
Biomedical Waste: Health vs Environment

Claes Fredriksson, Harriet Parnell
Granta Design, 300 Rustat House, 62 Clifton Rd, Cambridge, CB1 7EG UK

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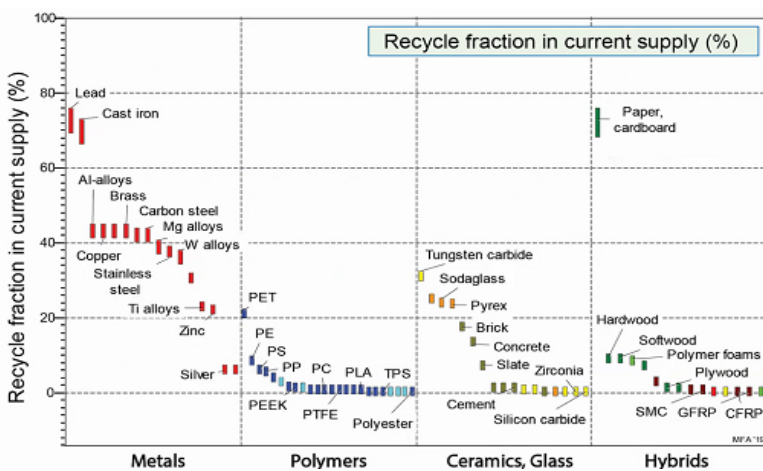
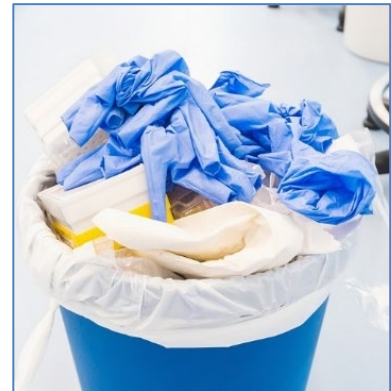
Summary

The Bioengineering database of CES EduPack offers the possibility to compare and select materials for various medical and biological applications. This is useful both for teaching students and for making materials decisions in the biomedical field. The Eco Audit tool included with the Bioengineering database also makes it possible to assess and compare different scenarios in terms of eco-design and end-of-life options.

In this advanced industrial case study, we explore how CES EduPack can be used to discuss aspects of materials and waste in the healthcare sector. Both material selection for performance and clinical requirements as well as environmental consequences of disposable material and waste. To add realism, we visit the external ASM Medical Materials Database™ which contains over 60,000 approved medical devices.

1. What is the scope?

The healthcare sector and life-sciences in general are known to produce large amounts of waste; plastics, rubber, glass as well as metals. Some of these are considered biohazardous and can therefore not easily be recycled but are treated as disposable. Of the total amount of waste generated by healthcare activities, though, about 85% is general, non-hazardous waste. The remaining 15% is considered hazardous since it may be infectious, toxic or radioactive. Protective clothing such as masks, gowns and gloves worn by doctors and nurses falls into this category and goes into bags. The average amount of waste created per hospital patient per day in Europe is around 3.3-3.6 kg (UK, France, Germany) and 8.4 kg in the US, with an additional 50 000 tonnes per year estimated to be generated by US home healthcare [B. Kaiser *et al.*, 2001]. One relevant question to ask is if there is any chance of improving circularity in the biomedical sector?



Clinical waste in the UK is divided into four categories by the NHS: Infectious, Sharp, Redundant Medical Waste, and Anatomical. According to WHO, the infectious fraction is the most voluminous. Sharp objects, like needles and blades are mainly metallic with minor parts of other materials. These cannot usually be reused (sterilized) because they would need to maintain the sharpness from their pristine state. Normally it is considered infectious because of their invasive character but no energy can be recovered by incineration.

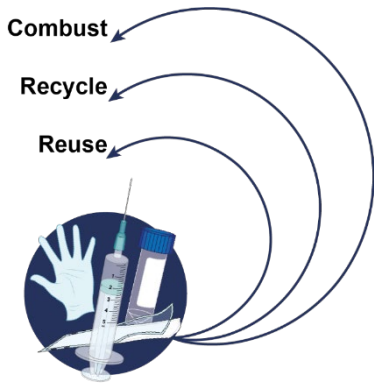
Plastic packaging and wrapping for sterile equipment could, of course, theoretically be recycled, provided they are separated into their polymer fraction to avoid contamination and that they are not mixed with infectious material. This is problematic in most clinical situations, where they come into contact with surgeons or nurses that might indirectly infect the material, e.g., in an operating theater. Rubber gloves, whether latex, silicone or polyurethane, are thermosets and cannot be recycled as materials. They have to be incinerated, possibly with energy recovery. Glass, if handled properly and not contaminated by other materials, can be re-melted at high temperature, and be recycled or downcycled.

Non-infectious			Infectious
Domestic waste, Recycling	Hygiene waste	Clinical waste	Hazardous waste
Cardboard, paper, plastic, tissues, disposable cups/cans, sandwich wrappers	Incontinence pads, nappies, protective clothes not contaminated with bodily fluids	Gloves, dressings, bandages, apron contaminated with bodily fluids	Blood preserves, organs or body parts
Landfill, recycling, incineration or energy from waste	Recycled, deep landfill, incineration or energy from waste	Incineration or treatment prior to landfill	Incineration
\$188 per tonne	\$317 per tonne	\$444 - 602 per tonne	

Adapted from report: <https://www.rcplondon.ac.uk/projects/outputs/less-waste-more-health-health-professionals-guide-reducing-waste>

- **Functional**
- **Economic**
- **Legal**
- **Hygienic**

There are many aspects that determine a products life, some relevant ones are shown to the left. The first life ends when the product fails and cannot perform its function, of course. Budget restrictions may affect what is considered the economic life but, in the healthcare sector, there is also legislation and regulations that control end-of-life options and hygienic requirements that may prevent circularity of such products.



Circular economy developed when the importance of lost raw material value and the environmental damage caused by disposable, single-cycle, products was realized [G.M. Kane *et al.*, 2018]. Introducing circular economy principles in the biomedical sector is challenging, though, because of the practical difficulties to sort mixed materials and the risk of infection. Realistically, only the options shown to the left exist. Some of the difficulties can be addressed at the design stage with the selection of more standardized and recyclable materials, better labelling and less mixed material products. The designer might also want to explore the potential for improvements regarding, for example, energy use and carbon footprint of these products in different life-cycle scenarios. Many products are already reused, following sterilization.

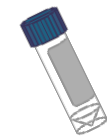
This case study makes use of the Bioengineering database of CES EduPack which includes both tools for material selection and to assess life-cycle performance and options in terms of energy and carbon footprint.

2. What can EduPack do?

EduPack has relevant materials data for biomedical applications as well as for consumer products, both at Level 2 and Level 3. Level 2 is less overwhelming for students and suitable for learning about material properties and selection. The *Bioengineering* Level 2 database, however, is extended with bio-related materials. This more than doubles the basic Level 2 materials data-table, resulting in 251 datasheets. The *Bioengineering* Level 3 database of EduPack contains data records for over 4000 materials with a full range of alloys and grades to provide data for realistic projects in biomedicine or engineering. Some bio-specific properties are also added to both Levels 2 and 3 of the Bioengineering databases. Furthermore, there are tools for material selection as well as the Eco Audit life-cycle tool to assess and compare different scenarios in terms of materials and end-of-life options.

Examples of basic materials in biomedical waste (Level 2):

- Soda-lime glass
- Polyethylene (PE)
- Polypropylene (PP)
- Polystyrene (PS)
- Latex
- Silicone
- Cotton
- Stainless steel



Vials and containers



Rubber gloves and textiles



Pans and trays

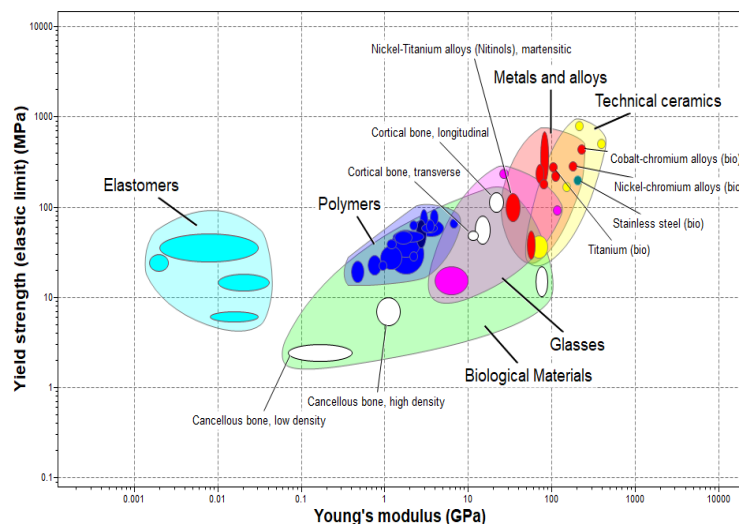


Syringes, blades and needles

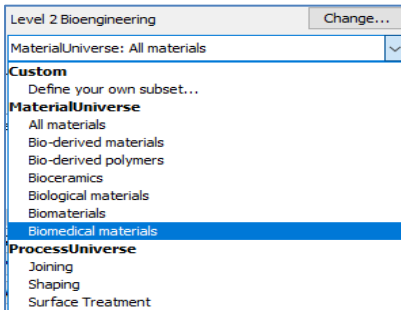
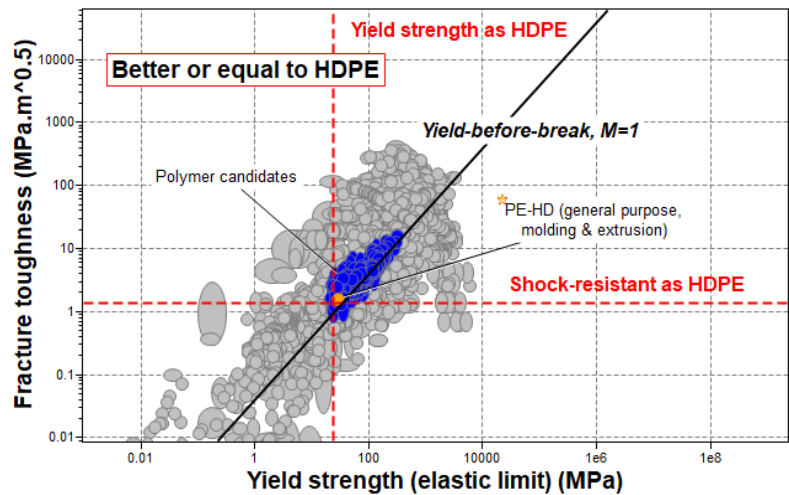


Medical packaging

One great feature of the Bioengineering databases is that they allow for property charts which simultaneously include both engineering materials and bio-related materials, such as the subset of *Biomedical materials*, to represent suitable candidates. An overview chart of any property in the database can easily be created, which covers the relevant materials. This can be done, both at Levels 2 and 3. These charts can then be used to compare and explain properties as well as to select compatible materials employing the systematic methodology developed by Ashby *et al.* with interactive, visual selection tools.



The selection tools can be used to improve some aspects of a certain product by finding materials with better values for specific properties. For instance, if tougher polymers to replace High-Density Polyethylene (HDPE) is desired. A plot of key properties will guide the decision and deliver an overview of potential improvements. The black line indicates the performance index (M) for non-brittle failure. For liquid and gas containers, a yield-before-break material is preferred (above the line), since failure by fracture is most likely catastrophic.



Regarding the design of biomedical products, EduPack offers a wide range of support for material selection. There are both health-related properties, and eco-properties as well as estimated costs that can be used to make decisions. Consider a *vial for biomedical samples*, for instance. In order to follow the systematic selection methodology, a selection can begin with the subset of all *Biomedical materials* at Level 3, then removing unsuitable materials with additional screening, and finally to consider one or more performance indices for ranking of candidates. The *Function, Constraints and Objectives* for the vial can be:

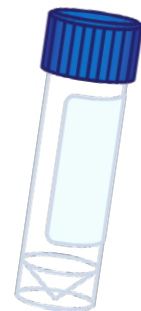
Function – Container for liquids, must sustain compressive load from gripping forces without deformation, so Stiffness-limited design assumed; the stiffer, the better.

Constraints for the container:

- Biomedical material, durable in water
- Unfilled grade, not opaque

Objectives for the container:

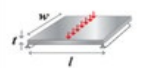
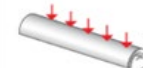
- Primary; minimize carbon footprint
- Secondary; minimize cost



Vial for biomedical samples

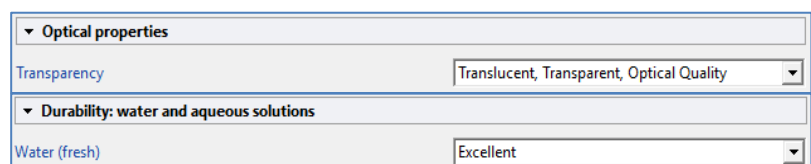
Learn > Table of performance indices > Stiffness-limited design at minimum environmental impact

Stiffness-limited design at minimum environmental impact

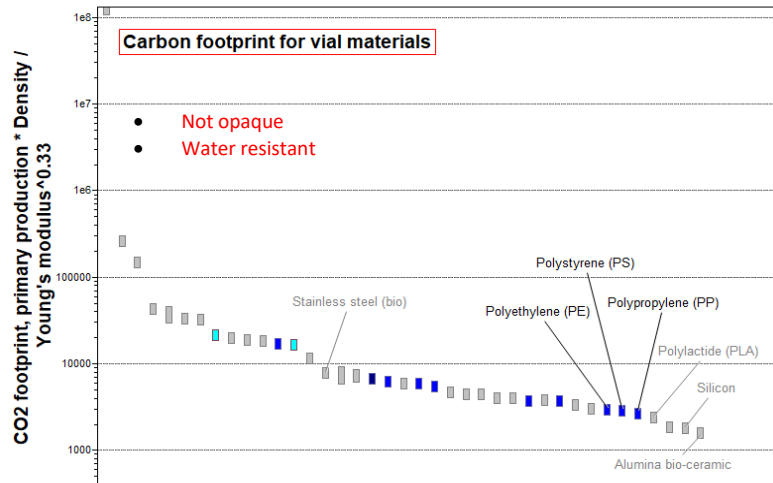
FUNCTION AND CONSTRAINTS		MAXIMIZE ¹	MINIMIZE ¹
Panel in bending		$E_f^{1/3} / CO_2\rho$	$CO_2\rho / E_f^{1/3}$
Single-curvature shell under linear load		$E_f^{1/3} / CO_2\rho$	$CO_2\rho / E_f^{1/3}$

The *Function* determines which performance index to plot on the axes of the property chart for visual selection. In this case, sufficient strength can easily be obtained by adequate thickness of the walls. A Stiffness-limited design best reflects the desired performance in terms of a rigid vial for a good grip (stiff, not flexible). The Learn button on the menu contains a *Table of Performance Indices*, with an option to minimize CO₂-footprint.

It turns out that a tubular shape has the same index to minimize as a panel in bending. In Level 2, we can use Young's modulus instead of flexural modulus, E_f . The *Limit stage* is used for constraints.



The results show the environmental performance for the biomedical materials. Alumina and Silicon have the lowest emissions but are greyed out as the opaque materials are excluded. Polylactide, PLA, is an interesting option, since it is both derived from renewable resources (such as corn) and biodegradable, but it has limited durability in water, which for this application is disqualifying. The three best options, PP, PS and PE are all commonly used polymer materials for containers and caps, such as the vial.

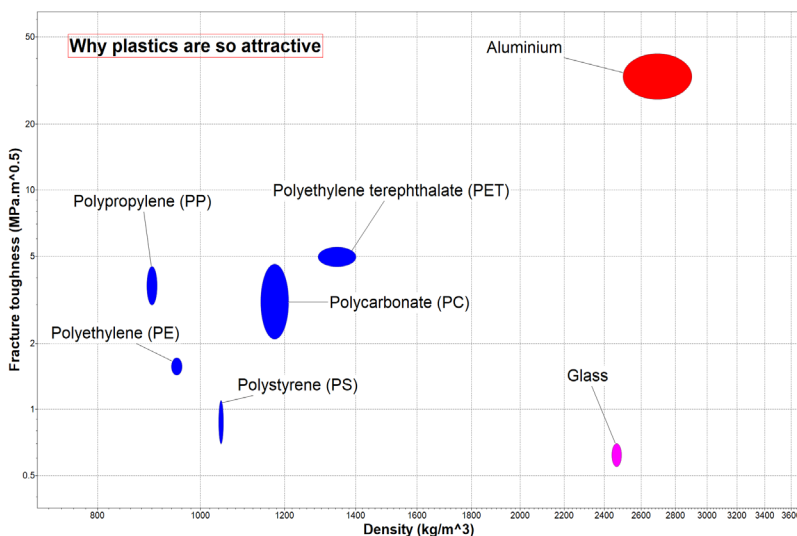
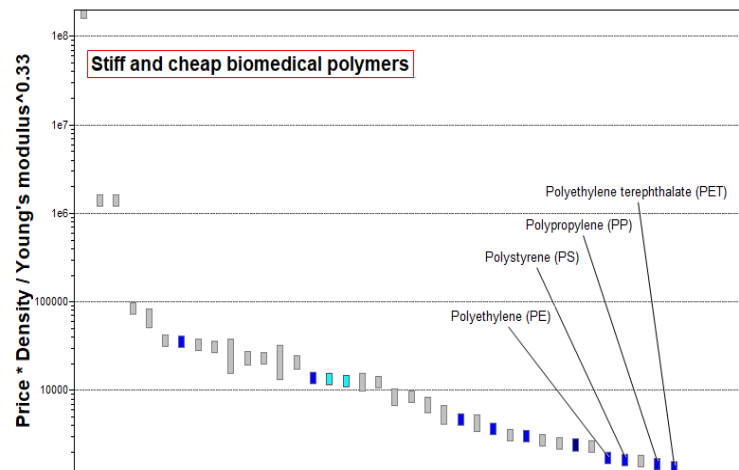


Rank by: Stage 3: Price * Density

Name	Price * Density
Polyethylene (PE)	1522 - 1573
Polypropylene (PP)	1526 - 1597
Polystyrene (PS)	2121 - 2469

A second objective, like cost, can be added on the second axis, or in separate property chart, coupled to the first one. If only the price per volume, obtained by multiplying the price, C_m [\$/kg], by the density, ρ [kg/m³] is plotted, PE is the cheapest of these three. The ranking for different criteria can be seen explicitly in the *Results* window to the left in EduPack.

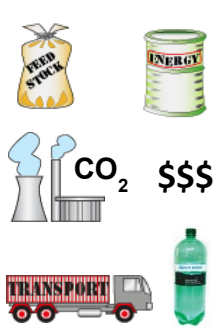
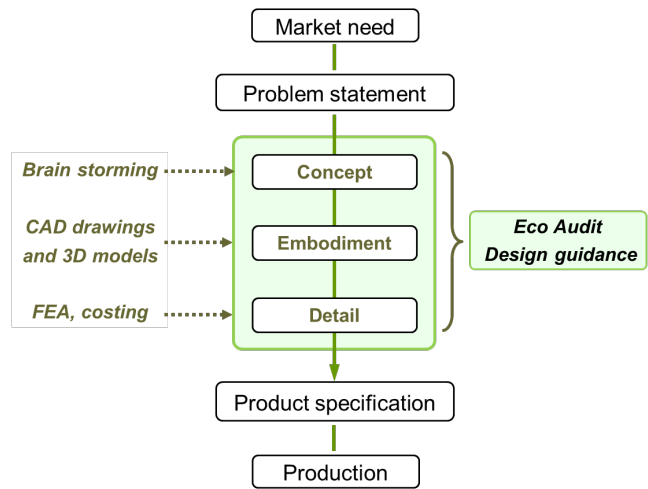
For a proper comparison, however, the full performance index must be used. This takes into account, not only density, but also how well the material delivers on stiffness. If this cost performance is plotted for the remaining materials, PET appears, slightly cheaper than the three previously considered polymers. Although PET is not commonly used for biomedical containers, it has many of the attractive properties for a vial; good mechanical properties to temperatures as high as 175°C. Crystal clear, impervious to water and CO₂. It is tough, strong, easy to shape and sterilize - allowing reuse.



Bubble charts are useful when several properties are compared at the same time. When considering materials for a vial, it is easy to see why plastics have come to replace glassware, not only for its low cost. Polymers, in particular the biomedical candidates discussed above, are considerably lighter than glass. This is due to both higher fracture toughness, allowing thinner walls, and lower density of the material itself. Glass is attractive if reused many times and not transported long distances. High density is also one relative disadvantage that PET has in comparison to the other polymers.

3. What can the Eco Audit tool do?

The Eco Audit tool has been developed to support the early product design process (see image to the right), where an estimate of eco-properties over the whole life-cycle is desired. This information can then be used to explore different scenarios and optimize the environmental performance of the product. It is also useful to re-design or assess existing materials from a standard requirements or legislative point of view as well as for cost minimization. It performs a streamlined Life-Cycle Inventory (LCI), rather than a full Life-Cycle Assessment (LCA). It is mainly concerned with estimating two of the most important parameters; the energy use [MJ/kg] and the carbon footprint [kg CO₂/kg] per kg of material over the life.



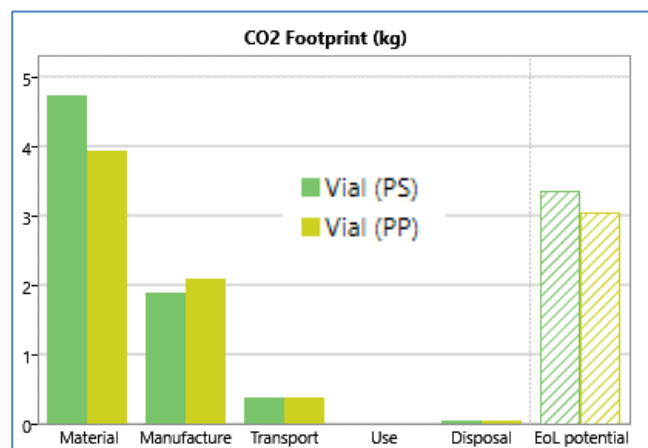
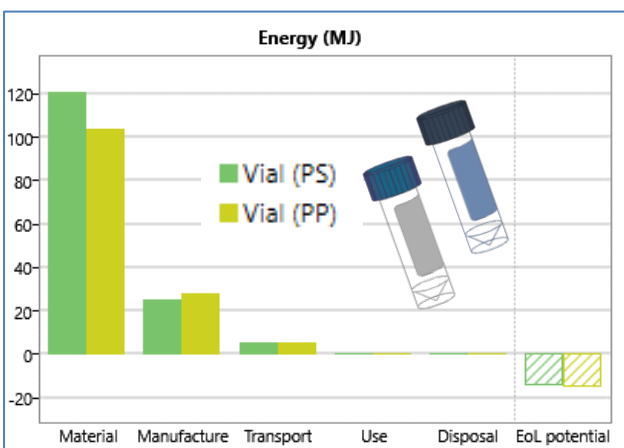
The reason for this simplification is that you can perform life-cycle investigations earlier in the design process and you can also save time, since it is now possible to compare different designs or end-of-life scenarios much easier. The inherent uncertainty of generic environmental data has to be acknowledged, though. EduPack contains many of the parameters that are needed. In addition to eco-properties of materials and processes (CO₂-emissions, energy, water consumption), emissions for various types of transports (trucks, shipping, air freight etc.) and cost estimates. It is product-centred, so the user needs to supply a Bill-of-Materials (BoM) including manufacturing processes, and to specify use phase as well as logistic information necessary for the assessment. The main parameters are shown to the left, where feedstock represents the materials.

As an example of an Eco Audit, we can use the vial described in the previous section. A typical base material is polystyrene (10 g) with a polypropylene cap (3 g), possibly with a thin silicone washer, so light that we will neglect it here. A hypothetical transport from asia to somewhere in the UK is included.

Material, manufacture and end of life ?						
Qty.	Component name	Material	Recycled content	Mass (kg)	Primary process	End of life
100	Cap	Polypropylene (PP)	Virgin (0%)	0.003	Polymer molding	Combust
100	Vial	Polystyrene (PS)	Virgin (0%)	0.01	Polymer molding	Combust

Transport ?		
Name	Transport type	Distance (km)
Ship Shanghai-UK	Ocean freight	2.2e+04
Lorry UK	14 tonne (2 axle) truck	100

Using the “Compare with...” function, another scenario, such as Polypropylene base with HDPE cap is added.



These output bar charts are created using the *Summary chart* button at the bottom of the screen. If more detailed numerical information is needed, a *Detailed report* button can be used. This report contains a breakdown of energy use and CO₂-emissions for each material in the BoM and each phase of the life-cycle.

In this example, the Eco Audit indicates that polypropylene (with HDPE cap) would have higher embodied energy and significantly higher carbon footprint in the material phase than polystyrene (with PP cap), but slightly lower values in the manufacturing phase. This is assuming that the vials and caps are produced having the same comparable masses. Virgin polymers have been assumed and combustion at the End-of-Life (EoL). If combustion is chosen at the EoL, the carbon footprint will include the CO₂ emitted during the incineration. The EoL potential indicates the hypothetical gain in the next life, if the materials are recycled instead of new. We can thus check the potential benefits of recycling instead of incineration. Different options for materials, logistics and disposal can easily be compared and benchmarked for design or re-design.



4. The part cost estimator

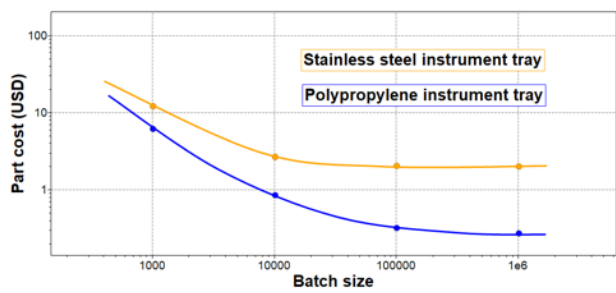
Another powerful tool for comparing design options is the *Part cost estimator* within the *Synthesizer tool* in the Bioengineering Level 3 database of the software. This addresses the important aspect of costs during the concept phase, including estimates of both the material and a set of standard manufacturing processes. The cost per part can be assessed for various production volumes, assuming a simple 5-term economic model described in detail in the embedded information. It enables comparisons of plastic disposable products manufactured by molding with metal alternatives produced by deformation processes and intended for sterilization and reuse. For example, a simple tray or pan, used in patient care, as shown below.

Stainless steel: two step process

<p>Source records Material = Stainless steel, austenitic, AISI 316L, annealed Primary Process = Cold shape rolling Secondary Process = Stamping</p> <p>Component details Value of scrap material = 0 % of virgin price Part mass = 0.3 kg Part length = 0.25 m Primary shaping process Load factor = 50 % Overhead rate = 150 USD/hr Capital write-off time = 5 years Availability = Custom form Part complexity = Simple Secondary shaping process Amount of scrap = 10 % of material Part complexity = Standard Scrap recycled? = Yes</p> <p>Additional attributes Tool life (length) - Primary process = 1.774e7 m Capital cost - Primary process = 7.8454 USD Production rate (length) - Primary process = 6.9936e m/hr Material utilization fraction - Primary process = 1 Tool life (units) - Secondary process = 2.172e4 Capital cost - Secondary process = 4.33764 USD Production rate (units) - Secondary process = 434.7 hr Material utilization fraction - Secondary process = 0.9 Part cost = 12.28 - 12.42 USD Material price per part = 1.21 - 1.357 USD Material price % = 10.28 - 10.28 % Primary process cost per part = 2.043 - 2.043 USD Primary process cost % = 16.54 - 16.54 % Secondary process cost per part = 9.023 - 9.023 USD Secondary process cost % = 73.07 - 73.07 % Tooling cost per part - Primary process = 2.043 USD Tooling cost per part - Secondary process = 8.673 USD Overhead cost per part - Primary process = 2.196e-5 USD Overhead cost per part - Secondary process = 0.3496 USD Batch size = 1000 Part mass = 0.3 kg</p>	<p>Source records Material = Stainless steel, austenitic, AISI 316L, annealed Primary Process = Cold shape rolling Secondary Process = Stamping</p> <p>Component details Value of scrap material = 0 % of virgin price Part mass = 0.3 kg Part length = 0.25 m Primary shaping process Load factor = 50 % Overhead rate = 150 USD/hr Capital write-off time = 5 years Availability = Custom form Part complexity = Simple Secondary shaping process Amount of scrap = 10 % of material Part complexity = Standard Scrap recycled? = Yes</p> <p>Additional attributes Tool life (length) - Primary process = 1.774e7 m Capital cost - Primary process = 7.8454 USD Production rate (length) - Primary process = 6.9936e m/hr Material utilization fraction - Primary process = 1 Tool life (units) - Secondary process = 2.172e4 Capital cost - Secondary process = 4.33764 USD Production rate (units) - Secondary process = 434.7 hr Material utilization fraction - Secondary process = 0.9 Part cost = 1.969 - 2.116 USD Material price per part = 1.21 - 1.357 USD Material price % = 62.76 - 62.76 % Primary process cost per part = 0.002065 - 0.002065 USD Primary process cost % = 0.1012 - 0.1012 % Secondary process cost per part = 0.7573 - 0.7573 USD Secondary process cost % = 37.1 - 37.1 % Tooling cost per part - Primary process = 0.002043 USD Tooling cost per part - Secondary process = 0.4076 USD Overhead cost per part - Primary process = 2.196e-5 USD Overhead cost per part - Secondary process = 0.3496 USD Batch size = 1e6 Part mass = 0.3 kg</p>
<div style="border: 1px solid black; padding: 5px; display: inline-block;">1000 pcs</div> <div style="border: 1px solid black; padding: 5px; display: inline-block; margin-top: 10px;">\$ 12.35</div>	<div style="border: 1px solid black; padding: 5px; display: inline-block;">1e6 pcs</div> <div style="border: 1px solid black; padding: 5px; display: inline-block; margin-top: 10px;">\$ 2.04</div>

Polypropylene: one step process

<p>Source records Material = PP (homopolymer, high flow) Primary Process = Injection molding (thermoplastics)</p> <p>Component details Value of scrap material = 0 % of virgin price Part mass = 0.1 kg Part length = 0.25 m Primary shaping process Load factor = 50 % Overhead rate = 150 USD/hr Capital write-off time = 5 years Availability = Custom form Part complexity = Simple</p> <p>Additional attributes Tool life (units) - Primary process = 5.078e5 Capital cost - Primary process = 5.961e4 USD Production rate (units) - Primary process = 1687 hr Material utilization fraction - Primary process = 0.9 Part cost = 6.306 - 6.33 USD Material price per part = 0.1611 - 0.1856 USD Material price % = 2.737 - 2.737 % Primary process cost per part = 6.145 - 6.145 USD Primary process cost % = 97.26 - 97.26 % Secondary process cost per part = 0 - 0 USD Secondary process cost % = 0 - 0 % Tooling cost per part - Primary process = 6.054 USD Overhead cost per part - Primary process = 0.09053 USD Batch size = 1000 Part mass = 0.1 kg</p>	<p>Source records Material = PP (homopolymer, high flow) Primary Process = Injection molding (thermoplastics)</p> <p>Component details Value of scrap material = 0 % of virgin price Part mass = 0.1 kg Part length = 0.25 m Primary shaping process Load factor = 50 % Overhead rate = 150 USD/hr Capital write-off time = 5 years Availability = Custom form Part complexity = Simple</p> <p>Additional attributes Tool life (units) - Primary process = 5.078e5 Capital cost - Primary process = 5.961e4 USD Production rate (units) - Primary process = 1687 hr Material utilization fraction - Primary process = 0.9 Part cost = 0.2637 - 0.2882 USD Material price per part = 0.1611 - 0.1856 USD Material price % = 62.71 - 62.71 % Primary process cost per part = 0.1026 - 0.1026 USD Primary process cost % = 37.23 - 37.23 % Secondary process cost per part = 0 - 0 USD Secondary process cost % = 0 - 0 % Tooling cost per part - Primary process = 0.01211 USD Overhead cost per part - Primary process = 0.09053 USD Batch size = 1e6 Part mass = 0.1 kg</p>
<div style="border: 1px solid black; padding: 5px; display: inline-block;">1000 pcs</div> <div style="border: 1px solid black; padding: 5px; display: inline-block; margin-top: 10px;">\$ 6.32</div>	<div style="border: 1px solid black; padding: 5px; display: inline-block;">1e6 pcs</div> <div style="border: 1px solid black; padding: 5px; display: inline-block; margin-top: 10px;">\$ 0.27</div>



The *Part cost estimator model* delivers a set of material records for a range of different batch sizes. In the Bioengineering level 3 database these contain the essential data that can be plotted using external software. The results estimate how much cheaper the plastic is, which can then be used to assess how many times the steel tray needs to be reused to recover the initial cost (this gap increases with production volume).

5. Reality check

More specialized information for biomaterials, such as surface properties and sterilization, can be found in the ASM Medical Materials Database, accessible via the Bioengineering Edition of EduPack with the appropriate subscription. It also contains information on over 60 000 FDA-approved medical devices.

The screenshot displays the ASM Medical Materials Database interface. The left sidebar shows a hierarchical menu with categories like Materials, Biologics, Ceramics and Glasses, Metals, Polymers, Additives, and Bioabsorbables. The main content area is titled "Poly(lactic Acid) (PLA)" and contains several sections:

- Interactions with blood and bodily fluid:**
 - Hemolysis:** The hemolysis of pure poly(lactic acid) (PLA) was investigated by Jia et al. (2011) by measuring the effects on healthy New Zealand white rabbit blood incubated with the PLA samples for 1 hour and this demonstrated that PLA has good hemocompatibility with a hemolysis value of less than 5%.
 - Thrombogenicity:** Nguyen et al. (2003) conducted experiments to investigate the hemocompatibility of PLLA stent fibers, using a closed-loop circulation system filled with human blood. Using flow cytometry, it was observed that PLLA triggers blood cell activation at the site of deployment. This was manifested by increases in CD11b, CD62P, and leukocyte/platelet aggregation relative to controls. Platelet aggregation and activation in these experiments may suggest that the PLLA used in these experiments may trigger thrombus formation. The Igaki-Tamai stent is made from poly(L-lactic acid) fabricated into a zigzag helical coil pattern (Tamai et al. 2000). The stent is deployed via a balloon catheter. In clinical studies, 25 stents were placed in 15 patients; the angiographic success rate was 100%. No thrombosis or major adverse cardiac event (MACE) was observed within 30 days of implant placement.
- Surface properties:**
 - Contact Angle:** 75 to 84
 - Surface Wettability:** In experiments by Barton et al. (1996), the water contact angle on a PLLA surface was measured as 84 degrees (+/-1). The high water contact angle recorded in these experiments showed that the surface of the material was poorly wetted by water. In experiments by Lee et al. (2002c), the water contact angle on a PLA surface was measured as 75 degrees. Lee et al. (2002c) have shown that the surface wettability of degradable polymers such as PLA is an important determinant of the adhesion and proliferation of both human chondrocytes and mouse NIH3T3 fibroblasts. Surface wettability was increased using chloric acid, and this was observed to increase the adhesion and proliferation of the aforementioned cell types.
 - Protein Adsorption:** In experiments by Lin et al. (2004a), proteins were microspattered onto PLA surfaces; other polymers were microcontact printed onto the PLA to stop protein adhesion. The authors reported protein adhesion on the exposed PLA surfaces. Lu et al. (2005) reported the adsorption of serum proteins onto scaffolds made from three different compositions of poly(alpha-hydroxyester) fibers, namely, poly(glycolic acid) (PGA), poly(L-lactic acid) (PLLA), and poly(lactic-co-glycolic acid) 82:18 (PLGA).
 - Change in Surface Layer Characteristics after Implantation:** In experiments by Anselme et al. (1993), PLA microbeads were implanted in artificial defects made in dog mandibles. Growth of fibrous tissue between the beads was observed 5 months after implantation. After 12 months, beads were observed to be encapsulated in individual fibrous capsules.
- Adverse effects associated with this material:**
 - Toxicity:** Investigations into the in vitro cellular viability of poly(lactic acid) (PLA) have shown through standard MTT assays that PLA is not toxic to murine fibroblast cells (L-929), which were shown to have healthy cell morphologies and readily proliferated during 3 days of culture (Jia et al. 2011).
 - Allogenicity/Sensitization:** According to Khor et al. (1996), poly(lactic acid) is nonallergenic.
 - Malignancy in Nonhumans:** According to the IARC (IARC-Surgical Implants and Other Foreign Bodies 1999), local tumors were observed following the implantation of poly(L-lactide) specimens in rodent models.
- Effect of sterilization methods on this material:**
 - Ethylene Oxide:** Wei et al. (2002) report on the ethylene oxide sterilization of PLLA. Ethylene oxide sterilization postannealing was observed to result in a modest increase in crystallinity.
 - Gamma Irradiation/Electron Beams:**

. Cambridge University Hospitals NHS Foundation Trust, UK

As part of the UK's goal to reduce carbon emissions by 80% by 2050, the Cambridge University Hospitals NHS Foundation Trust outlined specific targets in their 2013-2020 Sustainable Development Management Plan "Taking action for a sustainable future". These included:

2013 – 2020 Sustainable Development Management Plan "Taking action for a sustainable future"

1. **Waste Audits:** Undertake waste audits to identify areas of non-compliance as well as identifying possibilities for improving waste management and recycling
2. **Disposable curtains:** Identify a more sustainable disposal route for used disposable curtains
3. **Single use and reusable sharps items:** Single use items are to be reviewed with infection control procurement and waste management. This is to identify where current single items can be purchased as a reusable item and sterilised for next use.

US Benchmarks

- Kaiser Permanente: implemented reusable linens and patient gowns which can be washed and reused 60 times
- Ascent Healthcare Solutions: by reprocessing single use medical devices, saving 2150 tons of waste going to landfill as well as \$138 million in supply costs

6. What does CES EduPack bring to the understanding?

In this case study, we have come to the following conclusions:

- CES EduPack Bioengineering Level 3 database is useful to select and understand environmental and cost aspects of biomedical materials and consumables in the healthcare sector.
- We have seen examples of how environmental aspects can be brought in for the design of biomedical products as well as investigating their End-of-Life (EoL).
- The software was used to demonstrate how both the selection and the Eco Audit tools work as well as the part cost estimator of the Synthesizer tool at level 3.
- The ASM medical materials database can be invoked from within the software, provided subscription.