Life Cycle Assessment of Newly Manufactured and Reconditioned Industrial Packaging

Building a better working world

Rotterdam, The Netherlands

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Table of contents

1. Introduction

For nearly three-quarters of a century, the Reusable Industrial Packaging Association (RIPA) has been the trade association representing North American reconditioners, manufacturers and distributors of reusable industrial packaging. RIPA represents over 90% of the industrial packaging reconditioning industry in North America including many of the world's leading manufacturers of steel, plastic and fiber drums, as well as intermediate bulk containers. The RIPA membership also includes many of the leading suppliers of packaging parts and accessories.

As a condition of membership, all RIPA members agree to conform to a Code of Operating Practice, which sets forth specific guiding principles for operations, packaging reuse and recycling. These guidelines are intended to improve the industry's performance in the areas of regulatory compliance, environmental management, waste reduction and recycling.

RIPA is the industry's information clearinghouse. The association sponsors workshops and meetings that provide information about issues of importance to the industry's wellbeing and continued success. The group's Annual Conference, Technical Conference and compliance workshops help ensure that members understand key issues affecting their businesses, and can learn about technical and business developments. The association publishes an industry newsletter, "Reusable Packaging Today," and distributes Special Bulletins on issues of immediate concern to members.

RIPA has requested EY to analyze the environmental performance of industrial packaging. What are the ecological impact differences of reconditioning as compared with manufacturing a drum or IBC from raw materials? This report presents the goal and scope of the study performed (chapter 2), the results (chapter 3) and conclusions of the study (chapter 4).

2. Goal and scope

This chapter of the report discusses the goal and scope of the study. The functional unit and the specific products are involved as well. It also discusses the choices concerning allocation, system boundaries and assessment method.

2.1 Goal

The primary goal of the study is a head to head comparison between a new packaging and a reconditioned packaging of similar technical specifications, resulting from a single trip and multi-trip industrial packaging solution.

2.2 Functional unit

The functional unit of the comparison are packaging units with capacities of 55, 275 or 330 gallons, which are used to transport chemicals or other substances. The packaging content of 55 gallons is used for drums and the packaging of 275 gallons and 330 gallons are used for IBCs. The production, transport to customer and the end of life are included in the functional unit. The functional flow is one unit of packaging.

2.3 The product systems

The following product systems are part of the scope of the project:

Packaging type	Content	New	Reconditioned
IBC	275 US Gal 330 US Gal	Steel pallet	Steel pallet
Steel drum	55 US Gal	Tight head Open head	Tight head Open head
Plastic drum	55 US Gal	Tight head (virgin plastic) Tight head (Post consumer resin)	Tight head

IBC
An IBC has a 275 or 330 gallon volume polyethylene bottle which will contain the product during use. The bottle is inside a steel tube cage. The analyzed systems have a steel pallet.

Steel drum
A steel drum is completely made out of steel sheet, with an outside coating applied later in the process. The drum is manufactured as an open - or tight head. The top of the tight head is seamed to the body and only two small openings remain for filling and emptying the drum. The lid of the open head can be removed from the rest of the drum for filling. Lid and drum body are assembled with a bolt or clamp ring. Open head steel drums also utilize a plasticized gasket to facilitate proper closure.

Plastic drum
A plastic drum is made out of high density polyethylene (HDPE), either out of virgin resin or out of post-consumer resin (PCR). The tight head plastics drum is one piece blow molded. It has two small openings for filling and emptying the drum.

Collection process
It is normal practice to collect drums and IBCs from users who have emptied the packaging. The drums and IBC's are collected by truck and transported to a reconditioning facility. There, they are reconditioned as explained above and sold to customers again.

2.4 System boundary

The system boundary determines the unit processes included or excluded in each life cycle of the product system. One life cycle has connections with other life cycles. This is for instance the case with the life cycle of a packaging and the life cycle of the content of the packaging. Another example is the use of recycled materials that originate from another life cycle. It is important to determine and show which processes will be included, how they are included and also which will be excluded. This is essential for the interpretation of the results and conclusions of the study.

Below a process flow diagram is presented, which provides an overview of the flow of the processes in the system. The boxes with the dotted lines are not included in the life cycles of the product systems.

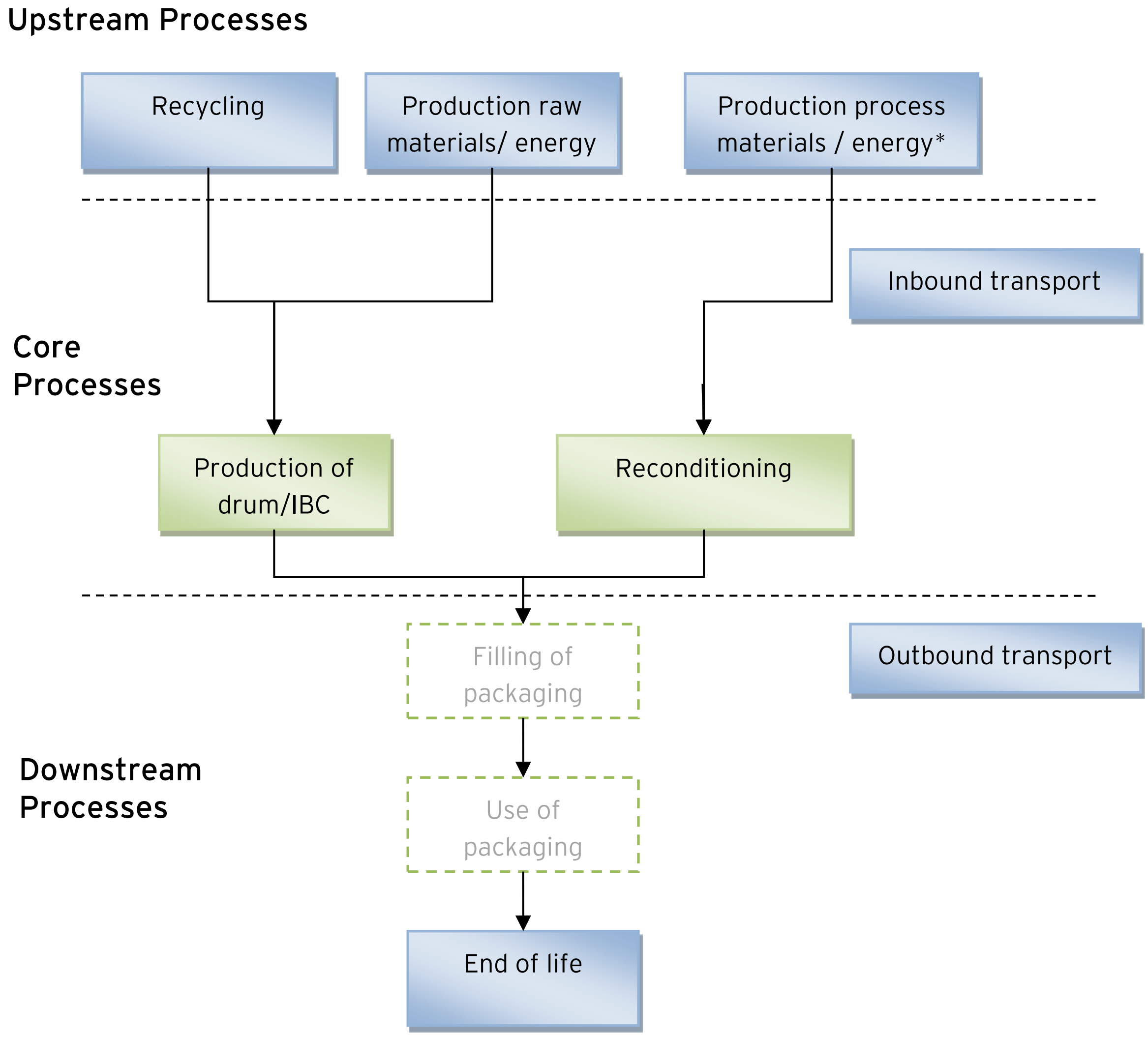

Figure 1 Schematic representation of the system boundary of the life cycle assessment

* Upstream processes involved in the reconditioning only reflect materials needed for washing (like e.g. caustic soda) and nothing of the packaging materials themselves.

Allocation and recycling
System boundaries are also set in the life cycle to determine the allocation of burdens and benefits regarding recycling. For instance, scrap is the output from the life cycle of steel drums and is used in another life cycle of perhaps a steel clamp ring of a drum. The boundary between the two life cycles should be set and be consistent throughout the whole study. The benefit of recycling should not be claimed twice. This happens if a benefit is provided to the drum that is scrapped and to the clamp ring that uses the scrap. The system boundary is set before the use of the recycled material by products downstream that has been provided by the products in this study. The benefits of providing materials for recycling are therefore not deducted from the burdens but also the burdens of the recycling process (for instance the scrapping process) are not taken into account here.

The recycled content of steel is set at the amount of steel that is recycled at the end of life. The reason of this choice is that steel is a closed loop material: it is possible to recycle steel an indefinite number of times. The limit is the steel that is kept in the loop and is recycled in the end of life phase.

Some recycling plants, as in energy recovery facilities, generate electricity and heat. This benefit is included in the national electricity mixes. This benefit is therefore allocated to the use of electricity and not to the material and product generating the energy when incinerated.

Drums and IBCs for collection
Each reconditioned drum or IBC was once newly manufactured. The drums and IBCs are collected after use by the reconditioning party. The impact of the newly manufactured drum is not included in any way in the life cycle of the reconditioned drum.

2.5 Impact assessment method

The focus of the study is on the emission of greenhouse gasses (GHG), which influences global warming. There are many different gasses that have this potential for global warming, but this potential is different for each gas. To be able to add up all these potentials, the global warming potential (GWP) of a substance is related to the GWP of carbon dioxide. Methane, for instance has a 25 time higher GWP than carbon dioxide, its conversion factor is therefore 25. To add up 1 kg of methane and 1 kg of carbon dioxide the amount of methane emitted is multiplied with 25 and then added to the amount of carbon dioxide emitted. This results in a total GWP equivalent to 26 kg carbon dioxide or CO_2e in this case.

Besides global warming there are other environment issues, for instance ozone depletion, toxicity, resource depletion. The results of this study will therefore be complemented with the results of several other impact categories as well. The impact potentials are calculated in these impact categories in a similar way as the GWP of the climate change calculated as explained above.

There are different impact assessment methods that have determined conversion factors for the impact categories. In this study the method Traci 2.1 is used. This is a method that is developed specifically for the North American continent. More information about this method can be found in Appendix D. The impact categories in Table 1 are included in the analysis.

Table 1 Impact categories of Traci 2.1

Impact category	Unit
Climate change	Lbs CO2e
Ozone depletion	Lbs CFC-11e
Acidification	Lbs SO2e
Eutrophication	Lbs Ne
Smog	Lbs O3e
Carcinogenics	CTUh
Non carcinogenics	CTUh
Respiratory effects	Lbs PM 2.5e
Ecotoxicity	CTUe
Fossil fuel depletion	MJ surplus

The main focus is on climate change, the other impact categories are discussed more briefly.

3. Life cycle inventory

The inventory data can be divided in foreground and background data. The foreground data are the core processes of the figures in and concerns processes like energy use of production and material use. This data is collected using questionnaires send to members of RIPA.
The background data are the upstream and downstream processes of the figures in 3.4.1 and concerns processes like energy production, raw material production, resource extraction etc. A specific database for the US will be used: USLCI database[1]. This database contains processes specific for the production processes and circumstances in the USA. Data gaps are filled with data from the database Ecoinvent 3[2], the most up-to-date and large LCA database available.

3.1 Inbound transport

The raw materials and the drums and IBC to be reconditioned need to be transported to the manufacturing or reconditioning facility. The inbound transport is set at 100 miles, these materials are typically purchased within this distance from the facility. The transport of drums and IBCs to be reconditioned is dependent on the size of the packaging, the size of the truck, the distance to the client and the number of drums or IBCs to be delivered. The number of 55 gallon drums per truck load is set at 250, the number of 275 gallon IBCs per truckload is set at 60, the number of 330 gallon IBCs per truckload is set at 50. The transport distance is set at 200 miles. These are typical values for this kind of transport.

3.2 Manufacturing

Ten manufacturers of drums and IBCs have responded to a request to provide data about the production of the manufacturing of both drums and IBCs. This resulted in data from sixteen different production lines, some manufacturers provided data of multiple lines. The database processes used and the assumptions used are presented in Appendix A. The inventory per manufacturer is confidential information, only the averages per packaging type are presented, see Appendix C

The main dimensions of the different packaging types are presented below.

Steel drum

Steel sheet thickness (mm) Top/body/bottom	Tight head Steel weight (lbs.)	Open head Steel weight (lbs.)
1.2/1.2/1.2	44.8	47.5
1.0/1.0/1.0	37.7	42.3
1.2/0.9/1.2	36.7	40.8
1.1/0.9/1.1	35.6	40.0
1.1/0.8/1.1	33.5	37.8
1.0/0.8/1.0	32.9	35.5
0.8/0.8/0.8	31.0	33.3

IBC – composite, steel pallet

IBC type	Steel weight (lbs.)	Virgin plastic weight (lbs.)	Recycled plastic weight (lbs.)
275 gallon IBC	80.3	36	6
330 gallon IBC	100	44	6

Plastic drum – tight head

IBC type	Virgin plastic weight (lbs.)	Recycled plastic weight (lbs.)
55 gallon virgin plastic	21	0
55 gallon recycled plastic	0	21

3.3 Reconditioning

Sixteen reconditioning facilities responded to a request to provide data about the production of the reconditioning of both drums and IBCs. This resulted in data from nineteen different reconditioning lines, some reconditioners provided data of multiple lines. The aggregated data of the reconditioning is presented in Appendix B.

3.4 Inbound transport

The manufactured (both new and reconditioned) drums and IBC need to be transported to the client. The outbound transport is set at 200 miles, the truck load is set equal to the truckload of the inbound transport.

3.5 End of life

No direct data of the end of life statistics of industrial packaging is available. The statistics of Municipal solid waste (MSW) are used as proxy data. The recycling percentage of the plastic and steel is obtained from the EPA[3]. The remaining waste is either incinerated or landfilled. This ratio is also based on EPA as included in the end of life scenario of the USA.

Recycling percentage of Plastics: 12.9%[a]. Recycling percentage of steel: 72%[b].

[a] From MSW category: Total Plastics in Cont. & Packaging

[b] From MSW category: Containers and Pack aging – Total steel packaging

4. Results

This chapter presents the results of the life cycle assessment. The results of the analysis of the carbon footprint of the open head steel drum, tight head steel drum, tight head plastic drum and IBC are discussed in the first four paragraphs and an overview of the results is presented in the fifth paragraph. The sixth paragraph discusses other impact categories like ozone depletion and ecotoxicity.

4.1 Carbon footprint: Open head steel drum

Figure 2 shows the head to head comparison of the life cycle of a newly manufactured drum and a reconditioned drum. The outbound transport and end of life of both systems is assumed to be the same. The differences are in the raw materials, inbound transport and the production/reconditioning process. The raw materials of the reconditioning process concern materials like steel shot that are used in the process but it also includes inner lining and coatings. The figure shows that the GHG-emissions of the life cycle of a reconditioned drum are less than half the GHG-emissions of a newly manufactured open head steel drum.

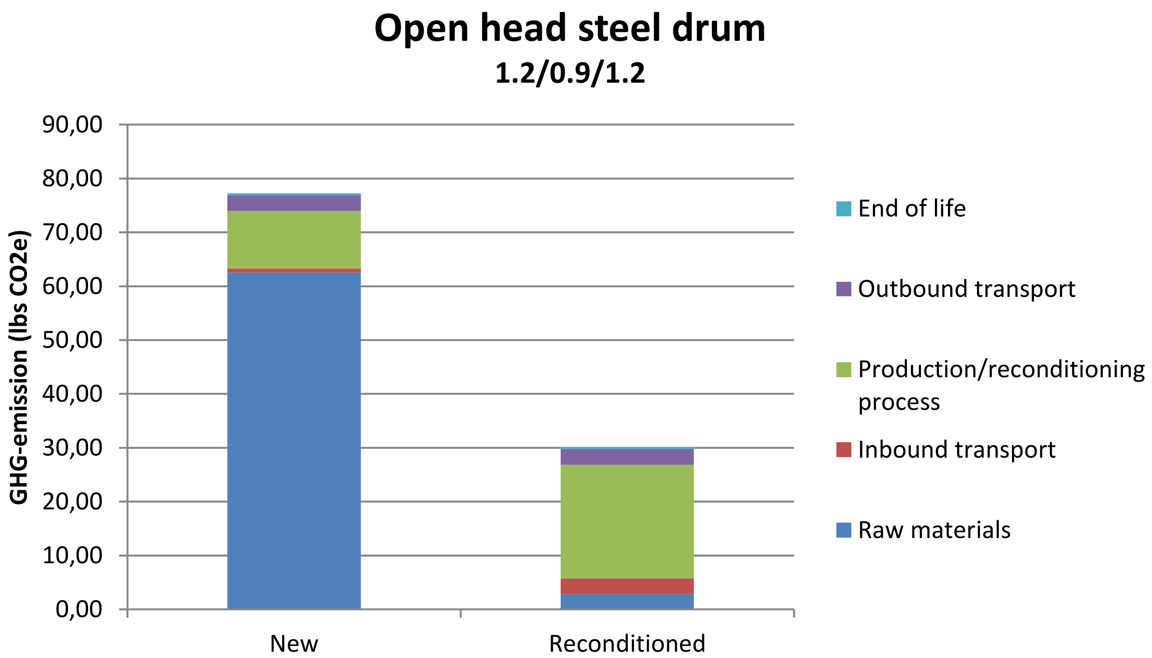

Figure 2 Comparison of carbon footprint between newly manufactured open head steel drums with the reconditioned open head steel drum

Open head steel drum – 1.2/0.9/1.2 – carbon footprint (lbs CO_2e)

	Raw materials	Inbound transport	Production/ reconditioning process	Outbound transport	End of life	**Total (lbs CO_2e)**
New	62.5	0.76	10.7	2.9	0.38	**77.3**
Reconditioned	2.9	2.9	21.0	2.9	0.38	**30.1**

Open head steel drums are manufactured with steel sheet of different thicknesses, from 0.8 to 1.2 mm. Figure 3 shows an overview of the GHG-emission of the different open head steel drums.

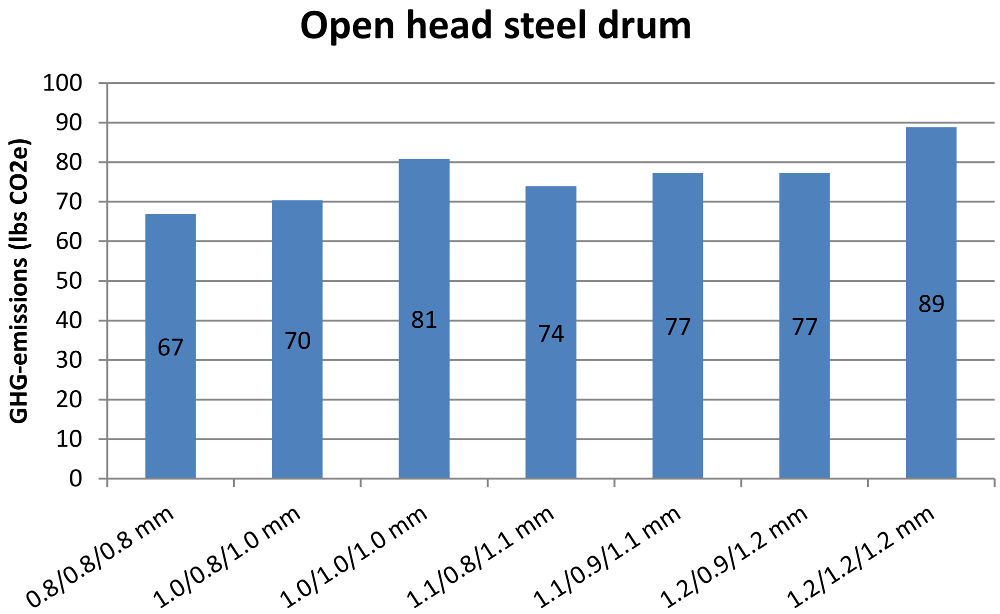

Figure 3 Comparison of the carbon footprint between open head steel drums with different thickness steel sheet. The codes refer to the thickness of the steel sheet: bottom/body/top

Figure 3 shows the expected results that the drums with the thinner sheet have lower GHG-emissions than the drums with thicker steel sheet. It should be stressed that the drums with thicker sheet can be reconditioned and can be reconditioned more often. The comparison with the reconditioned drum shows that the possibility of reconditioning the drums with thicker steel sheets outweighs the reduced impact of the drums with thinner steel sheet.

4.2 Carbon footprint: Tight head steel drum

Figure 4 shows a head to head comparison between a newly manufactured tight head drum (1.2/0.9/1.2 mm) and a reconditioned tight head drum.

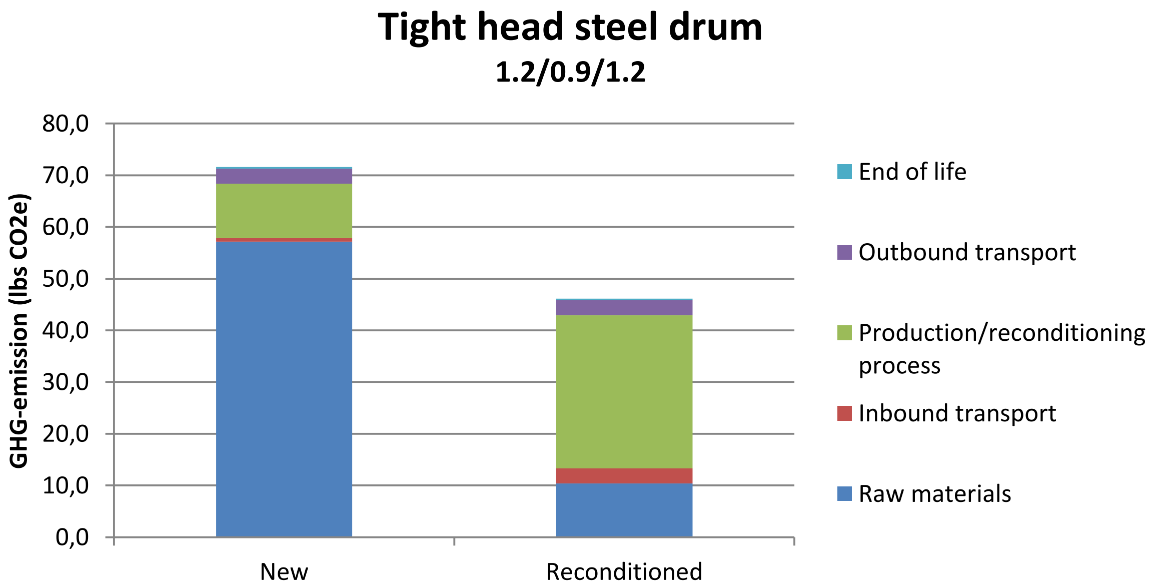

Figure 4 Comparison of carbon footprint between newly manufactured tight head steel drums with the reconditioned tight head steel drum.

Tight head steel drum – 1.2/0.9/1.2 – carbon footprint (lbs CO_2)

	Raw materials	Inbound transport	Production/ reconditioning process	Outbound transport	End of life	**Total (lbs CO_2e)**
New	57.2	0.72	10.5	2.91	0.33	**71.6**
Reconditioned	10.4	2.91	29.6	2.91	0.33	**46.1**

The above figure shows that the GHG-emissions of the reconditioned drum are about 65% of the GHG-emissions of a newly manufactured drum. The advantage of reconditioning a tight head drum is smaller than reconditioning an open head drum. This is mainly caused by the higher energy use of reconditioning a tight head drum. Figure 5 shows a comparison of tight head steel drums with different steel sheet thickness.

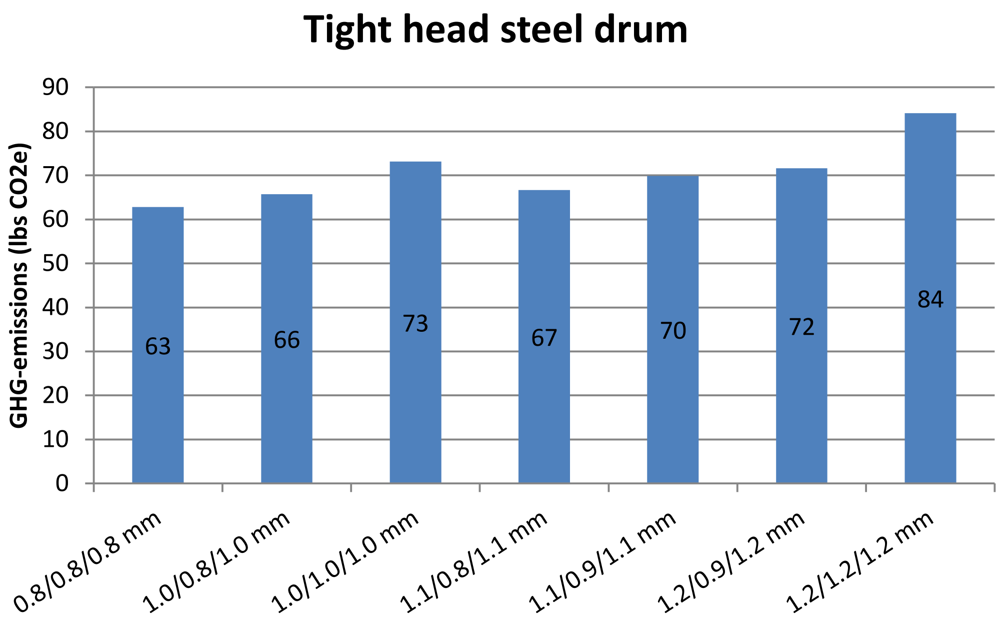

Figure 5 Comparison of the carbon footprint between tight head steel drums with different thickness steel sheet. The codes refer to the thickness of the steel sheet: bottom/body/top.

The figure above shows a difference of 25% in GHG-emission between the lightest and heaviest drum.

4.3 Carbon footprint: Tight head plastic drum

Figure 6 shows a comparison between the life cycle of a newly manufactured tight head plastic drum and a reconditioned drum. The new drum can be manufactured using virgin plastic or post-consumer resin (PCR). There is a clear advantage of using PCR instead of virgin plastic. The reconditioned drum has similar carbon footprint. It appears that the GHG-emissions related to scrapping of plastic and producing a drum from this scrapped plastic are similar to the washing of a whole drum. The emissions related to the scrapping process are from the US LCI database. Further analysis is required to back this findings.

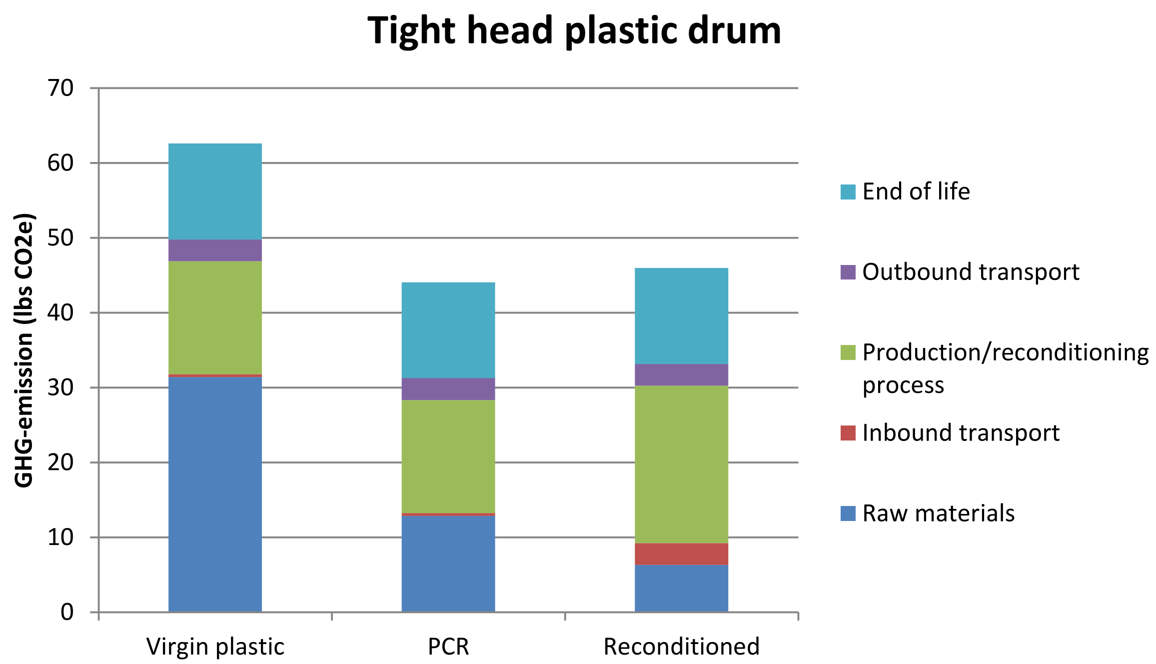

Figure 6 Comparison of carbon footprint between newly manufactured drums made from virgin plastic and PCR and the reconditioned drum

Tight head plastic drum – carbon footprint (lbs CO_2)

	Raw materials	Inbound transport	Production/ reconditioning process	Outbound transport	End of life	**Total (lbs CO_2e)**
Virgin plastic	31.4	0.4	15.1	2.9	12.8	**62.6**
PCR	12.9	0.4	15.1	2.9	12.8	**44.1**
Reconditioned	6.3	2.9	21.0	2.9	12.8	**46.0**

What would have happened if the plastic drum was not reconditioned? Or if the PCR was not recycled? Would the plastic have been incinerated? Reconditioning and recycling avoid emissions that would have been caused by the disposal. These avoided emissions are not taken into account but are a benefit of reconditioning and recycling.

4.4 Carbon footprint: IBC

Figure 7 shows a comparison between the life cycles of newly manufactured IBCs and reconditioned IBCs. The benefit of reconditioning an IBC is substantial. The GHG-emissions of reconditioned IBCs are about a third of the GHG-emissions of newly manufactured IBCs.

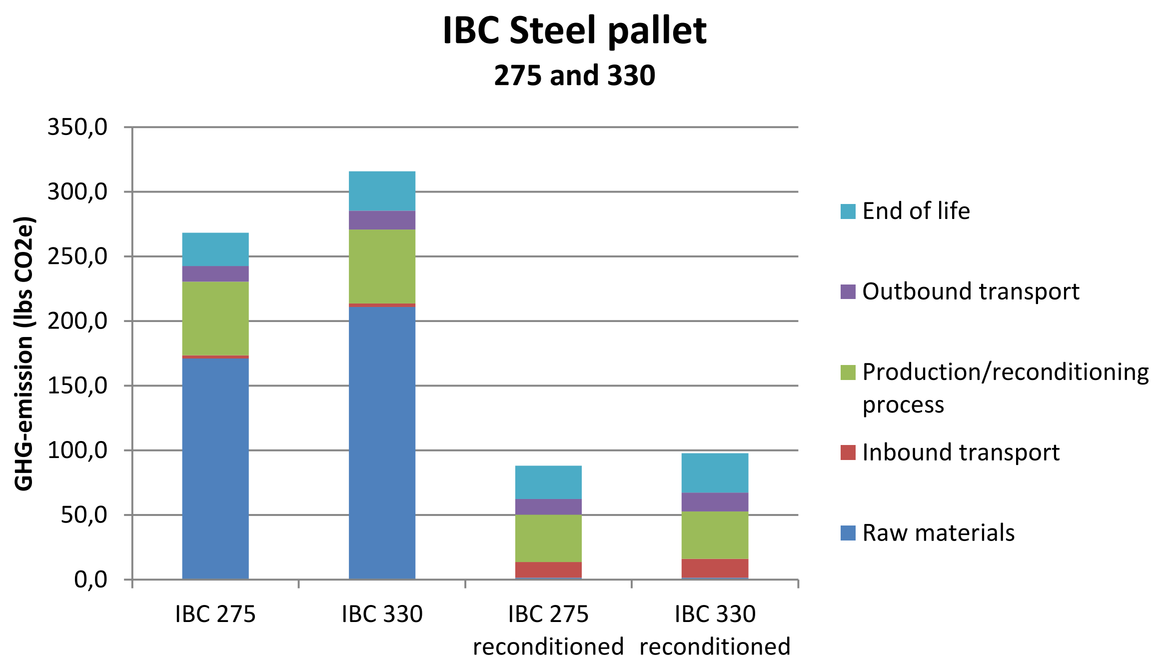

Figure 7 Comparison of carbon footprint between newly manufactured IBCs and the reconditioned IBCs with the sizes 275 and 330 lbs.

Intermediate bulk container (IBC) – carbon footprint (lbs CO_2)

	Raw materials	Inbound transport	Production/reconditioning process	Outbound transport	End of life	**Total (lbs CO_2e)**
IBC 275	171.1	2.4	57.1	12.1	25.6	**268.3**
IBC 330	210.9	2.9	57.1	14.6	30.5	**316.0**
IBC 275 reconditioned	1.5	12.1	36.8	12.1	25.6	**88.2**
IBC 330 reconditioned	1.5	14.6	36.8	14.6	30.5	**97.9**

4.5 Carbon footprint - results overview

Overview of carbon footprint results

Category		Type	New (lbs CO2e)	Reconditioned (lbs CO2e)
	**Steel drum**	Open head	77.3	30.1
		Tight head	71.6	46.1
	**Plastic drum**	Tight head Virgin plastic	62.6	46.0
		Tight head PCR	44.1	-
	**IBC**	275 gallon	268.3	88.2
		330 gallon	316.0	97.9

4.6 Environmental footprints

The emission of greenhouse gasses is not the only environmental issue. A comparison between newly manufactured industrial packaging newly manufactured industrial packaging and reconditioned packaging with more environmental topics are shown in the figures from topics are shown in the figures from

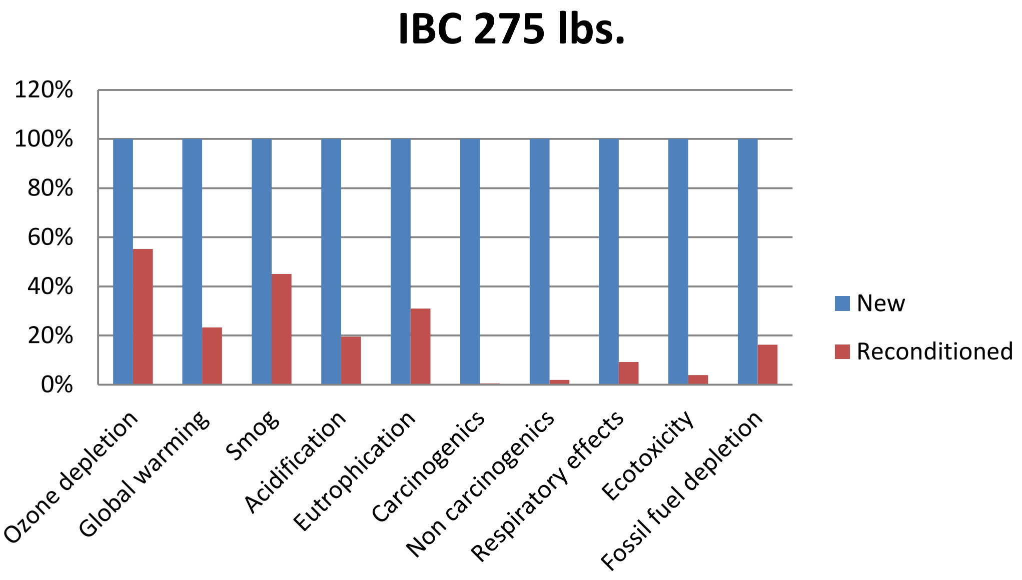

Figure 8 to Figure 12.

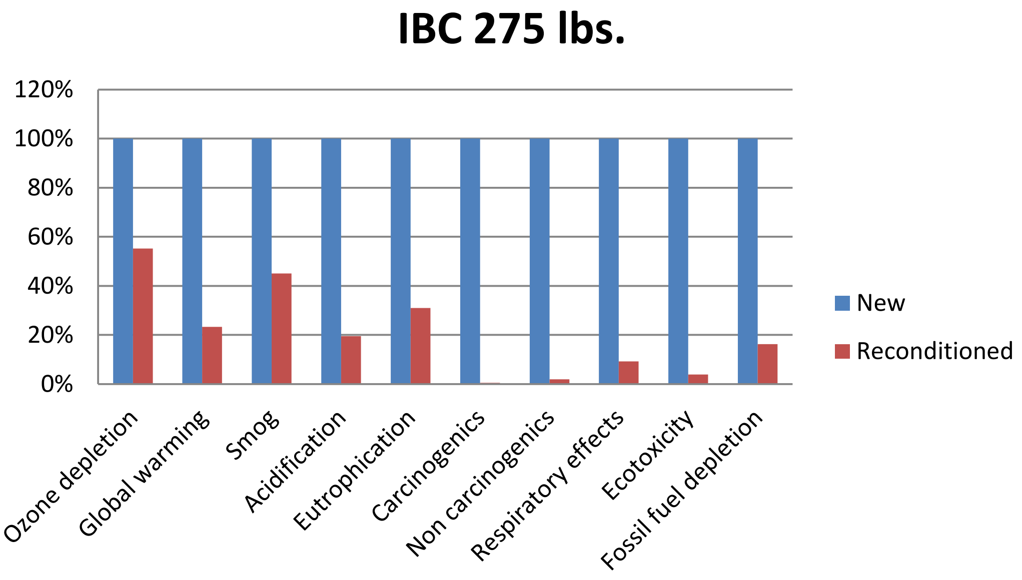

Figure 8 Comparison on multiple environmental issues between newly manufactured IBC and reconditioned IBC of 275 lbs.

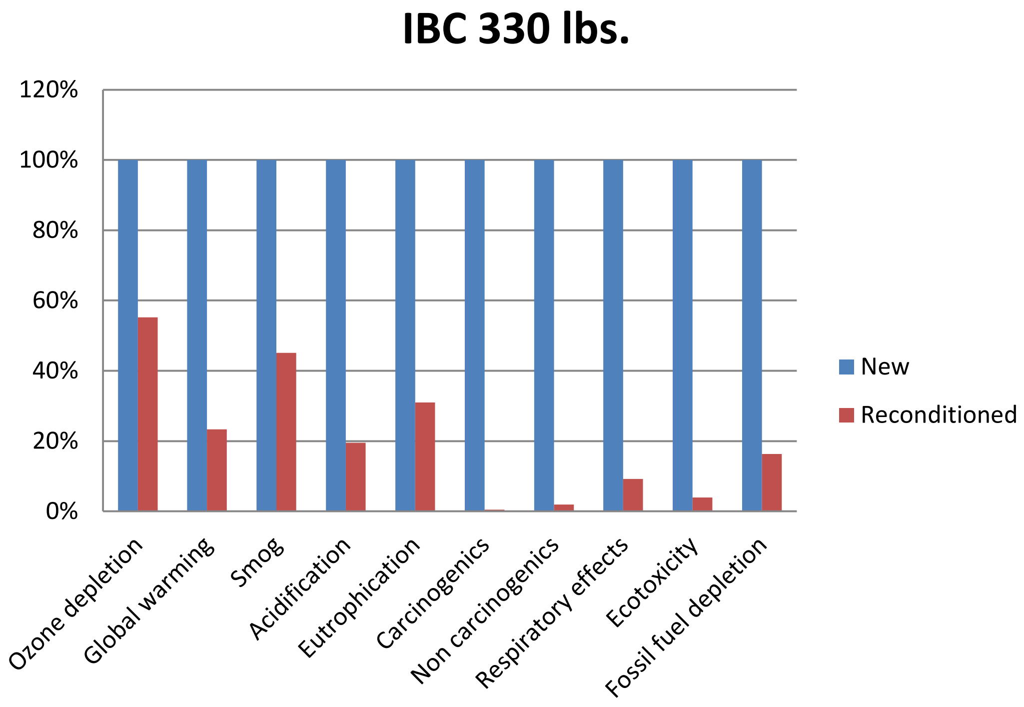

Figure 9 Comparison on multiple environmental issues between newly manufactured IBC and reconditioned IBC of 330 lbs.

Intermediate bulk container (IBC)

	Unit	New IBC 275	New IBC 330	Reconditioned IBC 275	Reconditioned IBC 330
Ozone depletion	Lbs CFC-11 eq	9.03E-06	1.10E-05	4.98E-06	5.95E-06
Global warming	Lbs CO2 eq	2.68E+02	3.16E+02	6.25E+01	6.74E+01
Smog	Lbs O3 eq	1.68E+01	1.97E+01	7.58E+00	8.69E+00
Acidification	Lbs SO2 eq	2.34E+00	2.77E+00	4.58E-01	4.94E-01
Eutrophication	Lbs N eq	1.51E-01	1.85E-01	4.68E-02	5.02E-02
Carcinogenics	CTUh	2.51E-05	3.11E-05	1.19E-07	1.23E-07
Non carcinogenics	CTUh	7.54E-05	9.34E-05	1.47E-06	1.55E-06
Respiratory effects	Lbs PM2.5 eq	2.74E-01	3.32E-01	2.53E-02	2.74E-02
Ecotoxicity	CTUe	4.33E+02	5.32E+02	1.70E+01	1.81E+01
Fossil fuel depletion	MJ surplus	2.29E+02	2.76E+02	3.73E+01	4.15E+01

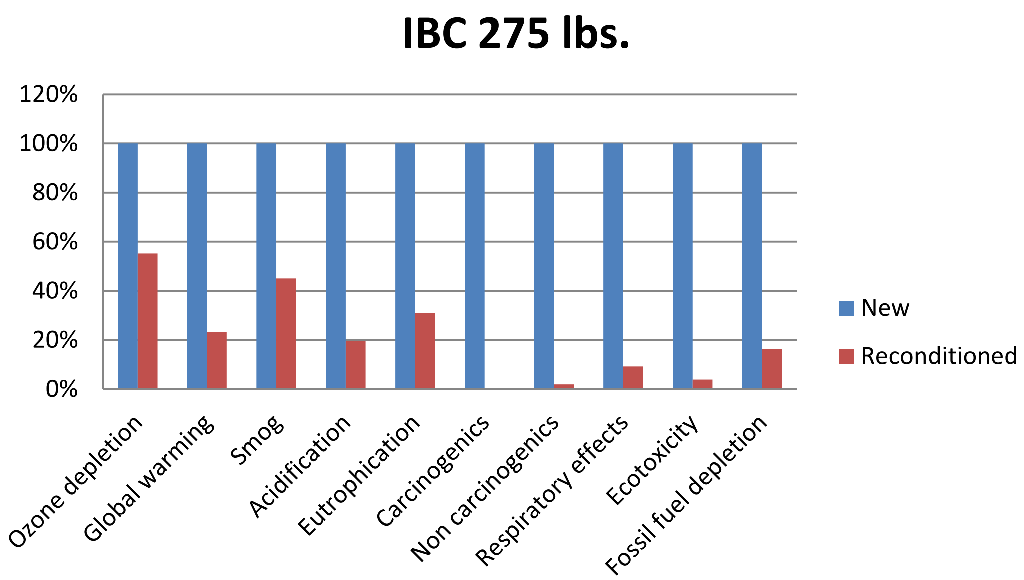

Figure 8 and Figure 9 show that the reconditioned IBCs have a lower score than newly manufactured IBCs on all analyzed impact categories.

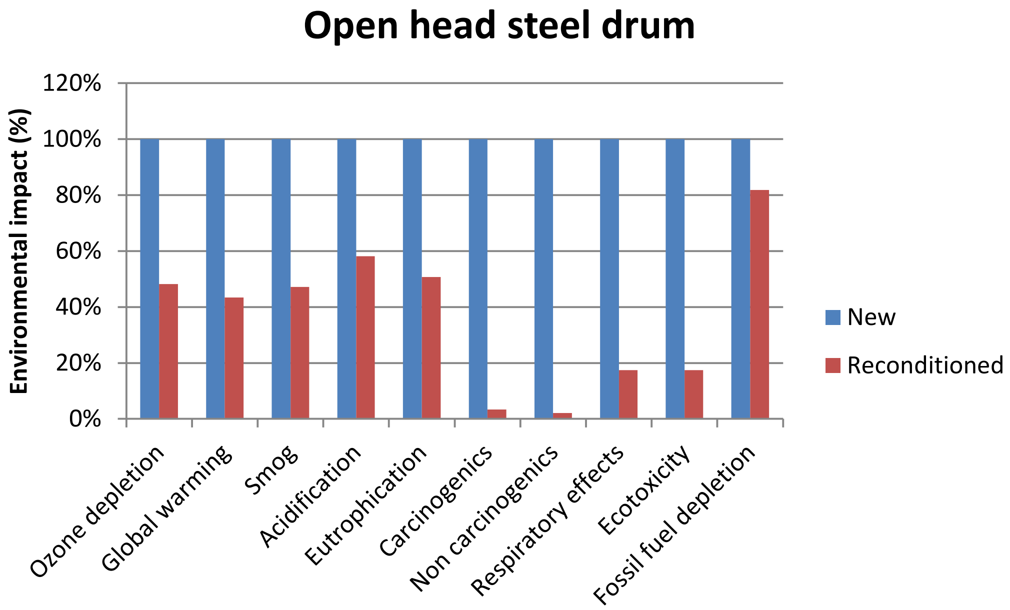

Figure 10 Comparison on multiple environmental issues between newly manufactured open head steel drum and the reconditioned drum.

Steel drum open head – 1.2/0.9/1.2

	Unit	New drum	Reconditioned drum
Ozone depletion	Lbs CFC-11 eq	3.74E-06	1.81E-06
Global warming	Lbs CO2 eq	7.73E+01	3.36E+01
Smog	Lbs O3 eq	5.25E+00	2.48E+00
Acidification	Lbs SO2 eq	4.61E-01	2.68E-01
Eutrophication	Lbs N eq	7.01E-02	3.56E-02
Carcinogenics	CTUh	1.24E-05	4.22E-07
Non carcinogenics	CTUh	3.47E-05	7.45E-07
Respiratory effects	Lbs PM2.5 eq	1.00E-01	1.74E-02
Ecotoxicity	CTUe	1.57E+02	2.74E+01
Fossil fuel depletion	MJ surplus	3.30E+01	2.70E+01

Figure 10 shows that the reconditioned open head steel drum scores better on all analyzed environmental issues.

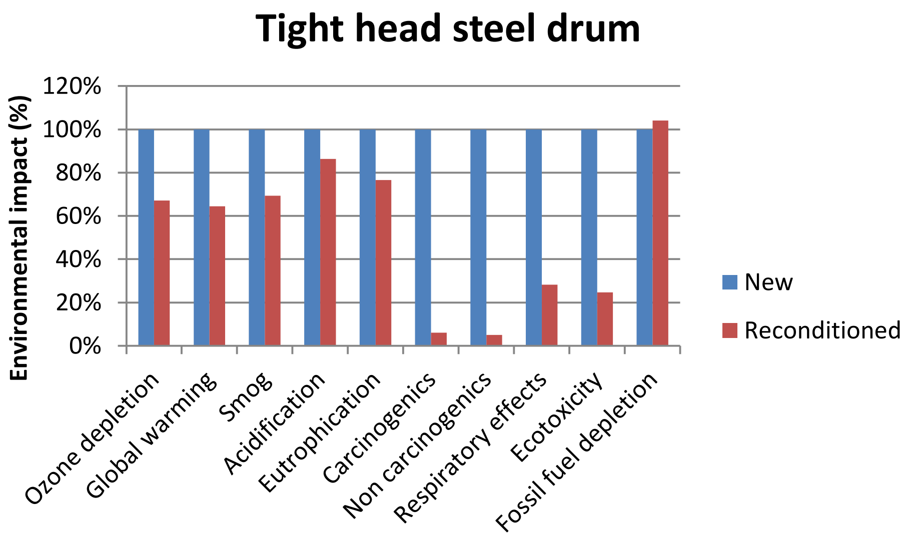

Figure 11 Comparison on multiple environmental issues between newly manufactured tight head steel drum and the reconditioned drum

Steel drum tight head – 1.2/0.9/1.2

	Unit	New drum	Reconditioned drum
Ozone depletion	Lbs CFC-11 eq	3.46E-06	2.32E-06
Global warming	Lbs CO2 eq	7.16E+01	4.61E+01
Smog	Lbs O3 eq	4.88E+00	3.39E+00
Acidification	Lbs SO2 eq	4.29E-01	3.71E-01
Eutrophication	Lbs N eq	6.35E-02	4.86E-02
Carcinogenics	CTUh	1.14E-05	6.92E-07
Non carcinogenics	CTUh	3.19E-05	1.59E-06
Respiratory effects	Lbs PM2.5 eq	9.23E-02	2.61E-02
Ecotoxicity	CTUe	1.44E+02	3.55E+01
Fossil fuel depletion	MJ surplus	3.07E+01	3.20E+01

Figure 11 shows that the reconditioned tight head steel drum scores better on most analyses environmental issues, except fossil fuel depletion. The slightly higher score on fossil fuel depletion is mainly caused by the higher energy use of the reconditioning process compared with the production of newly manufactured drums.

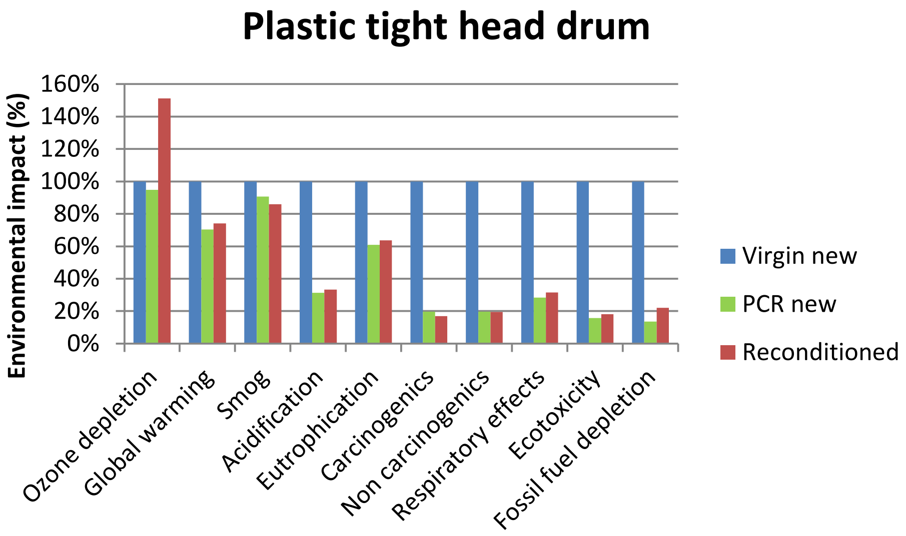

Figure 12 Comparison on multiple environmental issues between newly manufactured drums made from virgin plastic and PCR and the reconditioned drum

Plastic drum tight head

	Unit	Virgin new drum	PCR new drum	Reconditioned drum
Ozone depletion	Lbs CFC-11 eq	8.06E-07	7.64E-07	1.22E-06
Global warming	Lbs CO2 eq	6.26E+01	4.41E+01	4.64E+01
Smog	Lbs O3 eq	3.14E+00	2.85E+00	2.70E+00
Acidification	Lbs SO2 eq	8.41E-01	2.63E-01	2.81E-01
Eutrophication	Lbs N eq	1.27E-02	7.71E-03	8.06E-03
Carcinogenics	CTUh	3.14E-07	6.19E-08	5.31E-08
Non carcinogenics	CTUh	3.58E-06	7.03E-07	6.99E-07
Respiratory effects	Lbs PM2.5 eq	4.87E-02	1.38E-02	1.53E-02
Ecotoxicity	CTUe	7.75E+01	1.22E+01	1.40E+01
Fossil fuel depletion	MJ surplus	1.06E+02	1.45E+01	2.34E+01

The reconditioned plastic drum scores lower on most environmental issues than the newly manufactured drum and similar to the newly manufactured drum based on PCR. The exception is ozone depletion, which is mainly caused by the higher inbound transport of the drums to be reconditioned.

5. Conclusions

Reconditioning industrial packaging has environmental benefits compared with newly manufactured ones. The conclusions are discussed per packaging type below.

Open head steel drum
Reconditioning an open head steel drum instead of newly manufacturing it cuts the carbon footprint more than in half. The impact of energy during the reconditioning process is the main contributor to the carbon footprint.

Tight head steel drum
The reconditioning process of a tight head steel drum requires more energy, caustic and acid than open head steel drums. Reconditioning has still a clear benefit on the carbon footprint compared with newly manufacturing this drum. Also other impact categories have a lower score for reconditioned drums than newly manufactured drums, with the exception of fossil fuel depletion.

Tight head plastic drum
Reconditioning a tight head plastic drum reduces the carbon footprint about 25% if compared with a newly manufactured plastic drum. A drum made from PCR has a similar carbon footprint as the reconditioned drum. A reconditioned drum scores about five times better than a newly manufactured drum on several impact categories. The exception is ozone depletion because of the higher inbound transport of a reconditioned drum.

IBC
Reconditioning an IBC has a substantial benefit on the carbon footprint, it is lowered by a factor three. It has also a clear benefit on the other analyzed impact categories.

Reduction
The environmental burden of the reconditioning process can be further reduced by energy reduction programs as the use of energy is the main contributor to the scores of the different impact categories analyzed. The depletion of fossil fuel of the reconditioned drum is higher than of a newly manufactured tight head steel drum.

Green Packaging Calculator
The inventory data is integrated in an Excel based calculator. The Green Packaging Calculator offers a three-step process by which the environmental impact of industrial packaging solutions, expressed in carbon dioxide (CO_2) equivalents, may be determined. Calculated impacts enables RIPA members to select containers and understand the impact on the environment of such selections.

Appendix A Inventory data

Table XX: Comparable companies' XYZ			
Process	Database	Database process	Notes
Carbon steel bars	Ecoinvent 3	‣ Steel, low-alloyed {RoW}| steel production, electric, low-alloyed | Alloc Def, S ‣ Steel, low-alloyed {RoW}| steel production, converter, low-alloyed | Alloc Def, S ‣ Section bar rolling, steel {RoW}| processing | Alloc Def, S	72% is assumed to be from electric steel and 28 % is assumed to be from converter steel.
Carbon steel sheet	Ecoinvent 3	‣ Steel, low-alloyed {RoW}| steel production, electric, low-alloyed | Alloc Def, S ‣ Steel, low-alloyed {RoW}| steel production, converter, low-alloyed | Alloc Def, S ‣ Hot rolling, steel {RoW}| processing | Alloc Def, S	72% is assumed to be from electric steel and 28 % is assumed to be from converter steel.
EPDM gaskets	Ecoinvent 3	‣ Synthetic rubber {RoW}| production | Alloc Def, S ‣ Injection moulding {RoW}| processing | Alloc Def, S	
PCR	USLCI	‣ Recycled postconsumer HDPE pellet/RNA	Dummy processes of USLCI replaced with Ecoinvent 3 processes
Virgin HDPE - injection moulded	USLCI Ecoinvent 3	‣ High density polyethylene resin, at plant/RNA ‣ Injection moulding {RoW}| processing | Alloc Def, S	Dummy processes of USLCI replaced with Ecoinvent 3 processes
Virgin HDPE pellets	USLCI	‣ High density polyethylene resin, at plant/RNA	Dummy processes of USLCI replaced with Ecoinvent 3 processes
Virgin LDPE	USLCI	‣ Low density polyethylene resin, at plant/RNA	Dummy processes of USLCI replaced with Ecoinvent 3 processes
Paint solvent	Ecoinvent 3	‣ Chemical, organic {GLO}| production | Alloc Def, S	
Acetone	Ecoinvent 3	‣ Acetone, liquid {RER}| production | Alloc Def, S	
MEK	Ecoinvent 3	‣ Methyl ethyl ketone {GLO}| market for | Alloc Def, S	

Aromatic solvents	Ecoinvent 3	▸ Toluene, liquid {RER}| production | Alloc Def, S	
HCl	Ecoinvent 3	▸ Hydrochloric acid, without water, in 30% solution state {RER}| market for | Alloc Def, S	
Sodium hydroxide pellets	USLCI	▸ Sodium hydroxide, production mix, at plant/kg/RNA	
Sodium nitrite	Ecoinvent 3	▸ Chemical, inorganic {GLO}| production | Alloc Def, S	
Steel shot	Ecoinvent 3	▸ Steel, low-alloyed, hot rolled {RER}| production | Alloc Def, S ▸ Metal working, average for metal product manufacturing {RER}| processing | Alloc Def, S	
Exterior coating	Ecoinvent 3	▸ Alkyd paint, white, without water, in 60% solution state {RER}| alkyd paint production, white, water-based, product in 60% solution state | Alloc Def, S	
Interior Lining	USLCI	▸ High density polyethylene resin, at plant/RNA	Dummy processes of USLCI replaced with Ecoinvent 3 processes
Natural gas	USLCI	▸ Natural gas, combusted in industrial boiler/US	
Diesel	USLCI	▸ Diesel, combusted in industrial equipment/US	
Propane gas	USLCI	▸ Liquefied petroleum gas, combusted in industrial boiler/US	
Tap water	USLCI	▸ Tap water, at user/RER S	
Electricity	USLCI	▸ Electricity, at grid, US/US	Dummy processes of USLCI replaced with Ecoinvent 3 processes
Truck transport per mile	Ecoinvent 2.2	▸ Operation, lorry >16t, fleet average/RER S	
Truck transport per lbs*mile	Ecoinvent 2.2	▸ Transport, lorry >16t, fleet average/RER S	
Injection moulding	Ecoinvent 3	▸ Injection moulding {RoW}| processing | Alloc Def, S	
Welding	Ecoinvent 3	▸ Welding, arc, steel {RoW}| processing | Alloc Def, U without energy	
Waste water	Ecoinvent 3	▸ Wastewater, average {CH}| treatment of, capacity 5E9l/year | Alloc Def, S	
Other waste	Ecoinvent 3	▸ Municipal solid waste (waste treatment) {GLO}| market for municipal solid waste | Alloc Def, S	

Paint waste	Ecoinvent 3	▸ Waste paint (waste treatment) {RoW}| treatment of waste paint, sanitary landfill | Alloc Def, S	
Furnace ash	Ecoinvent 3	▸ Ash from deinking sludge {CH}| treatment of, residual material landfill | Alloc Def, S	
Sludge	Ecoinvent 3	▸ Inert waste (waste treatment) {GLO}| market for inert waste | Alloc Def, S	
Solid waste	Ecoinvent 3	▸ Municipal solid waste (waste treatment) {GLO}| market for municipal solid waste | Alloc Def, S	
Trash	Ecoinvent 3	▸ Municipal solid waste (waste treatment) {GLO}| market for municipal solid waste | Alloc Def, S	
Remaining waste	SimaPro 8	▸ Curb side collection (waste scenario) {US}| treatment of waste | Alloc Def, S	

Appendix B Data overview reconditioning

		Average IBC	Average OH steel	Average TH steel	Average poly
Electricity	kWh	14.04	2.91	6.03	8.56
Natural gas	cuft	43.69	89.70	115.35	80.71
Diesel	gallon			0.016	
Water	gal	32.97	1.08	11.48	13.91
NaOH Pellets	lbs	0.27		0.33	0.23
HCl 100%	lb			0.49	
Sodium nitrite	Lbs			0.011	
Steel shot	ton		0.000046	0.00031	
Weight exterior coating	lb		0.47	0.60	0.00022
Weight lining	lb		0.32		
Paint usage solvent	gallon		0.0029	0.0022	
Weight acetone	lbs	0.49	0.0090		0.28
Weight aromatic solvents	lbs				0.0053
Waste water	gal	61.73	0.25	1.59	12.38
Sludge	ton	0.017		0.000062	0.02
Furnace ash	ton		0.000053		
Solid waste generated	ton	0.00407	0.00100	0.00083	0.00138
Trash generated	ton	0.00117	0.00074	0.000498	0.00123
Shot dust	ton		0.000082	0.000202	
Paint Waste	Lbs		0.00371	0.081	
Scrap steel	Lbs	23.01	4.67	0.89	
Scrap plastic	Lbs	39.98		0.37	17.95
Other	Lbs			0.32	

Appendix C Data overview newly manufactured packaging

		IBC 275	OH steel 1.2/0.9/1.2	TH steel 1.2/0.9/1.2	Plastic tight head
Electricity	kWh	28.1	2.26	2.26	8.69
Natural gas	Cuft	0.325	41	40.9	1.1
Propane gas	Lbs.	0.081	0.0123	0.00494	0.00248
Tap water	Lbs.	0.667	44.3	42.5	
Aceton – MEK			0.13	0.0241	
HCl solution 50%	Gal		0.000011	0.000011	
Caustic solution 50%	Gal		0.000027	0.000027	
Injection moulded PE	Oz				6
EPDM gasket	Oz				1
Welding	inch	37	36	36	
Exterior coating	Lbs.		0.31	0.23	
Virgin PE		36			21
PCR		6			
Carbon steel sheet	Lbs.		40	36.7	
Carbon steel bars	Lbs.	80.4			

Appendix D Traci 2.1

The Tool for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI), a stand-alone computer program developed by the U.S. Environmental Protection Agency specifically for the US using input parameters consistent with US locations. Site specificity is available for many of the impact categories, but in all cases a US average value exists when the location is undetermined. TRACI facilitates the Characterization of environmental stressors that have potential effects, including ozone depletion, global warming, acidification, eutrophication, tropospheric ozone (smog) formation, ecotoxicity, human health criteria– related effects, human health cancer effects, human health non-cancer effects, fossil fuel depletion, and land-use effects. TRACI was originally designed for use with life-cycle assessment (LCA), but it is expected to find wider application in the future.

TRACI is a midpoint oriented life cycle impact assessment methodology, consistently with EPA's decision not to aggregate between environmental impact categories. It includes classification, characterization and normalization.

Characterization

Impact categories were characterized at the midpoint level for reasons including a higher level of societal consensus concerning the certainties of modelling at this point in the cause-effect chain. Research in the impact categories was conducted to construct methodologies for representing potential effects in the United States.

TRACI is a midpoint oriented LCIA method including the following impact categories:

- Ozone depletion
- Global warming
- Smog
- Acidification
- Eutrophication
- Carcinogenics
- Non carcinogenics
- Respiratory effects
- Ecotoxicity
- Fossil fuel depletion

Normalization

Morten Rybert from the Technical University of Denmark calculated normalization factors for the US and US + Canada. Data from 2008 and 2005 combined with 2008 was used for these reference geographies, respectively. A manuscript is now being prepared for publication at the International Journal of LCA.

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