-for-an>.

Evans, S., Fernando, L., and Yang, M. (2017) Sustainable Value Creation—From Concept Towards Implementation. In Stark, R., Seliger, G., and Bonvoisin, J. (Eds.), *Sustainable Manufacturing*. Springer, 203-220.

Evans, S., Vladimirova, D., Holgado, M., van Fossen, K., Yang, M., Silva, E. A., and Barlow, C. Y. (2017) Business Model Innovation for Sustainability: Towards a Unified Perspective for Creation of Sustainable Business Models. *Business Strategy and the Environment* 26(5): 597–608.

Guzzo, D., Carvalho, M. M., Balkenende, R., and Mascarenhas, J. (2020) Circular business models in the medical device industry: paths towards sustainable healthcare. *Resources, Conservation and Recycling* 160(104904).

Health Care Without Harm, and ARUP (2021) *Global Road Map for Health Care Decarbonization, Executive Summary*. Available at: < https://healthcareclimateaction.org/roadmap?mc_cid=be8836cd62&mc_eid=4a4557363b>.

Healthcare Plastics Recycling Council (2021) *Circularity for Healthcare Plastics: The Challenges and Opportunities*. Available at: <https://www.hprc.org/circularity-for-healthcare-plastics/>.

Jensen, J. P., Prendeville, S. M., Bocken, N. M. P., and Peck, D. (2019) Creating sustainable value through remanufacturing: Three industry cases. *Journal of Cleaner Production* 218: 304–314.

Kandasamy, J., Kinare, Y. P., Pawar, M. T., Majumdar, A., K.E.K., V., and Agrawal, R. (2022) Circular economy adoption challenges in medical waste management for sustainable development: An empirical study. *Sustainable Development* 30(5): 958–975.

Kane, G. M., Bakker, C. A., and Balkenende, A. R. (2018) Towards design strategies for circular medical products. *Resources, Conservation and Recycling* 135: 38–47.

Klein, A. (2005) 'Hospitals Save Money, But Safety Is Questioned', *The Washington Post,* 13th December, viewed 12th December 2022, <https://www.washingtonpost.com/archive/business/2005/12/11/hospitals-save-money-but-safety-is-questioned/ac112bb6-319c-4f90-b6b6-a294e461b8be/>.

Lahti, T., Wincent, J., and Parida, V. (2018) A Definition and Theoretical Review of the Circular Economy, Value Creation, and Sustainable Business Models: Where Are We Now and Where Should Research Move in the Future? *Sustainability 2018, Vol. 10, Page 2799* 10(8): 2799.

Leal, J. M., Pompidou, S., Charbuillet, C., and Perry, N. (2020) Design for and from Recycling: A Circular Ecodesign Approach to Improve the Circular Economy. *Sustainability* 12(9861): 1–30.

Lee, R. J., and Mears, S. C. (2012) Greening of orthopedic surgery. *Orthopedics* 35(6).

Lovins, A. B., Lovins, L. H., and Hawken, P. (1999) A Road Map for Natural Capitalism. *Harvard Business Review* : 145–158.

Macneill, A. J., Hopf, H., Khanuja, A., Alizamir, S., Bilec, M., Eckelman, M. J., Hernandez, L., McGain, F., Simonsen, K., Thiel, C., Young, S., Lagasse, R., and Sherman, J. D. (2020) Transforming The Medical Device Industry: Road Map To A Circular Economy. *Health Affairs* 39(12): 2088–2097.

Minoglou, M., Gerassimidou, S., and Komilis, D. (2017) Healthcare Waste Generation Worldwide and Its Dependence on Socio-Economic and Environmental Factors. *Sustainability 2017, Vol. 9, Page 220* 9(2): 220.

NHS England (2022) *Delivering a 'Net Zero' National Health Service*. Available at: < https://www.england.nhs.uk/greenernhs/wp-content/uploads/sites/51/2022/07/B1728-delivering-a-net-zero-nhs-july-2022.pdf>.

Philips (2022a) *Philips 2021 Annual Report*. Available at: <https://www.results.philips.com/publications/ar21#downloads>

Philips (/2022b) *Products*. Accessed: 11th December 2022 <https://www.philips.co.uk/healthcare/solutions. >.

Philips (/2022c) *Climate action*. Accessed: 10th December 2022 <https://www.philips.com/a-w/about/environmental-social-governance/environmental/climate-action. >.

Philips (/2022d) *Philips Lumea IPL*. Accessed: 12th December 2022 <https://www.philips.co.uk/c-e/pe/lumea-try-and-buy.html. >.

Philips (n.d.-a) *Sustainable Innovation through EcoDesign*. Accessed: 10th December 2022 <https://www.philips.com/a-w/about/environmental-social-governance/environmental/ecodesign#triggername=close_find_out_more. >.

Philips (n.d.-b) *Our approach to recycling*. Accessed: 10th December 2022 <https://www.philips.com/a-w/about/environmental-social-governance/environmental/circular-economy/recycle. >.

Philips (n.d.-c) *Ultrasound on demand.* Accessed: 12th December 2022 <https://www.philips.co.uk/healthcare/articles/fieldstrength/ultrasound-on-demand. >.

Practice Greenhealth (2022) *Waste*. Accessed: 11th December 2022 <https://practicegreenhealth.org/topics/waste/waste-0. >.

Scalia, G. la, and Benedettini, O. (2022) Green Servitization in the Single-Use Medical Device Industry: How Device OEMs Create Supply Chain Circularity through Reprocessing. *Sustainability 2022, Vol. 14, Page 12670* 14(19): 12670.

Science Based Targets (2022) *Approved science-based target*. Available at: <https://www.philips.com/c-dam/corporate/about-philips/sustainability/downloads/publications/science-based-targets-initiative-certificate-october-2022.pdf>.

Stahel, W. (2010) *The Performance Economy*. (2nd ed.). Palgrave Macmillan.

The Carbon Trust (18/09/2019) *What exactly is a science-based target?* Accessed: 12th December 2022 <https://www.carbontrust.com/news-and-insights/insights/what-exactly-is-a-science-based-target. >.

US Environmental Protection Agency (14/05/2022*) Medical Waste.* Accessed: 12th December 2022 <https://www.epa.gov/rcra/medical-waste. >.