Circular Business Models and UK-Nigeria Cross Border Collaboration for Remanufacture of Anaesthetic Machine and Neonatal Incubators

Kingsley Oturu[1§*], Akinwale O Coker [2*], Chibueze G Achi [2*], Olusola Idowu[2,3*]

[1]Design, Manufacturing and Engineering Management (DMEM), University of Strathclyde, Glasgow, United Kingdom
[2]Department of Civil Engineering, University of Ibadan, Nigeria
[3]University College Hospital (UCH), Ibadan, Nigeria

*These authors contributed equally to this work. [§]Corresponding author: kingsley.oturu@strath.ac.uk
Email addresses:
Dr. Kingsley Oturu: kingsley.oturu@strath.ac.uk
Prof. Wale Coker: cokerwale@yahoo.com
Dr Chibueze Achi: achicgjr@gmail.com
Dr Olusola Idowu: zolaspecky@yahoo.com

Abstract

Remanufacturing is the process returning a used product to at least Original Equipment Manufacturers' (OEM) original performance specification from the customers' perspective and giving the resultant product a warranty that is at least equal to that of a newly manufactured equivalent. Remanufacturing process is commonly split into six processes. These include inspection, cleaning, disassembly, reworking, reassembly and testing. Underpinning remanufacturing are different circular business models that enable sustainability. In literature and industry there are some 'conceptual confusion' with different sustainable manufacturing terms such as 'circular business models' and 'circular economy' being used interchangeably and occasionally merged (e.g. circular economy business model). Using the cross border (UK-Nigeria) remanufacture of anaesthetic machines in Ibadan as a case study, technical sustainable manufacturing strategies that make up the circular economy (e.g. recycling, refurbishing and remanufacturing) are distinguished from circular business models (e.g industrial symbiosis and product service systems). While on the one hand in the UK, there tends to be high levels of cores of medical equipment with frequent upgrades, in developing countries like Nigeria, there is a desperate need for medical equipment that can be remanufactured instead of going to the landfill.

Key words: Remanufacture, Circular Economy, Circular Business Models.

Introduction

With the just concluded COP 26 in Glasgow, there is a renewed drive to see how different recovery options can be harnessed to protect the environment. As MacNeill et al. (2018) suggest, medical devices are often designed for single use and contribute to massive amount

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of waste and pollution, with the health care sector contributing to up to 4.6% of Global Green House Gas emissions [1]. Julie Conrardy et al. argue on the need to reduce medical waste as current practices are unsustainable [2]. There are a couple of technical strategies that make up the circular economy. These include *recycling*, in which the series of activities by which discarded materials are collected, sorted, processed, and used in the production of new product. With *remanufacture* the reworked product is brought up to the quality specifications of a newly manufactured product with matching warranty. Using a *refurbishing/reconditioning* strategy, the reworked product is in working order, with warranty given to some parts (but not to the level of a newly manufactured product. As Ijomah WL, Bennett P and Pearce suggest, *reuse* is "of using a functional component from a retired assembly" [3]. These strategies that make up the circular economy have distinct advantages, pros and cons. A strategy may be more useful in one type of product and unsuitable in another. On the biological arm of the circular economy as depicted in The MacArthur foundation Model (Figure 1) [4], includes strategies such as anaerobic digestion or composting of biological materials to produce biogases that restore the biosphere and reduce CO2 emissions. Biogases emitted from a manufacturing process can also be reused in the manufacturing process in an *industrial symbiosis* business model.

Underpinning these strategies that make up the *circular economy* are *circular business models.* In this paper, the circular economy is a distinguished from the circular business model. A circular business model such as leasing may be used for remanufacturing, refurbishing, recycling or reuse. There appears to be some degree of stigma in the UK with regards to utilisation of recovered medical equipment. In contrast, these products are highly desired in developing countries as they can be repaired or remanufactured for continued use. Different cross border strategies include OEMS and third-party manufactures setting up businesses or collaborations in developing countries. There is a gap in the literature with regards to the ambiguity of the different 'sustainable manufacturing terms', with authors using terms interchangeably. While not attempting to provide all the answers, it is argued in this paper that greater integration and harmonisation of the terms are desperately needed to improve understanding and gather more support for sustainable manufacturing practices. Drawing on lessons learned from supply and remanufacture of anaesthetic machines in Nigeria, it is argued further that appropriate circular business models that could be employed in cross border collaborations will need to be responsive, include widespread stakeholder involvement and take unique local context and governance structures into consideration. Other concepts such as biomimicry and industrial ecology are beyond the scope of this paper. This paper in informed by a cross border collaborative project between the University of Strathclyde, Glasgow UK and the University of Ibadan on remanufacture of medical equipment.

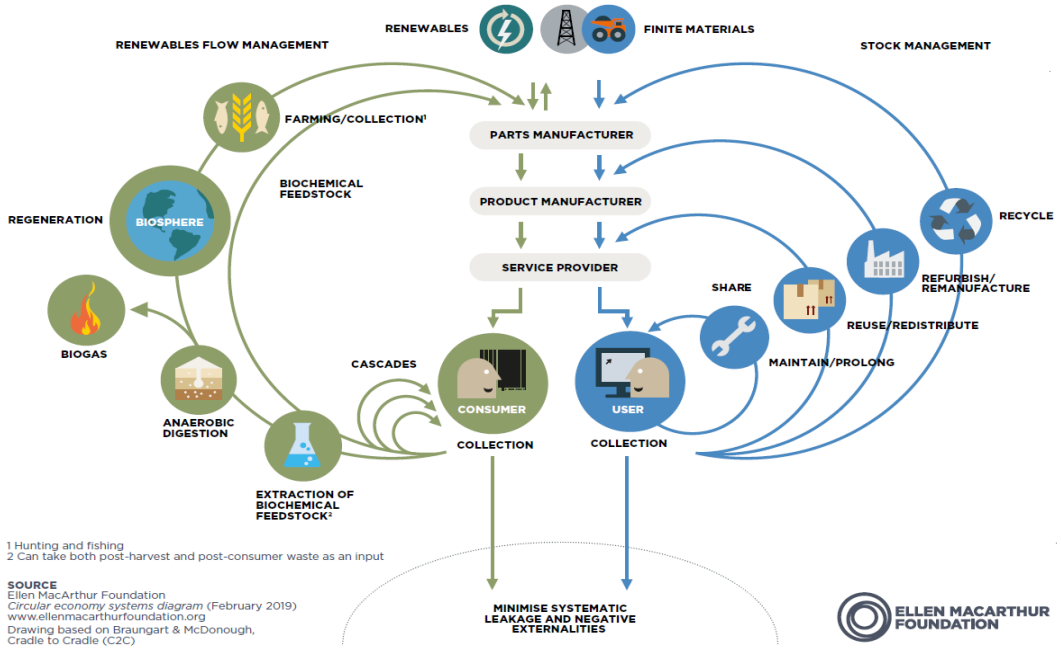


Figure 1 - Circular Economy Butterfly Diagram (Ellen Macarthur Foundation) [4]

Methods

Literature Review

A literature review was undertaken, using the databases of MEDLINE, SCOPUS, Google Scholar search engine and University of Strathclyde online database of journals. The databases provided a broad view of related articles from leading scientific journals. Key words in the literature search were based on aims of the paper include ‘‘circular economy’’, ‘‘medical devices’’, ‘‘circular business models’’ and ‘‘remanufacture’’. Reference lists of identified papers were also read through, selected and reviewed where relevant. The review was limited to studies in English mainly conducted within the last tow decades with keyword combinations utilising ‘or’ and ‘and’ reasoning (Table 1).

Tables

Table 1 - Key words used in studies for recovery options

Initial Keywords	Snowballed keywords
Circular economy	Recovery strategies
Circular business models	Cross border
Medical devices	waste
Anaesthetic machines	
Recycle	

Machine Disassembly and Reworking

An anaesthetic machine was donated to University of Ibadan to support research on reverse logistics. An anaesthetic machine was disassembled. The parts were checked to identify which parts needed to be reworked as well as which parts could be modified to suit the tropical context. Similar strategies were undertaken with a baby incubator. Information on the findings were obtained through remote interviews and correspondence with researchers in Nigeria.

Results

Circular Economy Recovery Strategies

While there are a lot of articles that highlight the importance of the circular economy and the need to move away from linear to circular, there is still some conceptual confusion with different authors using the terms in diverse manner. In Figure 1, [4], the McArthur foundation attempt to bring some clarity on the concept of the circular economy. They suggest that there are two arms. On the technical arm are end of life recovery practices such as recycling, remanufacture, refurbishment and reuse. This would deal mainly with technical products. On the biological arm are processes for biological product recovery. These include anaerobic digestion and release of biogas which could potentially be reutilised to power industrial plants onsite. According to the World Biogas Association (2018), biogas can reduce global carbon emissions by up to 20% and can be fed into electricity and heating networks or national grids [5]. However, even within the circular economy literature, there is still ambiguity and different authors use the terms in different ways. For example, G.M. Kane, C.A. Bakker and A.R. Balkenende (2018) suggest that refurbishment and remanufacture are one and the same process [6]. We agree with Ijomah et al. 2002 who distinguish different recovery options with refurbishment depicted as the process in which the end of life product is reworked but does not have the same specifications and warranty as a new product. This is distinct from remanufacturing in which the reworked product has quality specifications and warranty that matches a newly manufactured product as discussed in the introduction section of this paper (Table 2) [7][8]. Contributing to the conceptual confusion is the fact that one recovery strategy may be coined with different names by different authors in academia and industry. For example, remanufacturing may be called reverse engineering or inverse engineering. Some Asian and European languages also lump different recovery strategies such as recycling, remanufacturing as one word. This paper does not attempt to provide all the answers but to suggest that there is need for more research to streamline how these terms are used. As suggested earlier, different authors use the terms interchangeably. Salemdeeb et al. (2022), argues on the different strategies that contribute to zero waste with regards to the circular economy without defining what the circular economy [9].

Table 2 - Summary Recovery Options [6][7]

Table1.
Summary of Recovery options (adapted from Ijomah, 2002)

Recovery options	Definition
Remanufacturing	The process of returning a used product to at least OEM original performance specification from the customers' perspective and giving the resultant product a warranty that is equal to that of a newly manufactured equivalent
Reconditioning	The process of returning a used product to a satisfactory working condition that may be inferior to the original specification. Generally, the resultant product has a warranty that is less than that of a newly manufactured equivalent. The warranty applies to all major wearing parts
Repair	Repairing is simply the correction of specified faults in a product. When repaired products have warranties, they are less than those of newly manufactured equivalents. Also, the warranty may not cover the whole product but only the component that has been repaired.

Circular Business Models

There is need for a streamlined nomenclature system for terms that make up circular economy. As suggested earlier, the circular economy is distinguished from circular business models. Some literature refers to '***circular business models'*** while others refer to ***'circular economy business models***. They are being used interchangeably. For the purpose of this paper they are considered to be synonymous. Some business models (Fig. 2) [10] include:

Incentivised return: In which a financial or other incentive is given to the customer for the return of products (e.g. cores of anaesthetic machines).

Asset Management: Product life is maximised and new purchases minimised through tracking of assets with reuse, repair or redeployment to a different site.

Collaborative Consumption/Sharing economy: Products are rented or shared among customers/businesses usually through peer-to-peer networks. For example, a CT Scan machine may be shared/rented by different medical service providers so that customers can access them without the need for businesses to own the product. They are also assured of getting the latest upgrade at the end of life of the product.

Leasing/Hiring business models: The product is leased by business for a subscription fee but still owned by the original manufacturer who service the product and replace with upgrade at the end of life. For example, a high-end X ray machine may be leased to a business and replaced at the end of life with another X ray machine.

Long life models: Products are designed for long life supported by guarantees and trusted repair services rather than short life disposal systems. This is very important during the design phase as it has a critical impact on use of product and recovery options.

Access and Performance (Performance Service Systems): With this business model, the product is provided in form of a service. For example, a Surgical theatre lighting system

may be provided in form of a service, in which a company provides the lighting system for a surgical theatre. They provide the surgical lighting product and wirings and own the system. This service subscribed to or commissioned and replaced or removed at the end of life/contract. The users' needs are met without owning the physical products.

Encourage sufficiency: In this business models' solutions are actively sought to reduce end user consumption through improving durability, upgradability, warrantees, reparability and non-consumerist approach in sales and marketing.

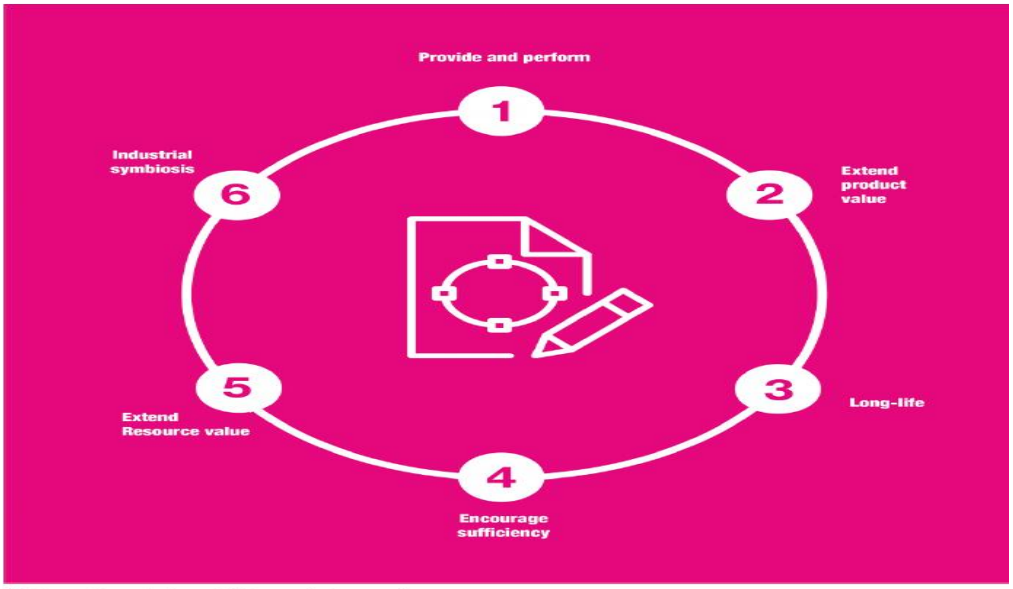
Extend resource value: In his business model, residual value of resources is exploited. Materials and resources that would have been turned to wastes or sent to the landfill are collected and turned into new forms of value.

Industrial symbiosis: Similar to extend resource value, this is a process-oriented solution model in which residual outputs from one process is used as feedstock for another process. It is usually utilised where there is geographical proximity of businesses. As suggested earlier biogas developed through a manufacturing process could be ploughed back as a source of energy.

Extend product value: at the end of life of the product the residual value of the product is exploited from manufacturers to consumers and back to manufacturers. Products could also be collected between distinct business entities.

Although the EU sustainability guide (2018) provides some overview on different types of circular business models, there could be areas of overlaps (for example with extending resource value and industrial symbiosis) [10].

Figure 2 - Circular Business model by EU sustainability guide [10]



(http://sustainabilityguide.eu/wp-content/uploads/2018/03/circular_business_model.png)

Using a complex model, the European Union Environmental Agency (2020) argue on an ambitious model in which they attempt to link circular business model goals with

enabling strategies for circularity. Although useful, it is a complex model and may make understanding circular business models challenging for those new in the field [11].

Lessons learnt from disassembly of anaesthetic machine and baby incubators in Nigeria

Remanufacture is still in infancy in Nigeria. The University of Ibadan, was chosen as a project site as it is one of the few institutions undertaking research in medical equipment remanufacture in Nigeria. The anaesthetic machine was inspected and disassembled. One of the features discovered was the need to change the PVC tubing as it is inappropriate for tropical climates. The major challenge with most of the anaesthetic machines available in Nigerian hospitals has to do with leakages from PVC/rubber tubes/pipes supplying oxygen and other gases. Considering that most of the donated incubators are fairly-used and coming from other countries with milder weather conditions different from that of the receiving countries, they are often subjected to varying weather conditions, humidity, temperature and pressure during supply of oxygen. Due to these conditions, the tubes become brittle over time and are often prone to breakages and leakages. The supply valves and fittings are also prone to leakages due to the use of different connectors since there are no standardized pressure connector for oxygen supply (Appendix 1 and 2).

There was also need to adapt the wheel mechanism for easy movement. Unlike other contexts where one anaesthetic machine is kept in one surgical room, it is common for an anaesthetic machine to be moved from one surgical room to another, hence the need for a strong wheel moving mechanism to support movement of the heavy machine. The neonatal incubator was disassembled into the following key parts: Canopy/hood, fan, heating element, air distributors, raised bed, base unit, humidification port, monitor, portholes, Inlets, Control Cabinets, sensor thermostat, Relay.

The major issue identified with most incubators available in many Nigerian hospital, is with the heating system. These incubators which were designed to function under a stable power supply often fail when they are subjected to varying voltages and power supply. The Relays, temperature control fail due to erratic power supply leading to general failure of the incubators.

During the remanufacture of the baby incubator, a 500w-heating element was used to replace the 1500w capacity heating element to achieve energy efficiency. The heating element was locally purchased and re-designed to fit the incubator system. Considering the lack of phototherapy lamps in many hospitals, we incorporated a phototherapy lamp system into the incubator to serve a dual function of phototherapy and neonatal incubation. The canopy was designed with a plexiglass to accommodate a phototherapy lamp (Appendix 3 and 4). There is need for testing of the remanufactured equipment to ensure that they adhere to quality standards of the original manufacturer with a matching warranty.

Discussion

As suggested earlier, it appears from the literature that there is increasing drive on the need to move from a linear economy of use and dispose to a circular economy where products are recovered and given a new lease of life. Remanufacture is one of a number of strategies that make up the circular economy with resulting product specifications and warranty that match a newly manufactured product. For the purpose of this paper, it is argued that the recovery strategies that make up the circular economy (such as refurbish, reuse and remanufacture) is distinct from the business models that underpin these strategies. This suggests that one circular business model could be utilised for a number of recovery strategies that make up the circular economy. See Figure 3. For example, an incentivised

return circular business model could underpin a remanufacture, recycling or refurbishing recovery strategy.

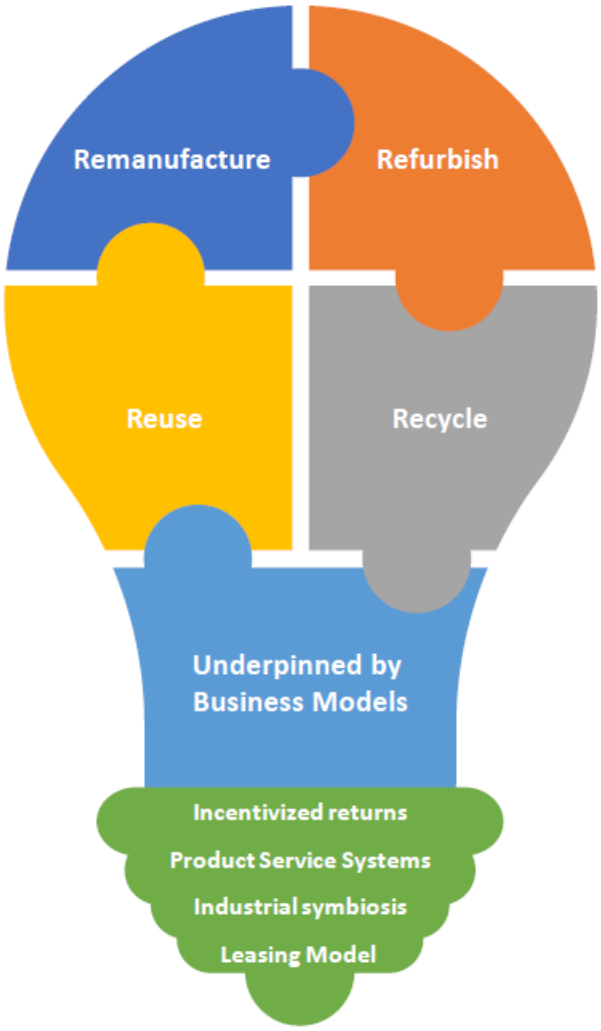


Figure 3 Light bulb framework linking the circular economy with circular business models

With an *incentivised return* circular business model, a product can be returned by the customer for an incentive. Depending on the product the appropriate recovery option may be employed. For the purpose of remanufacturing of anaesthetic machines in Nigeria initial analysis suggests hospital and medical facilities could return equipment at the 'end of life' to a remanufacturing centre of excellence (such as the University of Ibadan where the equipment is remanufactured and the hospitals provided with incentives (such as cash backs, or discounts). There is need for further research on theoretical and conceptual research on remanufacturing as well as hypothesis that tests the effectiveness of different business models [12] [13]. This will require stakeholder engagement to agree appropriate business models that could work and practicalities for reverse logistics. An overarching conceptual model is advocated in which the circular business models provides the root or foundation that underpins the recovery strategies that make up the circular economy.

Conclusions

Current linear models for manufacturing is unsustainable. There is need for industry to consider design of products that take advantage of recover options and make up the circular economy. Underpinning these strategies are different circular business models which also need to be taken into consideration. From lessons learnt in remanufacture of anaesthetic machine in Strathclyde University- University of Ibadan Remanufacture project, it is advocated that widespread stakeholder involvement is needed in development of strategy that could work in the local context. It is also advocated that more research is needed on ways of providing streamlined nomenclature of different concepts in the circularity debate.

Authors' contributions

Authors contributed equally in the work

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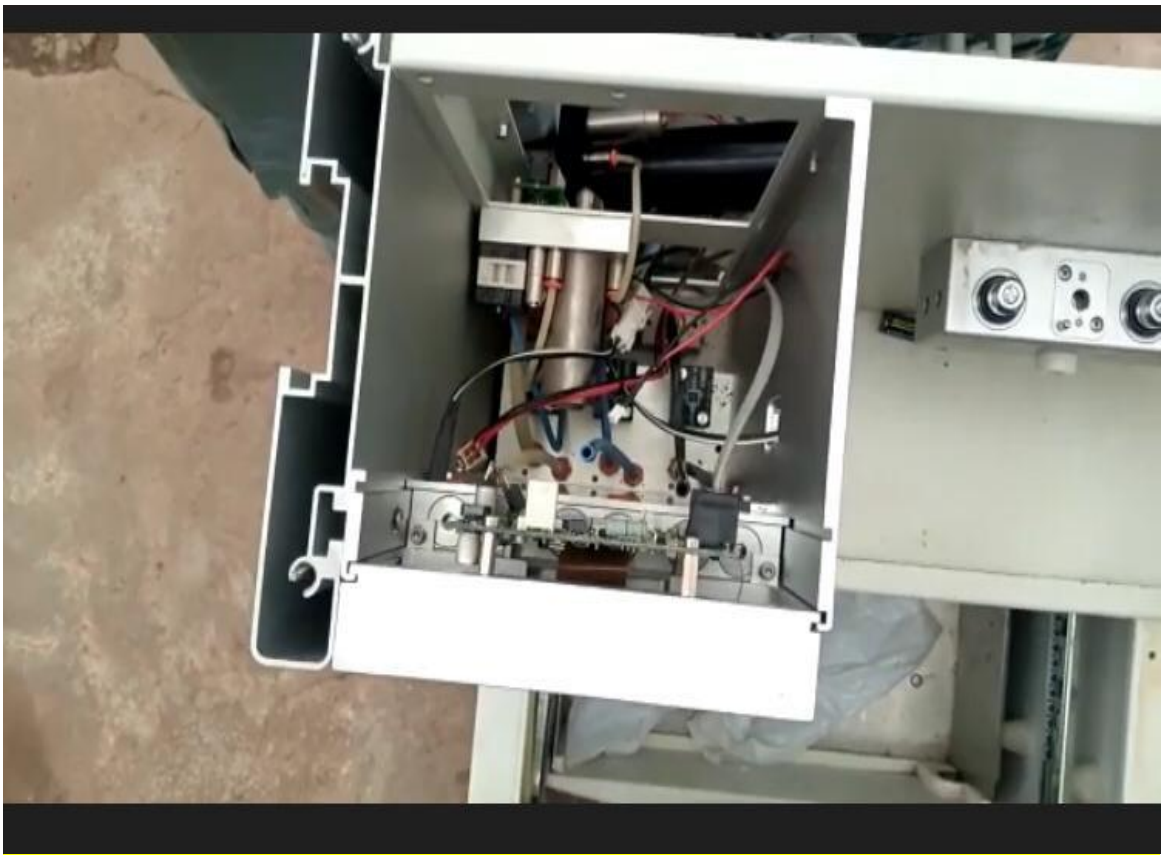
Appendix 1 -Anaesthetic Machine

Appendix 2 -Disassembled Anaesthetic Machine



Appendix 3 -Disassembled Neonatal Incubator

Appendix 4 - Neonatal Incubator before disassembly