Journal of Environmental Accounting and Management 1(2) (2013) 189-201

Journal of Environmental Accounting and Management

https://lhscientificpublishing.com/Journals/JEAM-Default.aspx

Streamlined Life Cycle Inventory of Dental Syringes Manufacturing

C. R. Munhoz, C. M. V. B. Almeida, F. Agostinho, S. H. Bonilla, and B. F. Giannetti†

Universidade Paulista (UNIP), Programa de Pós-graduação em Engenharia de Produção, Laboratório de Produção e Meio Ambiente, São Paulo, Brazil

Submission Info

Communicated by Sergio Ulgiati
Received 18 March 2013
Accepted 19 April 2013
Available online 1 July 2013

Keywords

Life cycle inventory
Carpule dental syringe
Solid wastes
Electricity consumption
Dematerialization

Abstract

Among the methods proposed to environmental management of productive activities, Life Cycle Assessment is one of the most integrated, complete and effective. The product assessed is the dental Carpule syringe. The aim of this work is to achieve a Streamlined Life Cycle Inventory (LCI) to quantify the electric energy consumption and the solid waste release from dental Carpule syringes manufacture. The methodological framework is based on ISO 14040/2006. The LCI covers the syringe life cycle from mining to disposal. The limits of the system include the stages of copper and zinc mining and ore beneficiation, the production of polyethylene used for syringe and needle packing, the production of steel for needles and syringe coils, and the use of the whole set by dentists. The functional unit was defined as 10^6 (one million) applied anesthesia. During improvement assessment, the proposed solutions allow reducing the energy consumption at about 20% in the manufacturing stage. The solid waste quantity may be reduced by almost 40 % in the manufacturing stage, equivalent to approximately 6.5 % of the total solid waste released during the entire life cycle of the Carpule dental syringe.

1 Introduction

Currently, the environmental assessment is an integral part of business functions and can be performed through an Environmental Management System (EMS), which is responsible for stages of development, deployment, implementation, evaluation and maintenance of environmental policy within companies. This environmental assessment aims to support and optimize decision making processes that involve the activities of enterprises in improving their environmental performance from minimizing the use of re-

† Corresponding author.
Email address: biafgian@unip.br

ISSN 2325-6192, eISSN 2325-6206/$- see front materials
DOI:10.5890/JEAM.2013.05.006

sources and disposal of waste and maximizing environmental benefits. Therefore, companies strive for appropriate tools to assess their environmental performance. One of most used tools is the Life Cycle Assessment [1-3], which is the compilation and evaluation of inputs, outputs and the potential environmental impacts of a product system throughout its life cycle [4].

The Life Cycle Assessment (LCA) is an environmental management tool that identifies and evaluates the impacts associated with the existence of a product. The life cycle of the product starts on the extraction of resources from nature, covers its manufacture and ends when the product is discarded and returns to the environment. Among the phases of the LCA, the life cycle inventory (LCI) is used to assess the environmental effects of a product, process or activity.

The LCI is widely used around the world for over forty years [5,6] and was incorporated into the ISO 14040/2006, which specifies the requirements and procedures for the preparation, interpretation and communication of an inventory lifecycle. The inventory phase of an LCA corresponds to the collection and processing of data and information, both qualitative and quantitative, on the flow of materials and energy involved in various interactions with the environment that occur during the life cycle of a product or service.

The LCI quantifies the resources and emissions from the extraction of raw materials to final disposal and, since the 90s, has been used as a step in the LCA analysis of various products [7-13], and different processes [14-17]. There are several studies aiming to improve and complement the tool, such as the search for ways to deal with incomplete data [18], with data uncertainties [19], and developing hybrid inventory analysis methods to enhance process analysis and input–output analysis [20] and to deal with aggregation methods [21]. Due to the quantity and reliability of the data needed for the analysis and interpretation of the impact, the execution of a complete Life Cycle Assessment is expensive, time consuming and impractical [22]. An LCA study requires the availability of large amounts of data and national databases consisting of inventories of the life cycle of products and key inputs used by a given society. Thus, many researchers and companies have prefer the direct use of LCIs for the evaluation of production systems to suggest improvements [21,23-25] and to contribute to the consolidation of national databases [26-28]. Presently, the LCI is also widely employed directly as a tool for environmental management of large companies [29,30] to assess improvements in products and processes based on the results energy consumption or amount of emissions. With the use of the inventory results one can identify opportunities for improvement, and especially the relationship of the system under study with the environment [31]. With LCI results, it is possible to adjust the system directly with a decision or indirectly by influencing the behavior of the consumer market in search of a product with improved environmental performance.

This article presents the streamlined LCI of carpule dental syringes manufacturing to quantify the use of electricity and the generation of solid waste from mining to product disposal. It is noteworthy that this study applies the LCI inventory to a small business.

2 Method

National and international standards specify the requirements and procedures for the preparation, interpretation and communication of a Life Cycle Inventory, as part of the Life Cycle Assessment. The study of LCA follows the methodological framework proposed by ISO 14040/2006.

The results are structured according to the rules, and this arrangement determines the phases and the general procedures of implementation of the LCA study, in accordance with international standards and national correspondents. Key features for the realization of a LCA study should be mentioned:

- systematic approach and appropriate with respect to the environmental aspects of product systems, from raw material acquisition to eventual disposition;

- possibility of varying accuracy and time period of the LCA study, depending on the definition of the purpose and scope;
- transparency regarding the scope, assumptions, description of data quality, methods and presentation of results;
- possibility of inclusion of new scientific discoveries and improving the state of the art of the technology;
- lack of scientific basis for reducing LCA results to a unique number or overall score;
- lack of a single method for conducting LCA studies.

As the LCI aims to quantify the materials and energy that cross the boundaries of a system, determining the limits of the system is a critical step because it is based on a variety of factors that depend primarily on the objective of the analysis and reliable data availability. The result of the inventory is a listing of materials and required energy, products, co-products and wastes that are discarded. This listing can be called material balance and energy inventory table or eco-balance of the product. Based on the results of the inventory, the possibilities for improving the system can be explored.

2.1 Description of the setting and the system boundaries

The starting point of the system under study is a small industry, founded in 1951, located in São Paulo, a manufacturer of dental equipment. The LCI focuses on the brass dental syringe used for anesthesia application (Fig. 1).

The carpule syringes are manufactured in brass with chrome plating, its size is standardized, and it may or may not have a reflux device (which allows the aspiration of blood into the cartridge preventing improper intravascular injection of anesthetic). They are typically used for the injection of the anesthetic. The needle tip made of steel bevel-cut to facilitate tissue penetration and proper fluid injection, and a plastic cap that allows threading the cartridge (Fig. 2a). It is supplied in a plastic package, which protects the tip. The cartridges are plastics tubes containing the anesthetic solution, with one tip of metal and other of rubber (Fig. 2b). The cartridge of anesthetic is inserted in its receptacle with the metal tip toward the location where the needle is screwed.

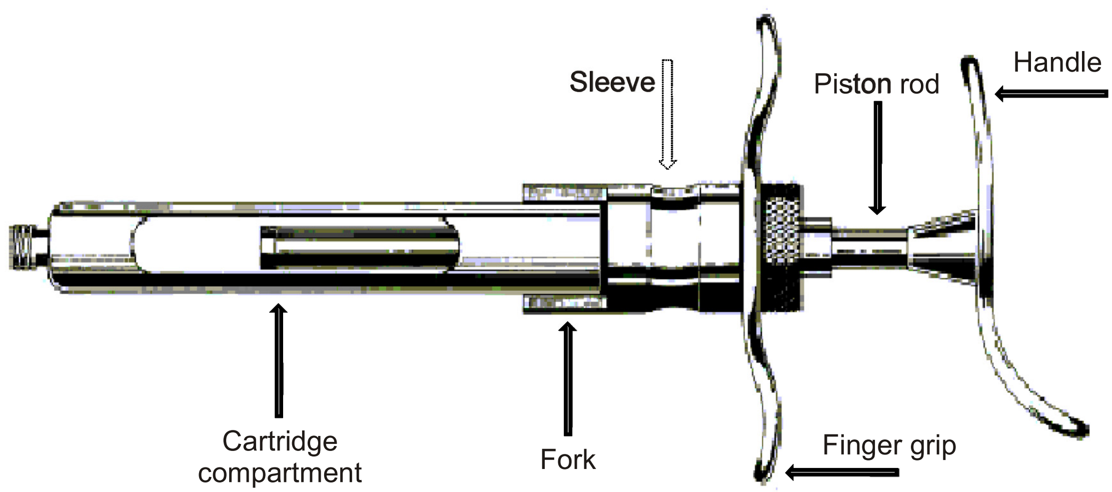

Fig. 1 Carpule dental syringe for anesthesia (with the nomenclature used by the manufacturer for each piece). The dashed arrow corresponds to a sleeve mounted inside the syringe, where the is also a steel coil, purchased from a third party

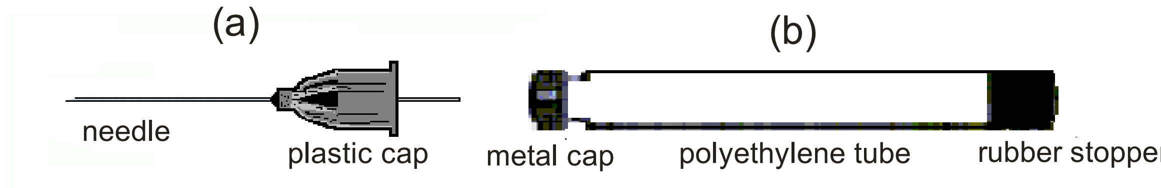

Fig. 2 The anesthesia needle (a) and the anesthetic cartridge (b).

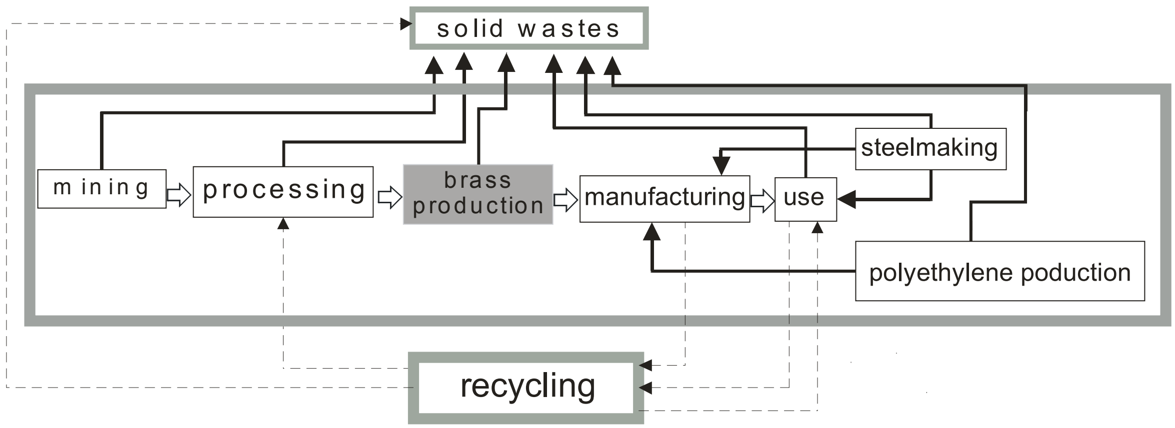

Fig. 3 The system limits for the manufacture of dental syringes.

The boundaries defined for the system include the steps of (i) mining, milling and manufacturing of brass parts; (ii) the production of polyethylene used to produce the cartridge and the needle cap and packaging; (iii) production of steel, used in the manufacture of the needle and syringe coil; (iv) use of the set (syringe, needle and anesthetic cartridge) by dentists (Fig. 4). The system was evaluated in terms of electricity consumption and solid waste disposal at all stages. Transportation between the stages was not considered.

Figure 3 shows the solid waste resulting from the production chain of dental syringe, from extraction and processing of brass, steel production and polyethylene production and the syringe use, when cartridges and needles are discarded. In the stage of manufacturing, metal waste is sold to scrap dealers. The solid residue generated in the surface treatment of the syringe, which is outsourced by the manufacturer (galvanic sludge, not shown) was also considered in the inventory table.

Recycling was represented with dotted lines as it is not exclusive of the system under study since it is shared with the larger system, which includes all other companies using brass, steel, plastic and paper as raw material. In this larger system, some companies recycle internally, but most of them, such as the dental syringes manufacture under study, sells waste materials to scrap dealers, which make possible the circulation of material and increases the efficiency of the entire system. Flows associated with recycling were not accounted because they are outside the limits established in this study (Fig. 3).

2.2 Wastes identification and consumption of electricity by life cycle stage

2.2.1 Mining and processing

The dental syringe is manufactured with brass, which refers to the mining and processing of copper and zinc. We used data from the average world production of both metals to calculate the amount of solid waste and energy consumption in mining and processing stages [32]. The global copper production in weight is made up of 73% copper obtained from sulfide ores and 27% of copper contained in oxide ores. Each ore generates different types of waste, both in quantity and quality (Table 1). The average mass percentage of copper is 0.65% in sulfide ores and 0.58% in copper oxides. Zinc is also obtained from sulfide ores (75%) and ores containing zinc oxide (25%) and waste generated also depend on the type of ore from which metal is extracted (Table 3). The zinc content is 8.3% in zinc oxide ores and 9% of sulfide ores. The values shown in Table 3 refer to obtain one kilogram of each metal.

The brass for manufacturing the dental syringe is composed of 65% copper and 35% zinc, generating approximately 130,000 kg of waste in mining and 4,500 kg of waste in the processing stage for each ton of brass produced. Brass production wastes (shown in dotted lines in Figure 3) were not considered in this study due to lack of available data.

A study of the global consumption of electricity for the production of zinc showed that it takes 17,000 kWh to 20,000 kWh for extraction and the processing of one ton of zinc [33]. The production of one ton of copper consumes 35,000 kWh and 21,000 for mining and processing, respectively [34].

Table 1 Amount of solid waste in the mining and processing of copper and zinc (World average; [32])

	kg_{waste}/ kg_{metal}	
Waste of copper mining		
Solid waste of the extraction from copper oxide	47.45	
Solid waste of the extraction from copper sulfide	141.65	
Subtotal		189.10
Waste of copper processing		
Solids leaching	3.14	
Slag	2.95	
Sludge	0.03	
Subtotal		3.23
Waste of zinc mining		
Solid waste of the extraction from zinc oxide	2.90	
Solid waste of the extraction from zinc sulfide	12.45	
Subtotal		15.35
Waste of zinc processing		
Dust particles	0.04	
Slag	1.02	
Sludge	0.39	
Subtotal		1.45
	Total	209.13

Table 2 Amount of solid waste in steel production in Europe [35]

	kg_{waste}/kg_{steel}
Waste	0.14
Sludge	1.43
Slag	0.18
Total	1.75

2.2.2 Steelmaking

The data are from the study of a global inventory lifecycle for steel products, conducted in 1996 by the International Iron and Steel Institute (IISI) and updated in 1999 and 2000. The inventory was released in order to collect the data needed for a Life Cycle Analysis, encourage the optimal environmental performance of the steel production and promote initiatives to increase steel reuse. The quantity of solid waste to produce 1 kg of steel is 1.75 kg with consumption kWh 111.24 [35]. Table 2 shows the quantities of the main solid wastes generated by the production of 1 kg of steel.

2.2.3 Production of polyethylene

The data were obtained from the report published by the Association of European Industrial Plastic in 2003. The eco-profile data were obtained from 27 plants producing 4.48 million tons of polyethylene and represent 93.5% of European production. The average energy consumption to produce 1 kg of polyethylene equals 280.80 kWh, ranging between 230.40 kWh and 345.60 kWh. The amount of solid waste is 0.041 kg per kg of produced polyethylene [36].

2.2.4 Manufacture

The data from this stage were obtained directly from the production process of dental syringe manufacturing. In 2002, 5,020 syringes for anesthesia were produced, which are made up by seven different pieces of brass (Fig. 1). For each of the seven pieces, the mass of solid waste generated during machining brass was weighted (Table 3).

Table 3 Masses of solid waste of the parts of the dental syringe, 2002

Piece	$kg_{waste\ (brass)}$/year
Cartridge	256.02
Piston rod	10.04
Fork	200.80
Sleeve	25.10
Screw	55.22
Finger grip	80.32
Handle	65.26
Total Solid Waste	*692.76*

The electricity consumption required for the production of 5,020 syringes in 2002 was 582.47 kWh. This value was obtained from the measurement of the machining time and multiplied by the power of engines used in each process.

The surface treatment is outsourced and is equal to 0.2% of the entire supplier consumption, and equivalent to 66,000 kWh per year. The amount of galvanic sludge generated by the surface treatment of dental syringe was estimated at 0.83 kg per year.

The product assembly is performed in a room powered by four 40W lamps. One hundred (100) syringes are produced in two (2) hours, resulting in annual consumption of 16.06 kWh of electricity. Packaging is also performed in the same room, and two hundred (200) syringes a packed in one (1) hour, with annual consumption of 4.02 kWh. The packaging consists of a cardboard box with 0.009 kg (0.300 kg/m2 cardboard) and a polypropylene bag of 0.00083 kg/unit. The shipment of the product is done by trucks distribution networks throughout the Brazilian territory but, as previously mentioned, shipping is not the object of this study.

2.2.5 Use

Data from this stage were obtained through questionnaires answered by dentists in the city of São Paulo in March 2003. Fifty professionals were interviewed in several specialities: ten general practitioners, eight bucomaxillofacial experts in surgery, eight endodontics, eight pediatric dentists, eight oral pathologists and eight periodontists. All fifty respondents actuate for at least 25 years. With the results of the questionnaire, it was possible to determine how many anesthetics are applied per day, how many syringes each dentist use, and the frequency of sterilization that leads to the electricity consumption of autoclaves.

The use of the product by the dental professionals, also involves the disposal of the following parts: a cardboard box by syringe, a plastic bag by syringe, one cartridge of anesthetic and one disposable needle for anesthesia applied. For the year 2002, the purchase of 5,020 syringes by dentists resulted in the disposal of 5,020 cartons and 5,020 polypropylene bags. On the other hand, 173,379,360 vials of anesthetic (0.0017 kg/unit) and an equal number of needles (0.0002 kg/unit) and needle packages (0.0016 kg/unit) were discarded.

2.3 Definition of the functional unit

The functional unit (FU), clearly defined, establishes measurable and relevant relationships among the elements of the system, and is the foundation that allows comparisons between studies using LCA or LCI. By defining the functional unit, one must consider not the amount of the product, but the role it plays. For the same function, there may be several products, made up of different materials, in quantity and quality. Thus, the functional unit may refer to the purpose to which the product is made for. In the case of dental syringes, the function is the application of anesthesia and the functional unit chosen is 10^6 (one million) applied anesthesia. The amount of energy required, and the amount of solid waste for each process was calculated considering the number of dentists working in Brazil in 2002 (197,022 dentists, [37]), the number of anesthetics applied in the same year (173,379,360 anesthesia), the number of 6 syringes per dentist and the lifetime of each syringe (20 years).

Table 4 Solid waste generated at each stage of the life cycle of the syringe dental corresponding to 106 (FU) anesthetics applied

Step		Solis waste kg / FU	Main potential impacts
Mining and processing	Copper extraction	588.22	Depletion of non-renewable resources and ecotoxicity
	Zinc extraction	316.73	
	Copper processing	190.16	
	Zinc processing	102.39	
	Subtotal	1197.50	
Auxiliary raw materials production	Steelmaking	54.19	Depletion of non-renewable resources
	Polyethylene production	140.35	
Manufacture	Machineries	47.05	Human toxicity, ecotoxicity and acidification
	Steel coil	0.92	
	Surface treatment	< 0.01	
	Sub-total	47.97	
Use	Needle		Human toxicity
	polyethylene	180.00	
	steel	30.00	
	Polyethylene needle pack	1620.00	
	Polyethylene cartridge	1640.00	
	Polyethylene bag	< 0.01	
	cardboard box	< 0.01	
	Subtotal	3570.00	
	Total	5010.01	

3 Results

3.1 Lifecycle Inventory

The results allow the construction of inventory tables that show the generation of solid waste (Table 4) in all seven stages of the life cycle of the Carpule dental syringe.

It should be noted that the data relating to the disposal of the anesthetic cartridge take into account its total mass that actually consists of three materials: polyethylene, rubber and aluminum. The mass of rubber and aluminum were considered negligible compared to the total mass of plastic.

The potential impacts caused by disposal of materials throughout the life cycle of the dental syringe are listed, considering that human toxicity refers to harmful to humans caused by material dispersion in the environment while ecotoxicity refers to toxicity in aquatic ecosystems caused by the scattering material disposed in the environment, such as the dispersion of heavy metals from sludge disposed in the processing of copper and zinc [38].

The electricity consumption (Table 5) recorded along the lifecycle of the dental syringe shows that, despite the high energy consumption on the steps of extraction and processing, the highest consumption occurs in the use stage syringes that are sterilized, on average, twice a day in autoclave.

Table 5 Electricity consumption at each stage of the life cycle of the dental syringe for 106 (FU) anes-thetics applied

	kWh / FU
Extraction	1,962.89
Processing	1,390.84
Subtotal	3,353.73
Steelmaking	955.43
Production of polyethylene	1,0947.30
Manufacture	
Machining	39.56
Surface treatment	8.96
Assembly	1.09
Packing	0.27
Subtotal	49.88
Use	37,500.00
Total	52,806.04

3.2 Evaluation for improvement

One of the advantages of assessing the life cycle of a product is to recognize in detail each step required for its production and use. However, this information does not allow any interference before or after the manufacturing steps. This fact is aggravated when one is dealing with small business as the manufacturer evaluated in this study. Such a company cannot influence the processes of mining, or product design since it contributes with a remarkably small portion of the supply chain. Based on this type of argument, the effect that changes in manufacturing processes have on the entire life cycle is often overlooked or neglected. However, it was observed that an improvement assessment based on LCI can bring benefits both in manufacturing and in other stages of the life cycle of a product. The improvements proposed are based on the dematerialization of the manufacturing process. Dematerialisation is one of the tools of industrial ecology, which refers to the reduction in use of raw materials in processes.

3.2.1 Solid waste

Although solid waste phase manufacturing represent, in weight, approximately 0.3% of total waste generated by the production of dental syringe along its life cycle, the development of the LCI identified possibilities for improvement at this stage. It has been observed that for every 0.08 kg of syringe approximately 0.14 kg of brass waste are generated. That is, 37% of the material entering the company remain in the syringe, and the remaining 63% are sold to scrap dealers. The largest amount of waste was associated to the machining process of cartridge chamber and fork parts (Table 3). In this process, the syringe cartridge set is made from a bar round which the brass removed to accommodate the cartridge and the sleeve. The mass of solid waste (0.051 kg) to make the compartment for the cartridge corresponds to approximately 3.5 times the mass product (0.015 kg). In the case of the fork also machined, the relationship between the solid waste and finished part is 3:1 in weight. The proposed solution was to replace the rods by round brass tubes with consistent dimensions.

With the solution, the annual production of solid waste in the manufacture of the tube and the fork was reduced from 256.02 kg to 43.52 kg, and 200.80 kg to 142.57 kg, respectively, with a total reduction of approximately 40%. It can be also said that the lower the amount of brass used in the machining process by the replacement of rods by tubes, is proportional to the reduction of the required quantities of copper and zinc extracted, reducing the depletion of non-renewable resources. With this change in the manufacturing process, the amount of material used in the fabrication of dental syringe would be reduced by approximately 25%. Figure 4 shows an estimate of the benefits considering a proportional reduction of the solid waste in the mining and processing steps.

In step surface treatment, despite the relatively small amount of waste (0.06%), one should take into account in a future assessment that the chemical sludge is deposited in landfills and can affect human toxicity and ecotoxicity and acidification with potential damages to the flora and fauna.

The fate of the cardboard box and plastic bag used as a container for the product were considered of responsibility of the manufacturer and the best solution was to replace these two items for a package consisting of a paper bag with a cellophane window, which remains recyclable. In this case, in addition to decreasing the mass of waste discarded during the product use stage, there was also a ten times reduction of the cost of packaging.

Solid waste in the use phase represents 74.2% of the total, 4.4% regarding the disposal of needles, 33.6% to the plastic caps and 34.2% to the cartridges. It is pertinent to note that the needle used in the process of dental anesthesia (Residue Class A / Infectious Waste Type A4) is discarded as medical waste [39]. As the collection cycles are variable according to each region of the country, these wastes are, in many cases, simply discarded along common trash. The cartridge used is also classified as medical waste, due to the possibility of the occurrence of a backflow of blood during anesthesia, resulting in over 4800 kg of needles/cartridges and packaging for every million anesthetics applied. This value, in 2002, was equal to 840 kg of waste.

3.2.2 Electricity consumption

The highest consumption of electricity in the life cycle of the dental syringe occurs during use stage, due to the sterilization process in autoclaves. An important factor is the market introduction of new models of autoclaves that consume on average 20% less electricity.

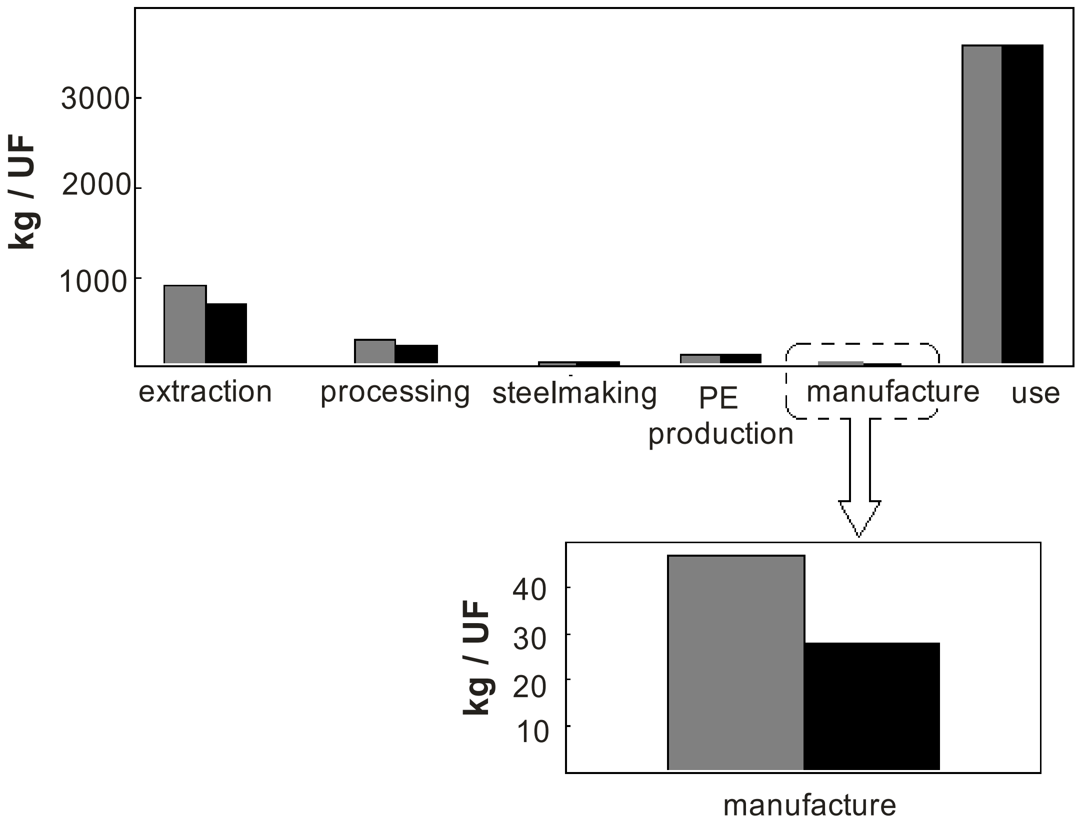

Fig. 4 Distribution of solid waste in the life cycle of the dental syringe (FU = 106 anesthetics applied) considering the actual amounts of process' wastes accounted (in gray) and after the proposed changes (in black)

It should be emphasized that the solution to reduce solid waste in manufacturing also allows a reduction in electricity consumption due to less machining time. The data obtained after the introduction of improvements - replacing rods tubes to make the cartridge compartment and the fork, show that the electricity consumption was reduced from 190.76 to 103.01 kWh and from 135.54 kWh and 107.08 kWh, respectively, leading to a total reduction of 19.95% compared to 2002 production. Figure 5 shows the results considering an estimate of the proportional reduction of 19% in mining and processing steps. In the use stage, a reduction in consumption of 20% was simulated.

4 Concluding remarks

The main result of the LCI syringe for dental anesthesia was a detailed knowledge of each production step, allowing to identify possibilities for improvement and to propose modifications in part of the cycle through promoting materials replacement in order to reduce disposal.

With the substitution of brass rods for tubes of the same material, it was possible not only to reduce the generation of solid waste, but also significantly reduce the electricity consumption. Despite the contribution of manufacturing to both waste generation and electricity consumption, being small relative to the entire supply chain, a change at this stage can result in significant benefits, which may occur in previous steps (reducing the need for mining and processing) and in later stages with reduction in packaging disposal.

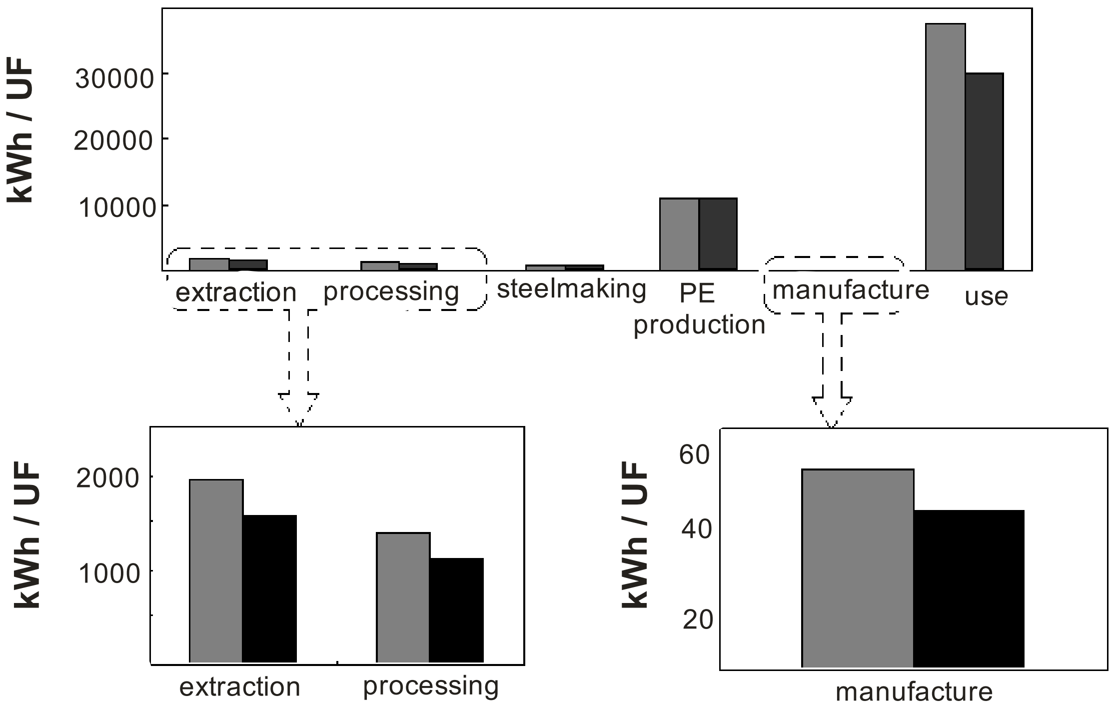

Fig. 5 Electricity consumption in the life cycle of the dental syringe (FU = 106 anesthetics applied) considering the actual amounts of process wastes (in gray) and the proposed changes to manu-facturing process (in black).

Figure 6 shows that, with the proposed changes to the manufacturing process, the total reduction of solid waste in the life cycle of the dental syringe is equivalent to the elimination of waste processing, which corresponds to approximately 6.50% of the total manufacturer's wastes generation. In the case of electricity consumption, the proposed changes, although they represent 20% of the consumption of use stage, are not sufficient to significantly reduce the total energy consumed in the life cycle of the dental syringe.

It is worth to note, both in the case of solid waste disposal and of electricity consumption, that the largest quantities are associated with the use stage. In case of using autoclaves with 20% less consumption, reduction in electrical energy consumption would be equivalent to the energy consumed for the production of polyethylene, which corresponds to 20% of total consumption of electricity in the life cycle of the syringe. The disposal of packaging in polyethylene use stage corresponds to 45% of the solid waste in this step and 32% of the total production chain. Thus, actions leading to dematerialisation of the needles packaging and modernization of autoclaves used by dentists would significantly reduce the potential environmental impact associated with the anesthesia application. However, there are still actions that are outside the domain of syringes manufacturing and would require the cooperation of those responsible for each stage of the production chain for the changes in products and processes that could result in the maximum reduction of solid waste disposal and electricity consumption.

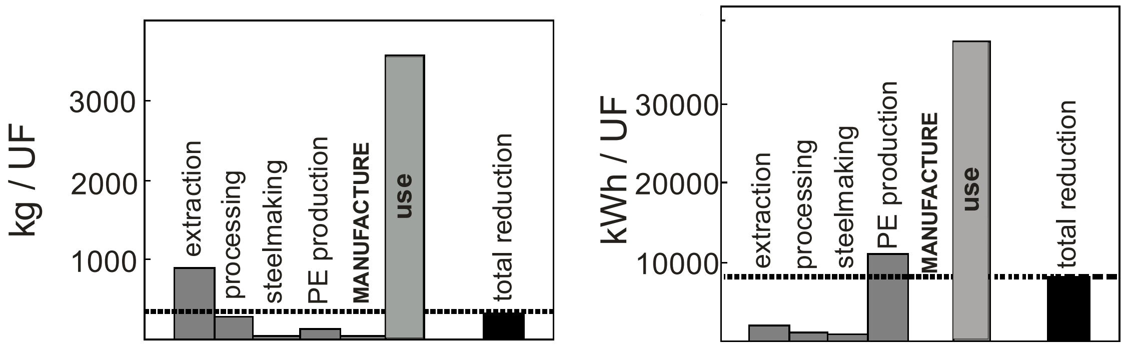

Fig. 6 Total solid waste and electricity reduced (in black) in the life cycle of dental syringe (FU = 106 anesthetics applied) compared with the quantities of solid waste and electricity before the pro-posed changes to manufacturing (in gray).

Acknowledgements

The authors thank Farbe Metallurgical Ltd. for providing the data necessary for the execution of this study. This study had financial support from Vice-Reitoria de Pós-Graduação e Pesquisa da Universidade Paulista.

References

[1] Alting, L.E. and Legarth, J. B. (1995), Life cycle engineering and design, *Annals of the CIRP*, **44**, no.2.

[2] Finnveden, G., Hauschild, M.Z., Ekvall T., Guinée, J., Heijungs, R., Hellweg, S., Koehler, A., and Suh, S. (2009), Recent developments in Life Cycle Assessment, *Journal of Environmental Management*, **91**, 1-21.

[3] Ulgiati, S., Ascione, M., Bargigli, S., Cherubini, F., Franzese, P.P., Raugei, M. Viglia, S., and Zucaro, A. (2011), Material, energy and environmental performance of technological and social systems under Life Cycle Assessment perspective, *Ecological Modelling*, **222**, 176-189.

[4] Ekvall, T., Tillman, A.M., and Molander, S. (2005), Normative ethics and methodology for life cycle assessment, *Journal of Cleaner Production*, **13**, 1225-1234.

[5] De Smet, B., White, P.R., and Owens, J.W. (1996), *Integrating Life Cycle Assessment within an Overall Framework for Environmental Management,* Em Curran, M.A., Ed., Environmental Life Cycle Assessment, McGraw-Hill Companies, Nova Iorque.

[6] Suh, S. and Huppes, G. (2005), Methods for Life Cycle Inventory of a product, *Journal of Cleaner Production*, **13**, 687-697.

[7] Furuholt, E. (1995), Life cycle assessment of gasoline and diesel, *Resources, Conservation and Recycling*, **141**, 251-263.

[8] Andersson, K., Ohlsson, T., and Olsson, P. (1998), Screening life cycle assessment (LCA) of tomato ketchup: A case study. *Journal of Cleaner Production*, **6**, 277-288.

[9] Cederberg, C. and Mattsson, B. (2000), Life cycle assessment of milk production - A comparison of conventional and organic farming, *Journal of Cleaner Production*, **8**, 49-60.

[10] Burgess, A.A. and Brennan, D.J. (2001), Application of life cycle assessment to chemical processes, *Chemical Engineering Science*, **56**, 2589-2604.

[11] Nicoletti, G.M., Notarnicola, B., and Tassielli, G. (2002), Comparative Life Cycle Assessment of flooring materials: ceramic versus marble tiles, *Journal of Cleaner Production*, **10**, 283-296.

[12] Verbeeck, G. and Hens, H. (2010), Life cycle inventory of buildings: A calculation method, *Building and Environment*, **45**, 1037-1041.

[13] Andersen, J.K., Boldrin, A., Christensen, T.H. and Scheutz, C. (2011), Mass balances and life cycle inventory of home composting of organic waste, *Waste Management*, **31**, 1934-1942.

[14] Finnveden, G. and Ekvall, T. (1998), Life-cycle assessment as a decision-support tool - The case of recycling versus incineration of paper, *Resources, Conservation and Recycling*, **24**, 235-256.

[15] Finnveden G. (1999), Methodological aspects of life cycle assessment of integrated solid waste management systems, *Resources, Conservation and Recycling*, **26**, 173-187.
[16] Azapagic, A. and Clift, R. (1999), The application of life cycle assessment to process optimization, *Computers and Chemical Engineering*, **23**, 1509-1526.
[17] Xiao, B., Suo C.X. and Yan, X.F. (2011), Comparing Chinese Clean Coal Transformation Technologies with Life Cycle Inventory. *Procedia Environmental Sciences*, **10** Part A, 414-419.
[18] Moreau, V., Bage G., Marcotte, D., and Samson, R. (2012), Statistical estimation of missing data in life cycle inventory: an application to hydroelectric power plants, *Journal of Cleaner Production*, **37**, 335-341.
[19] Tan, R.R., Briones, L.M.A., and Culaba, A.B. (2007), Fuzzy data reconciliation in reacting and non-reacting process data for life cycle inventory analysis, *Journal of Cleaner Production*, **15**, 944-949.
[20] Crawford, R.H. (2008), Validation of a hybrid life-cycle inventory analysis method, *Journal of Environmental Management*, **88**, 496-506.
[21] Georgakellos, D.A. (2005), Evaluation of life cycle inventory results using critical volume aggregation and polygon-based interpretation, *Journal of Cleaner Production*, **13**, 567-582.
[22] Marvuglia, A., Benetto, E., Rios, G., and Rugani, B. (2013), SCALE: Software for CALculating Emergy based on life cycle inventories, *Ecological Modelling*, **248**, 80-91.
[23] Ahmadi, A., Williamson, B.H., Theis, T.L., and Powers, S.E. (2003), Life-cycle inventory of toner produced for xerographic processes, *Journal of Cleaner Production*, **11**, 573-582.
[24] Seyler, C., Hofstetter, T.B., and Hungerbuhler, K. (2005), Life cycle inventory for thermal treatment of waste solvent from chemical industry: a multi-input allocation model, *Journal of Cleaner Production*, **13**, 1211-1224.
[25] Rydh, C.J. and Sun, M. (2005), Life cycle inventory data for materials grouped according to environmental and material properties, *Journal of Cleaner Production*, **13**, 1258-1268.
[26] Silva, G.A. and Borges, F.J. (2004), Life-cycle inventory of polyvinyl chloride manufacture in Brazil, *SETAC Globe, Pensacola*, **5**, 60-61.
[27] Silva, G.A. and Kulay, L.A. (2005), Environmental performance comparison of wet and thermal routes for phosphate fertilizer production using LCA A Brazilian experience, *Journal of cleaner production*, **13**, 1219-1223.
[28] Silva, G.A. and Kulay, L.A. (2003), Application of life cycle assessment to the LCA case studies single superphosphate production, *The International Journal of Life Cycle Assessment*, **8**, 209-214.
[29] Poeschl, M., Ward S. and Owende P. (2012), Environmental impacts of biogas deployment – Part I: life cycle inventory for evaluation of production process emissions to air. *Journal of Cleaner Production*, **24**, 168-183.
[30] Ribeiro, F.M., and da Silva, G.A. (2010), Life-cycle inventory for hydroelectric generation: a Brazilian case study, *Journal of Cleaner Production*, **18**, 44-54.
[31] Tillman, A.M. (2000), Significance of decision-making for LCA methodology, *Environmental Impact Assessment Review*, **20**, 113-123.
[32] Ayres, R.U., Ayres, L.W., and Råde, I. (2002), *The Life Cycle of Copper, Its Co-Products and By-Products*, report commissioned by the MMSD (Mining, Minerals and Sustainable Development) project of IIED (International Institute for Environment and Development), World Business Council for Sustainable Development (WBCSD).
[33] Report of Energy and Environmental Profile of the U.S. Mining Industry. (2010), Office of Industrial Technologies, *Office of Energy Efficiency and Renewable Energy, cap. 5*, http://www.eere.energy.gov/industry/mining/pdfs/miningbro05.pdf, acesso em 2003.
[34] Report of Energy and Environmental Profile of the U.S. Mining Industry. (2010), Office of Industrial Technologies, *Office of Energy Efficiency and Renewable Energy, cap. 6,* http://www.eere.energy.gov/industry/mining/pdfs/miningbro06.pdf, acesso em 2003.
[35] IISI. (2000), *Life Cycle Inventory Data for Steel Products,* IISI – International Iron and Steel Institute, Bruxelas.
[36] Boustead, I. (2003), *Ecoprofiles of the European plastics industry, POLYOLEFINS*, a report for the Technical and Environmental Centre of the Association of Plastics Manufacturers in Europe (APME). APME, Brussels.
[37] CFO. (2003), *Conselho Federal de Odontologia*, http://www.cfo.org.br/index.htm. acesso em 2003.
[38] ISO 14040/2006. International Standardization Organization. *Environmental Management—Life Cycle Assessment—Principles and Framework. International standard ISO 14040/2006*, 2nd ed, Genebra: ISO, 2006. Available in: http://www.iso.org/iso/catalogue_detail.htm?csnumber=37456
[39] CONAMA. (2001), *Resolução nº 283 de 12 de julho de 2001.*