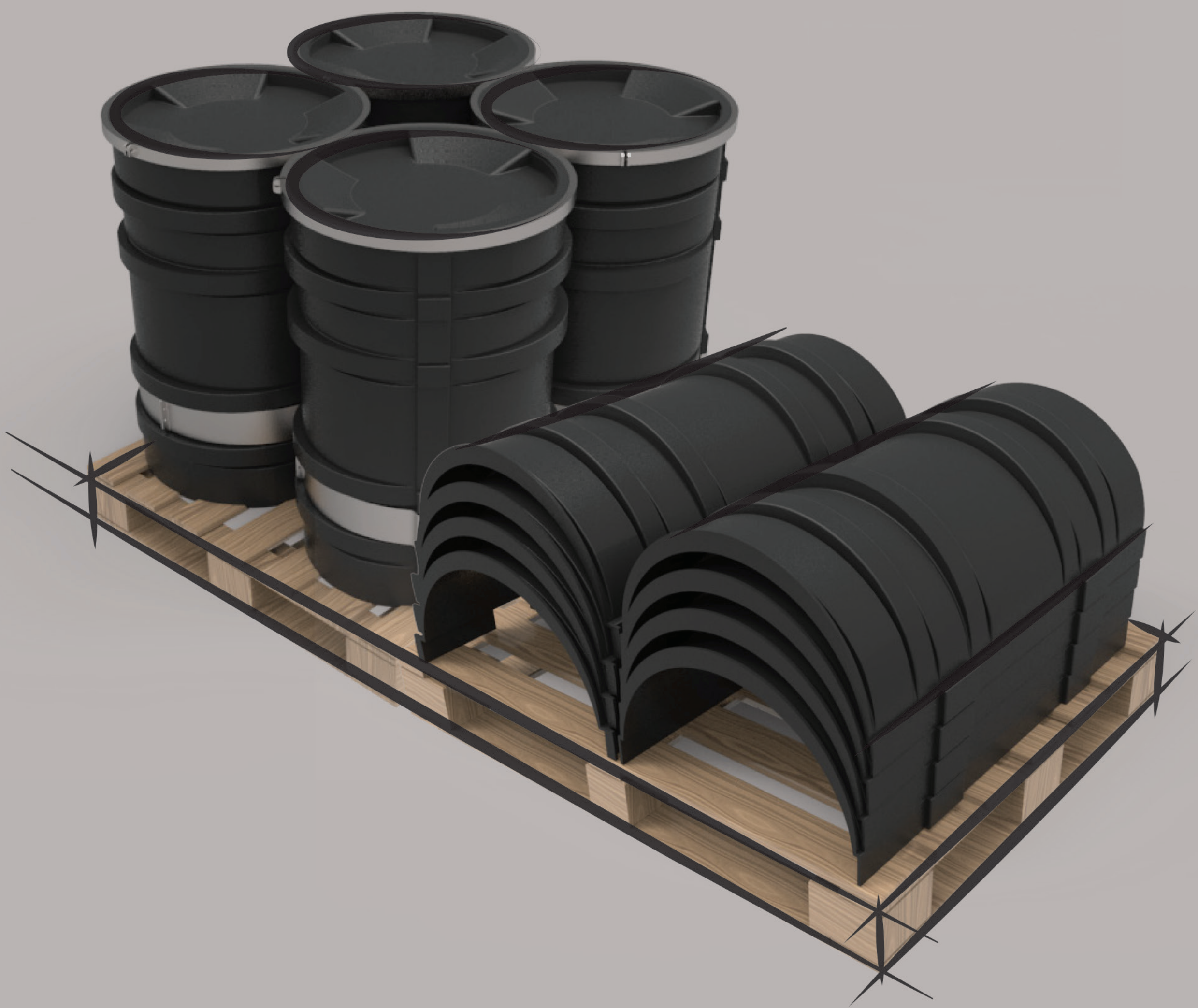

Designing a low carbon footprint drum container

Master Thesis, Integrated Product Design

Kristiina Ranta

August 11, 2017

Master thesis

Designing a low carbon footprint drum container
August 11, 2017

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1. CONTENTS

2. INTRODUCTION

Blue Ocean Containers B.V. approached the TU Delft in search of a student who could design a "low carbon footprint drum container". This container will initially be used to transport fruit juices around the globe. I took it upon myself to explore the possibilities and create a design which provides a sustainable alternative to existing solutions, shown in Figure 2. In particular the most popular packaging type; the 200 liter metal drum, Figure 1.

When designing a new container there are many more issues to consider than only the carbon footprint and environmental impact. Topics which have been addressed during this project include; usability of the drum, the supply chain of drums and juice, return logistics and the reasoning behind industry preferences for specific packaging types.

This report will guide you through the design process. Starting with the analysis phase, in which the current situation and future wishes are analysed. Followed by a conceptualisation phase, in which solutions are created. Ending in the embodiment phase, in which the final design will be elaborated and evaluated.

Figure 1. 200 liter metal drum (Newpig, 2017)

Figure 2. A selection of containers, used to transport juices, varying in shape and material (Alberta Industrial, 2017)

3. GLOSSARY

A list of abbreviations and definitions used within the context of this project.

BOC:	*Blue Ocean Containers B.V.; the project client.* *Part of a diversified group with Maia Global and Sono Global.*
Customer:	*The company which orders juice and decides which packaging is used.*
IBC:	*Intermediate Bulk Container; industrial packaging for transport of 1.000 - 3.000 liters of liquid.*
HDPE:	*High-density polyethylene, the material most plastic drums are made of.*
Hugger:	*A tool placed on a forklift which grabs hold a drum around its body.* *Also referred to as a grabber. (see chapter: Cold storage)*
Maia Global:	*Supply chain logistics company for temperature sensitive products.* *Part of a diversified group with BOC and Sono Global.*
Nesting:	*Stacking of empty containers, one inside another.*
NFC juice:	*Juice which is not from concentrate. Has a higher density than concentrate juice.*
Orca:	*The main product of Blue Ocean Containers; a flexible container for +/- 1.000 liters of liquid.*
Payload:	*The load carried by a vehicle exclusive of what is necessary for its operation.* *For example: the weight of the juice in a container, excluding the weight of the container*
Pincher:	*A tool placed on a forklift which grabs hold of the rim of a drum to pick it up.* *Also referred to as a claw or hook. (see chapter: Cold storage)*
PP:	*Polypropylene*
Reefer:	*A transport container with an active cooling system (refrigerated). Typically 40 foot long.*
Return ratio:	*The volume reduction of empty (nested) drums compared to full ones.*
Sono Global:	*A company which trades and produces fruit juice.* *Part of a diversified group with BOC and Maia Global.*

4. PROCESS STRUCTURE

This graduation project started with Blue Ocean Container's wish for a new drum container. The goal was to provide a sustainable alternative for the commonly used metal drum. The steps of the design process are illustrated below.

Design brief

Design a low carbon footprint drum container for Blue Ocean Containers. To be used for the transport and storage of juices

Appendix: Assignment

↓

ANALYSIS

Blue Ocean Containers

Together with Maia Global, the company aims to create efficient supply chains with a minimal carbon footprint.

Chapter: Company analysis

Supply chain

The current container travels long distances in its lifetime, during multipe lifecycles. Many different stakeholders are inolved.

Chapter: Supply chain

Competitors

Very little innovation takes place in the drum market. The metal drum is the industry standard.

Chapter: Brief competitor analysis & Existing products

Use environment

It is preferred to use the existing handling equipment. Stackability is very important for efficient storage.

Chapter: Use environment

Sustainability

The focus will be on reducing the environmental impact, looking at the entire lifecycle.

Chapter: Sustainability

CONCEPTUALISATION

Requirements

The discovered requirements and wishes for the new design are listed here.

Chapter: Design requirements

Ideation

Solutions have been created for the desired function of the drum.

Chapter: Product level ideation

The larger system

During this exercise we zoom out and take another look at the system which the drum is a part of. RFID tags are promising.

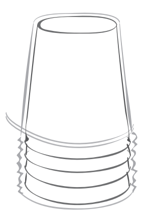
Chapter: System ideation & The future system

Concepts

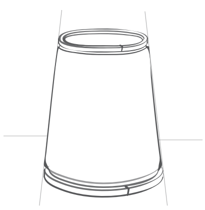
Concepts have been created which combine the function based solutions.

Chapter: Initial concept development

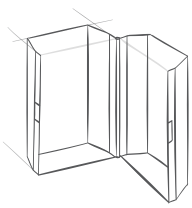
The no liner
(elimates the use of plastic liners inside the drum)



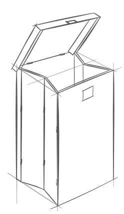
Upside down drum
(very stable and nestable)



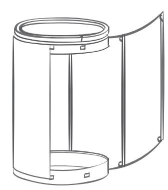
Clamshell
(folds open for compact nesting)



Collapsible crate
(rectangular container folds very compactly)



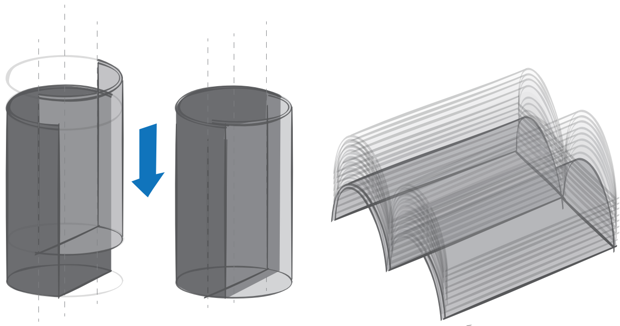
Wrap around drum
(the flexible wall is detached when empty)



Concept choice

At this point of the design process, a decision is made to focus in more detail on only one of the concepts. This is an improved version of the clamshell concept.

Chapter: Comparison of concepts
& Improved concept



EMBODIMENT

Production technique

I chose to create a twin sheet thermoformed HDPE drum

Chapter: Production technique
& Cost price estimation

Shape iterations

The shape of the drum will be embodied futher, to create a functional design.

Chapter: Shape iterations
& Producible shape

Transport scenario

In this loading of drums in transport containers is explored.

Chapter: Transport scenario

Measured carbon footprint

An estimation is made of the carbon footprint of the new design.

Chapter: Carbon foorprint

SolidWorks simulations

Initial calculations are made to evaluate the feasibility of the design.

Chapter: Mechanical calculations

Final design

The new design is a thermoformed drum. The mainly selling points is its improved return ratio.

Chapter: Final design

EVALUATION

Conclusions

The design will be evaluated base on the main requirements/criteria.

Chapter: Conclusion

Recommendations

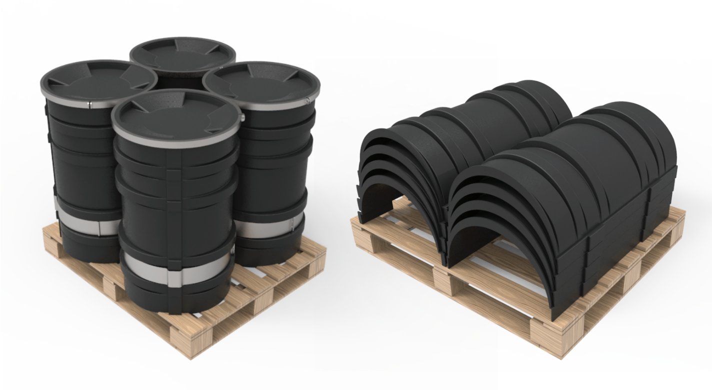
I will give recommendations for the further development of the drum.

Chapter: Recommendations

Reflection

I will reflect on the design process and project in general.

Chapter: Reflection



Takeaway

Short on time?
These orange "takeaway" notes will guide you through the highlights of the project.

Analysis

In this chapter, the results of analysis phase of the design process are presented. The current situation has been investigated; looking at existing solutions and the current supply chain of drums and juice. The goal is to find what the current problems and requirements are, to be able to determine how value can be added with a new design.

Figure 3. Empty containers outside the Kloosterboer cold storage in Rotterdam

5. COMPANY ANALYSIS

In this chapter, the client; Blue Ocean Containers B.V. will be introduced. The company has been analyzed briefly in order to gain more insight into the design context, as well as to define the initial goals and requirements set by the company for this design assignment.

About Blue Ocean Containers

Blue Ocean Containers B.V. (BOC) is a provider of high quality bulk packaging. The company strives for competitive prices, while reducing the environmental footprint of liquid bulk transport. The core activities of the company include the design and engineering of intermediate bulk containers, also called IBCs. These are currently produced by a partner in Thailand (BOC, 2017). This category of containers is described as; industrial packaging with a maximum capacity of 3000 liters, designed for transport, storage and mechanical handling (BusinessDictionary, 2017).

The founders of BOC have been involved in bulk liquid packaging and logistics since 2002 and in 2011 started actively operating with their main product the Orca container, shown in Figure 4. The Orca is a lightweight, flexible polypropylene container, which can be folded up to save space when empty. This design drastically decreases the volume and weight in transport, especially when empty and sets it apart from competitors (see Chapter: Existing products). These characteristics make it suitable for a return logistics system.

Currently the core team at BOC consists of two persons, operating in Rotterdam, working on optimizing the current product and operations. The company is keen to reduce the carbon footprint of its products by means of geometry, usability and product life cycle, together with other companies with whom they form a diversified group.

Figure 4. BOC's main product; the Orca. Right: 16 folded Orcas fit on one Europallet (BOC, 2017)

Diversified group

BOC is part of a diversified group (see Figure 5), which is active in the production of fruit juice, packaging and supply chain solutions. This provides the possibility to engage internal users and implement new container designs quickly.

Maia Global is specialised in the management and optimisation of temperature sensitive supply chains. Whilst Sono Global are fruit juice traders and producers

SONO GLOBAL

TRADERS AND PRODUCERS OF FRUIT JUICE

MAIA | GLOBAL

TEMPERATURE SENSITIVE SUPPLY CHAINS

boc | blue ocean containers

PACKAGING DEPARTMENT OF MAIA GLOBAL

Figure 5. Members of the diversified group and their focus (Sono Global, 2017)

PRODUCT PORTFOLIO

ORCA

Figure 6. The Orca in different phases of use (BOC, 2017)

VEGGY

Figure 7. The Veggy in different phases of use (BOC, 2017)

AUXILIARY EQUIPMENT

HEAT IT **DRAIN IT** **STACK IT** **SQUARE IT** **STRAP IT**

Product portfolio

BOC has two main container types; the "Orca" for the transport of liquids (shown in Figure 6) and the "Veggy" for fresh produce like fruit and vegetables (see Figure 7).

The Orca is a lightweight polypropylene "bag" with reinforced panels for rigidity. The black loops at the top allow for the container to be lifted without a pallet. An additional food-grade plastic liner is used inside the Orca, to prevent contamination. When empty the container can be folded up to save space.

Two different sizes, 1.000 L and 1.150 liter are available. There is also a variant with a bottom discharge, eliminating the need for a tipping machine to empty the contained liquid. Making it suiable for more handling locations.

The Veggy, available in four different sizes, has a similar structure to the Orca. The main difference is that it is perforated, allowing the contents to "breathe".

BOC also provides custom made auxiliary equipment for maximum performance of their products. These include heaters to melt frozen content and metal frames to be able to stack the containers.

Container pooling

BOC's containers can economically be used as disposable packaging after a single trip, due to the low manufacturing costs (BOC, 2017). Using disposables removes the need for customers to track and trace assets.

However the containers can also be returned to BOC, for reuse, which reduces waste from discarded containers (Figure 8). Customers can lease a container, for a rate lower than the purchase price. In many cases this is the cheaper option for the customer, as shown in Figure 9. Depending on quantities and location.

These containers enter a pooling system; they are collected from customers by a third party or returned to BOC by the customer. A third party inspects and cleans the containers. There are current two locations where this is done, in Belgium and the east coast of the US. The containers which are in good condition re-enter the supply chain for reuse. If this not directly possible, they are refurbished or recycled. Inner liners, which must be of food-grade are not reused (Lutzu G., 2017). Similar pooling systems of reusable containers, to replace cardboard boxes, have proven to be operating successfully in Germany for many years already, partially due to strict environmental legislation (Kroon, L. and Vrijens, G.,1995).

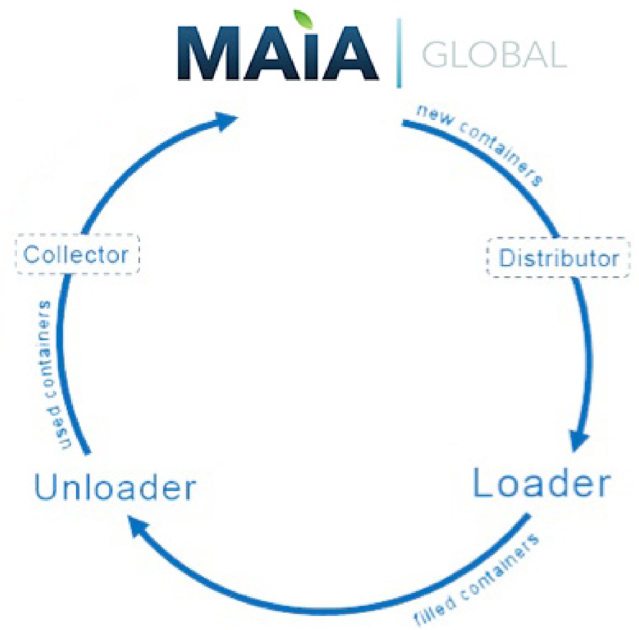


Figure 8. The cycle of containers (BOC, 2017)

Within the pooling system Maia Global aims to optimise the customers supply chain by:

- Working with customers to manage their packaging forecasts.
- Providing bundled delivery of the Orca and the single use packaging (like inner liners + aseptic bags).
- Working with and guiding loaders to ensure the load is optimised based on the destination.
- Managing the collection & de-hire process for the final customer.

Assignment

Currently Maia Global encourages customers to use Orca packaging, however if the customer does not want this, they provide 200 liter drums. These drums are ordered by Maia Global from an external company. They have not been designed or produced by BOC.

BOC is looking for a new design of their own, which can compete with these drums. The main differentiating factor which is desired for this design, is a lower carbon footprint. Initial wishes include decreasing the volume of empty nested drums, whilst maintaining stackability when full.

Takeaway

Blue Ocean Containers, as part of a diversified group, aims to create optimized supply chain solutions; which are cost efficient, whilst reducing the environmental impact. This is achieved with products with low manufacturing costs, which are lightweight and foldable; decreasing the volume in transport. A pooling system has been created in which used containers are returned and reused. The current portfolio is missing a direct alternative, however with a lower carbon footprint, for the 200 liter metal drum which is the most popular packaging type in the industry.

Less packaging weight allows more cargo payload (higher ratio of juice vs. packaging material)
& Reduced shipments
+ Use of rental packaging leads to lower packaging costs & less waste
=
Achieving improved margins & reduced carbon footprint

Figure 9. Ideology of BOC

6. DESIGN ASSIGNMENT

Blue Ocean Containers approached the university for a student to design a new drum container with a reduced carbon footprint. In this chapter the design assignment will be elaborated.

Assignment

Currently Maia Global encourages their customers to use reusable packaging, preferably the company's own Orca packaging. This is done to cut down costs in transport, as well as lower the carbon footprint of the supply chain. However, if a customer does not want this, Maia Global provides +/- 200 liter reusable plastic drums. This is the N55 drum by U.S. Coexcell) (Figure 10). Maia Global prefers this drum over others, due to the high return ratio, meaning that more empty drums can be transported in a container (Lutzu, G., 2017). This also makes the drum more suitable for reuse (read more in Chapter: Supply chain). This is because these drums can be nested, without rusting together (read more in Chapter: Existing products).

If a customer is reluctant to use plastics drums, due to reasons explored in Chapter: Product life cycle, metal drums are provided. The metal drum is the standard in the juice industry and has been used for many years (Lutzu, G., 2017). The plastic drum however is seen as a more sustainable alternative to the metal drums (see Chapter: Sustainability).

Maia Global would like to be able to provide customers with an improved version of the N55 drum, a drum with a low carbon footprint compared to the metal drum. This drum will be developed within the Blue Ocean Containers department of the diversified group. Preferably this would be a patentable design, giving the company a sustainable competitive advantage.

Figure 10. The currently used plastic drum container N55 (U.S. Coexcell, 2017). On the left two drums are nested.

55 gallons

When designing packaging with a reduced carbon footprint, an obvious strategy is reducing the amount of packaging material used. This can be achieved by using packaging with a larger content, in this case: more juice per container. The external surface, which requires packaging of 4 volumes of 250 liters is higher than 1 volume of 1.000 liters. However, Maia Global wishes to introduce a packaging (drum) with a volume of +/- 205 liter (55 gallons). Because this is the industry standard.

Many customers make blends using this unit in their juice blending recipes (West, P., 2017). When customer makes a mixed fruits juice, a drum of pineapple and two drums of orange juice, it is not desired to open an extra large package (with a volume of 4 drums) of juice and close it again. Juice can get contaminated in this process. Also, handling equipment, such as the most common juice dumping devices, are design for the dimensions of a standard 55 gallon drum.

Limitations of the Orca

The current packaging of BOC; the Orca, seems like an ideal solution, which could easily be adopted as a solution to this assignment. By creating a "mini Orca", with a smaller content. However, the Orca has limitations which should be addressed in the new design. The main limitation being that Orca can not be stacked. For this reason the new design will be created from scratch. For more requirements see Chapter: Design requirements.

Takeaway

Maia Global wishes to design their own alternative for the N55 plastic drum which they currently use. This project will be an exploration of the possibilities. The drum should have a content volume of 55 gallons; an industry standard, used for juice blending recipes and a suitable size for the most commonly used handling equipment. The unique selling point of the drum will be the reduced carbon footprint. A way to achieve this, which is currently done with the Orca, is a high return ratio (low empty volume). The new design should address the flaws of the Orca and the N55 drum.

7. SUPPLY CHAIN

The lifecycle of a container is closely linked to the supply chain of its content; what is inside the packaging, juice. In this chapter the supply chain of juice and containers will be explored, based on information provided by Maia Global. A simplified illustration of the current supply chain has been created (Figure 11) and will be used to describe the process.

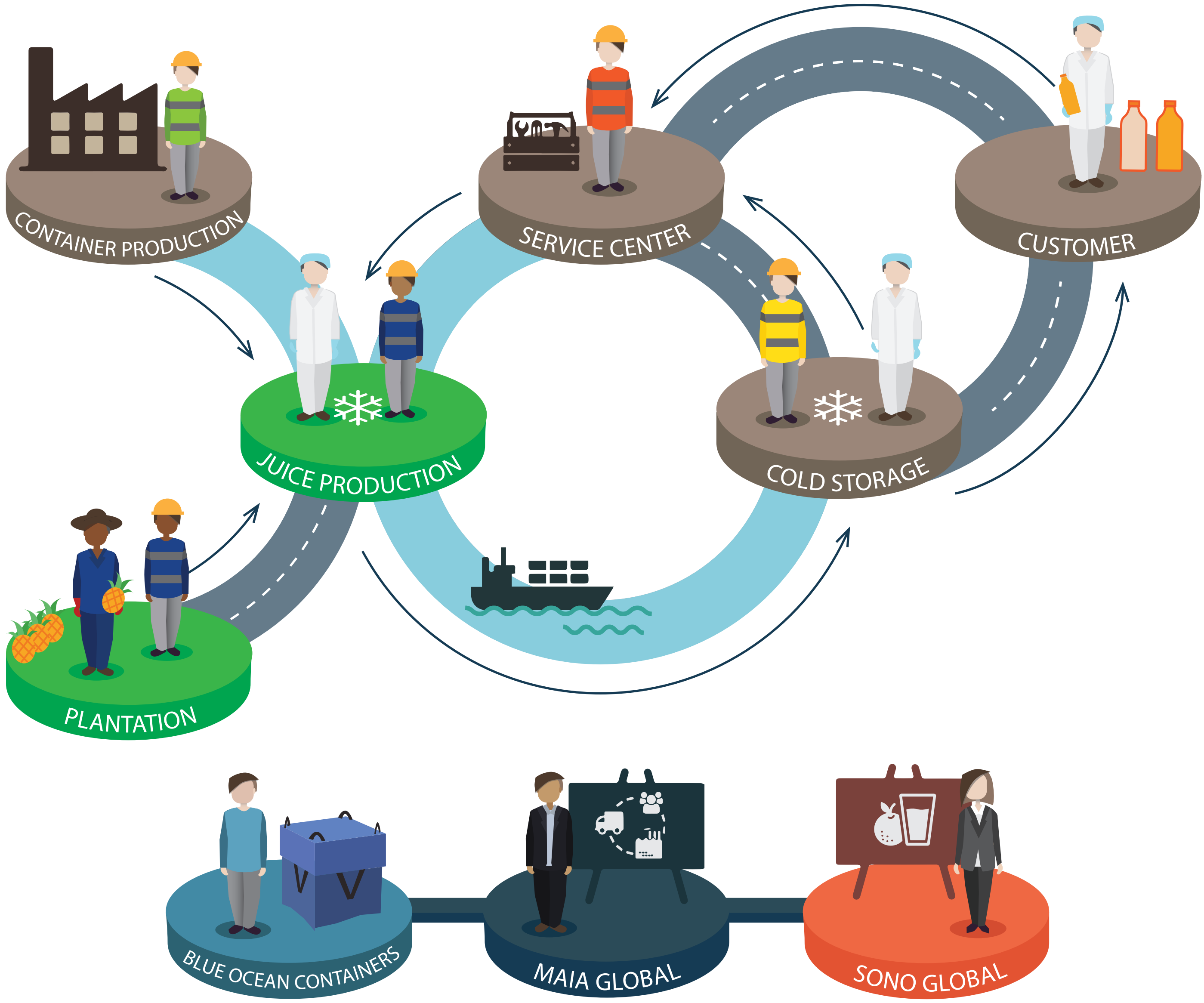


Figure 11. The current supply chain of juice and containers. The arrows indicate the transport direction of containers.

Scenario used throughout the project

Throughout this project the example of fruit juice transport will be used, as this is what Maia Global mainly transport in BOC containers and other drums. Also because packaging juice sets strict requirements about food safety, currently resulting in the use of a plastic inner liners (see Chapter: Existing products). However other contents may also be interesting to transport in the new design.

Scenario in this chapter

The supply chain which will be described is that of pineapple juice from Ghana, which is bought by a customer in Europe. The packaging used is Blue Ocean Containers' own Orca. This is a typical situation for Maia Global.

This illustration can also be used in other scenarios, the steps are always similar, however the location in the world is different. For example; the illustration can be used for the supply of apple juice from China to a customer in the United States, where the service center is in Newark. The current supply chain may also be suited for the new design.

Initiation of the process

Containers are required if a customer (Figure 11, top right corner) orders juice. The customer receives juice from Maia Global in IBCs. The customer himself is responsible for the blending and bottling of juice, before it becomes a consumer product in the supermarket (Figure 13). Customers include Prodalim, Ariza, Niederrhein Gold and Döhler.

Maia Global organizes the logistics of the supply chain for the customer. Sono Global provides the juice. Maia Global prefers to use Blue Ocean Containers' Orca container, unless this is not possible or desired by other parties. The customer makes the final decision.

The types of juice order demand are explored in chapter: System ideation. Some customers periodically order large quantities, whilst other fruits are available seasonally.

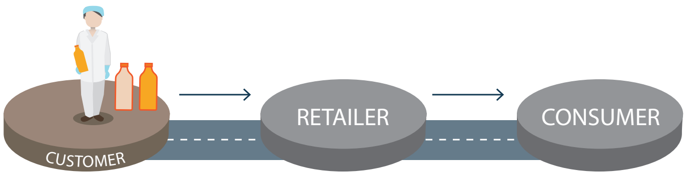


Figure 13. The following steps in the supply chain are outside of the scope of Maia Global.

Lifecycle of containers

Orcas are produced in a factory in Thailand (Figure 11, top left corner). From here they are shipped to the juice producer in Ghana, where juice is produced from pineapples (see chapter: Plantation). The fruit is sometimes grown at another location than where the juice is produced.

The containers are filled with juice and shipped to Rotterdam, the Netherlands. The ship arrives at the harbour of Kloosterboer cold storage. Here the containers are unloaded from the ship and stored (read more in Chapter: Cold storage). Once the juice has been emptied out of the Orca into juice blending tanks, either at the cold storage or at the customer, the Orca is transported to the service center in Turnhout (Belgium) for reuse. At the service center, the Orca is inspected, cleaned and repaired if necessary. From here the Orcas are shipped to the next juice producer.

The specific steps in the product lifecyle will be discussed in detail in Chapter: Product life cycle.

Empty containers

In the supply chain containers are not always full of juice, they are often empty in transport and storage (Figure 12). The Orca allows for efficient use of space when it is empty unlike some competitors (see Chapter: Existing products). The current plastic drum is nestable however still has a relatively high volume. By focusing on the decreasing the volume in storage and transport savings can be made. Storage space costs money, as does the transport of volume. In this way the environmental impact could also be reduced. Read more about this in Chapter: Sustainability.

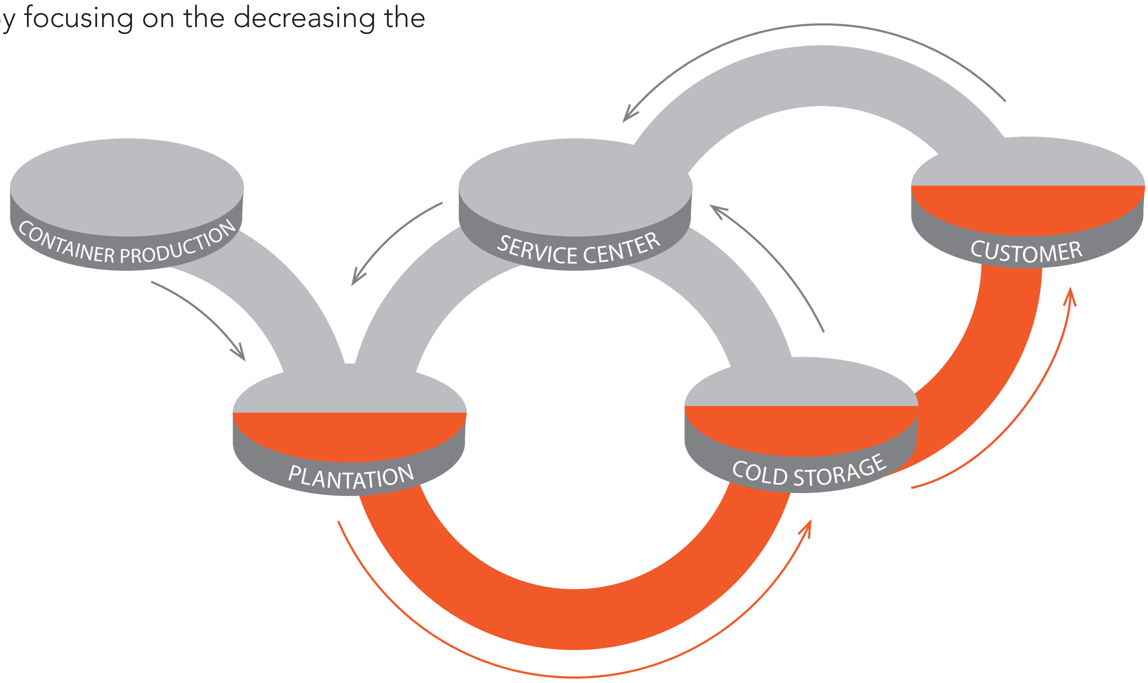


Figure 12. Orange indicates where in the supply chain containers are full of juice. In the grey areas containers are empty.

Pooling system

Maia Global keeps track of their 15.000 Orcas which are in circulation, in their pooling system for reuse. They know how many new Orcas enter the cycle, as well as roughly at which phase they are in the cycle, when a party confirms they have received a delivery. Maia Global also knows the condition of the containers when they arrive in at the service center (see the different drum conditions and other types of information in the supply chain which can be valuable, in Chapter: System ideation).

However also 10.000 Orcas have been sold directly, outside of the pooling system. Maia Global currently also uses metal drums, as disposable packaging (no reuse). The plastic N55 drums are often included in the pooling system for reuse.

Similar plastic drums are also supplied to customers by another company named TradeWork, in a different type of reuse system. TradeWork brands their containers ("Property of TradeWork" is painted on it) and collects them back at the cold storage and customer, sending them directly forward to a juice producer, without inspection or cleansing, as illustrated in Figure 14.

The benefits of having passing the new drum design through the current service center, instead of going directly to the next juice producer, as TradeWork does, are that:

- The quality of the drums which are delivered to the juice producer can be ensured. Unusable drums do not get shipped all the way to Africa. Also the juice producer can rely on Maia Global for good quality drums.

- The amount and approximate location of drums can be tracked, without requiring an update to be sent by the cold storage or customer. This prevents drums from going missing and creates insight into whether more should be produced.

- The plantation or cold storage do not have to cleanse and inspect the drums. The quality checks are done by personnel who know what to check for, as they work with the product frequently.

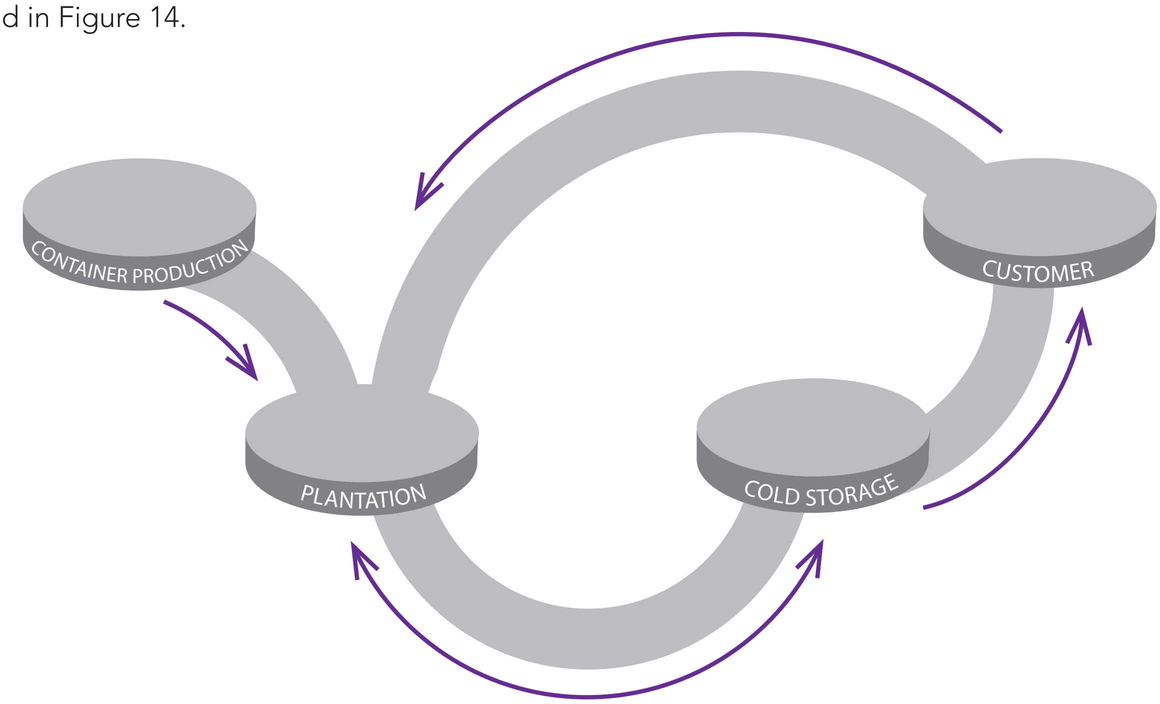


Figure 14. The return system used by TradeWork. There is no service center, the drums are directly transported to the next juice producer.

Ideal drum for reuse

Not every container is suitable to be used in a sustainable way in a pooling system for reuse. Existing drum types are explored in Chapter: Existing products. And guidelines for an ideal reusable drum are given in chapter: Ideal reusable drum.

Takeaway

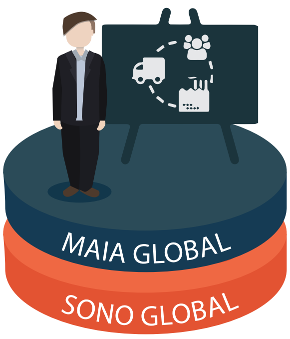
During its lifecycle the container travels long distances and visits many different locations where it is handled or stored. Focusing on the volume reduction by nesting of empty containers is an important aspect when working with a reverse logistics system. This can save fuel costs (less trips) and is also better for the environment. The existing service centers could be used for the new design as well. In a reuse system, passing the drums through a service center instead of directly sending them to the next client allows for better insight into the state of the inventory as well the quality which you can provide to your customers.

8. STAKEHOLDERS

As introduced in the previous chapter, there are many stakeholders involved with the new product in different phases of its lifecycle. Their most important motives and wishes have been gathered in this overview. The input for this overview has been gathered from information provided by Maia Global, Sono Global and Blue Ocean Containers, as well as a guided tour by an employee of a cold storage. The results have also been used to formulate design requirements in the Chapter: Design requirements.

The customer wants to be assured of the **quality of the juice** they order, for the most **competitive price** for the packaging and logistics. Order **quantities vary**, sometimes a 20.000 liter tank-truck is desired, other times this is far too much. The customer may not have the facilities to store juice, therefor the **moment of delivery** is important. The customer charges Maia Global storage fees. The container must be **compatible with the devices** they own (forklifts, dumping).

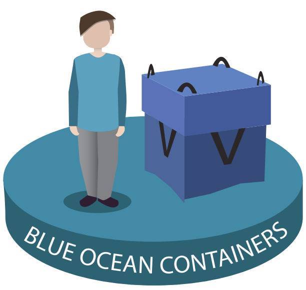
Sustainability is valued to create a positive company image and to comply with regulations in the industry (Mann, H. ,2010). For a customer the advantage of using reusable packaging is the **lower investment cost** (instead a reduced fee is charged per use). Also the packaging is always up to date and the latest model and of good quality; as it has passed through the service center.



Sono Global aims to sell as much of their product, juice, as possible. To provide competitive prices, Maia Global (member of the diversified group) aims to optimise **supply chain efficiency**. Efficiency in logistics often goes hand in hand with **carbon footprint reduction**, as it can result in fuel savings. The goal is to cut down costs from different parties in the supply chain, concerning; **transport, storage and handling**. This is where the design of the new container can play a role.

The price for the customer is determined by the **quantity of juice** which is transported, for example as a price per 1.000 liters. If more juice can be transported in the same space in a truck, higher margins can be made.

Due to the return system of containers, the **tracking of containers** is important. To be aware of where they are and in which condition. If necessary a damage fee is charged. It is also useful to be able to forecast the availability, for new orders.

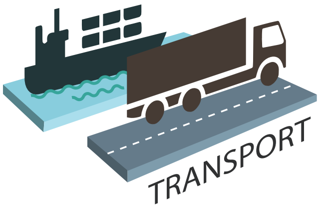


Blue Ocean Containers (BOC) products are used by Maia Global, they are also part of the diversified group. BOC products aim for **cost-efficiency, sustainability, customer/handler satisfaction**. The company is continually improving their current product and wishes to create a new innovative drum container. They are open for customers outside of the usual Maia Global and Sono Global clientele.

The handlers at the cold storage are willing to do what the customer asks, however this is reflected in increased handling costs. They wish to minimize their risks by using proven packaging, such as the metal drum which has been around for many years. The lowest handling costs are achieved by a design which can be **handled with current devices**, has a **low volume in storage**; stacked when full and nested when empty. The more frequently empty bins are collected the less storage costs need to be payed. Read more about the demands from the cold storage in Chapter: Cold storage.

The circumstances at a plantation and juice producers are often less advanced than in the other steps of the supply chain. At some plantations **drums are moved manually**, if the customer does not own a forklift. In these cases packaging with a maximum volume of 200 liter is used . Read more about the plantations in Chapter: Plantation.

The service center is also willing to do what the Maia Global wishes, however this is reflected in the costs. To make the functioning of the service center most efficient, the design should address topics such as; making the **inspection, cleansing and maintenance** of the drums simple as possible.



Between each step in the supply chain transport takes place. Containers are **loaded and unloaded**, this should be simple and fast, preferably **not requiring additional materials**, such as a plywood board which is currently placed between Orcas, or plastic wrap. **Fuel costs** should be minimised, by fewer trips or lighter products/lower volume.

The chosen container producer must be capable of delivering the desired quality of product for a convenient price.

Other stakeholders include:

- The environment: Everyone benefits from less pollution, read more in Chapter: Sustainability.
- Government: Regulations exist with regards to packaging, for example with regards to food safety, read more in Chapter: Design requirements.

9. BRIEF COMPETITOR ANALYSIS

Blue Ocean Containers and Maia Global have many competitors. Competing companies are present on all levels of operation. These levels and the companies will be introduced in this chapter.

Levels of operation

Worldwide there are many companies operating in the supply chain of juice. The diversified group which Maia Global and BOC are a part of (together with Sono Global), operates on four main levels (Maia Global, 2017):

- Packaging designers: BOC has their own packaging type; the Orca. This packaging is currently being improved based on feedback from users. BOC packaging is not exclusively used by Maia Global, external packaging orders are also accepted.
- Juice logistics: Maia Global is involved in organizing and managing the cold supply chain of juice. Where possible BOC packaging is used, however other packaging suppliers/designers are also used.
- Juice traders: Sono Global focuses on buying and selling juice. From multiple plantations for numerous customers. Once juice has been ordered, the logistics are arranged by Maia Global, or the logistics company of choice.
- Juice producers: Sono Global also owns a couple plantations where fruit is grown and juice is produced, exclusively for Sono Global clients.

Within each level of operation auxiliary companies/partners, are used. These include:

- Transport companies: These companies transport containers/Reefers, by sea, road or rail.
- Cold storages: These are cooled warehouses who mainly store drums. Some cold storages also create juice blends. Read more in Chapter: Cold storage.
- Service center: These companies store, inspect, cleanse and repair empty drums, so that they can be reused. Maia Global works with two service centers; one in Belgium, the other in the United States.

Competitors

The diversified group which Maia Global is a part of, is not unique. Integrating the different levels of operation within one company is common. Although some companies are specialized in one level and work together with others to complete the supply chain. This can be seen in Figure 15, where companies have been plotted to illustrate which levels they operate in.

To give an indication of the scale of the competitors, some of the largest companies, who are also present in the European market, will be introduced briefly. Citrosuco is the largest orange-juice exporting firm worldwide. It produces 40 percent of Brazil's orange juice output (Citrosuco, 2017). Louis Dreyfus Company accounts for 15 percent of global orange juice production (LDC, 2017). These large companies manage their own entire supply chain of juice.

Many smaller players, such as Maia Global, are also present in the industry. The main competitors identified by Maia Global are CHEP, DB Schenker and Goodpack (West, P., 2017). As an indicator of the company size, the previous year profits were; Maia Global £140.000, CHEP £12.776.820.000, DB Schenker £768.320.000 and Goodpack £40.000 (Zdravkova, A., 2017).

Packaging designers

As mentioned in the previous chapter, Maia Global does not only use BOC packaging. When it comes to packaging services, there is a strong degree of rivalry and the costs of switching between suppliers are low (MarketLine, 2017). The pros and cons of different types of packaging currently on the market will be explored in the next chapter.

Metal drums, which are the industry standard, are produced and supplied by numerous companies, as are plastic drums. There is very little differentiation in the designs. However, in the market of larger packaging, so called IBCs, the packaging is more differentiated, patented and linked to a specific supplier brand name.

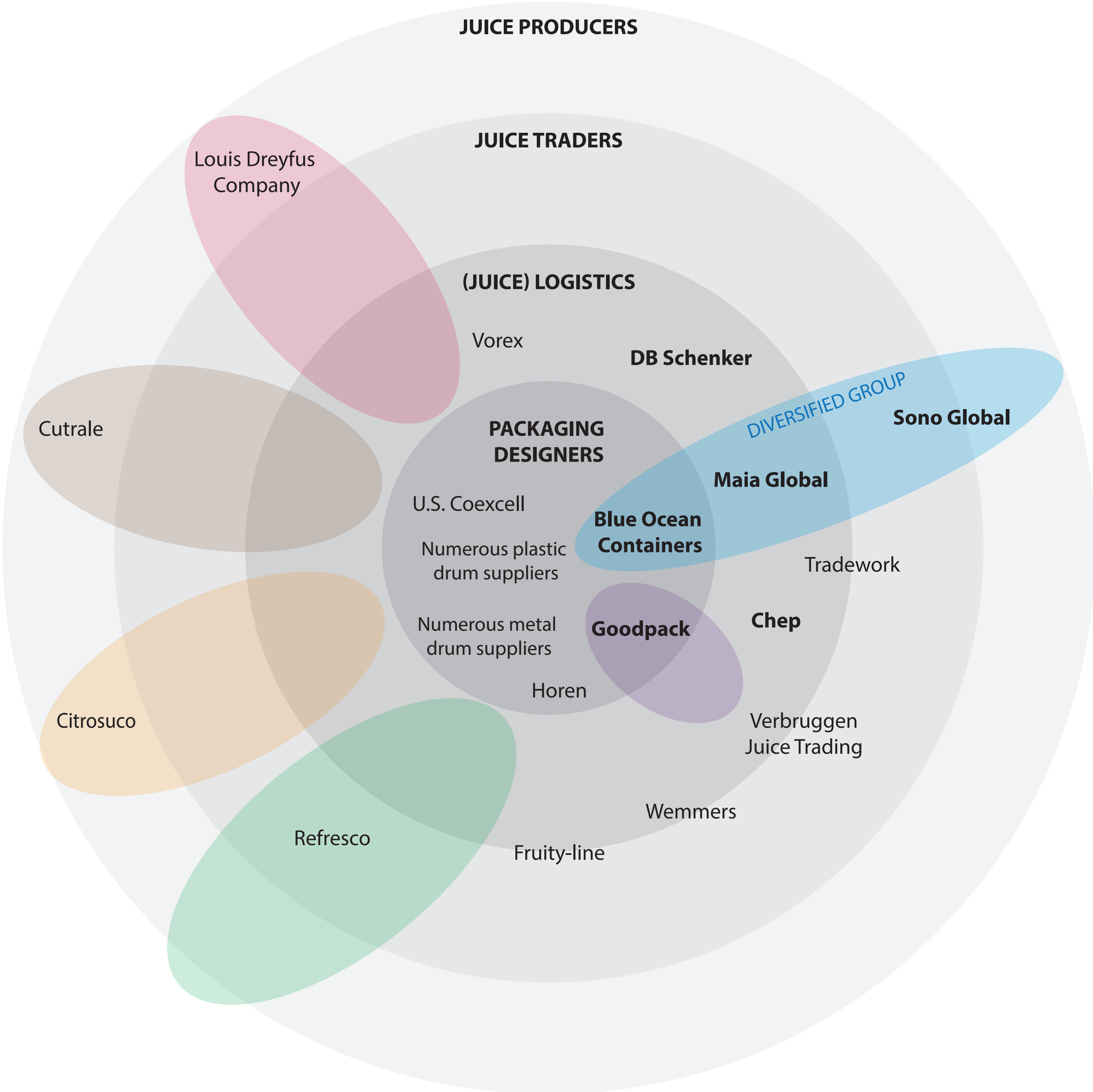


Figure 15. Competing companies in the juice market

Takeaway

There is a lot of competition on all levels of the juice supply chain industry. Maia Global is a small player in this field. By having an integrated packaging design department (BOC), experiences from all phases of supply chain can be explored during product development. Without depending on external parties, in this way a patentable design can be kept secret. The new design is not limited to only be used for Maia Global operations, similar to the Orca. This increases the potential market size of the new drum. Exact figures are not yet available.

10. EXISTING PRODUCTS

The goal of this competitor analysis is to explore which packages are currently in the market and the attributes of these designs which are appreciated or cause problems.

Current situation

The new drum design will have competitors on multiple levels, as illustrated in Figure 16. The most direct competitor is the plastic drum which is currently used by Maia Global. This is the U.S. Coexcell N55 drum (referred to as the N55). Why not carry on with business as usual? There are multiple reasons for BOC to desire a new drum:

- Sustainability: Companies in the shipping industry are more and more interested in the environmental impact of their processes. Companies are proud to promote new achievements in the field of sustainability (Mann, H. ,2010). This creates a demand for sustainable products, beyond BOC's own intrinsic moral values.

- Economics: Decreasing the weight of a drum and the nesting volume, are topics which have high priority. These can significantly decrease shipping costs.

- Innovation: The designs of current drums are all quite similar, this is a very conservative market. This poses an obstacle, which can to a small extent be overcome by deploying the new drum to Sono Global (part of the same diversified group) customers. Due to this lack of changes over time, there are many possibilities for innovation. Maia Global is willing to implement differentiating new designs and promote these to their customers, if they meet their demands.

- Handling: The current N55 drum has some issues during handling, such as the lid popping open unwantedly (read more in Chapter: Product life cycle). The new drum could exceed the N55 in ease of handling.

Drum containers

Direct competitors include drums made of other materials besides plastic (Cary Company, 2017). Plastic drums are analyzed later in this chapter. The most commonly used drum is the metal drum. This is the standard option and often easily be locally sourced nearby the juice producer. However its main negative points are its weight and vulnerability to rusting and denting. Different types of coatings can be used to prevent corrosion (Subramanian, N, 2008), however these contribute to a harmful environmental impact. The conical metal drum (which is less common) sometimes nests so tightly it is difficult to get loose, especially if it starts rusting. This makes it unsuited for reuse.

Paper board drums are also used to transport liquids. These are very light and inexpensive, however they are vulnerable to external moisture and difficult to handle. The commonly used devices can not get a grip of the drum.

Large intermediate bulk containers

The IBC is also a competitor of the new design. A costumer may choose to package their product in a larger container. There is quite some variation in the field of IBCs:

- Materials: Some materials are best suited as disposable packaging as they are very inexpensive however not durable (cardboard, wood). Others are suitable for reuse and have a higher purchase price or are offered in a pooling system (steel or durable plastic). The Orca stands out as it is very inexpensive yet reusable.

- Collapsible: Some designs can easily be folded up to decrease the volume when empty.

- Stackable: Not all designs can be stacked when full (the Octabin and Orca), this is seen as a strong disadvantage in storage.

COMPETITORS IN BULK LIQUID PACKAGING

CURRENT SITUATION:

blue ocean containers

- NEW PRODUCT -

NEW DESIGN VS. THE CURRENLY USED U.S. COEXCELL N55 DRUM

DIRECT COMPETITORS: DRUM CONTAINERS

Metal drum (standard & conical)

+ can often be sourced locally
(if not, the conical drum is preferred as it can be be nested, however they sometime get stuck in nesting)
+ inexpensive
+ customer can sell it as scrap metal
- vulnerable to rust and denting
- heavy

Plastic drum

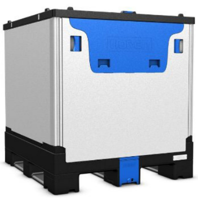
+ nestable without airlocking/getting stuck
+ lightweight
- less widely available than metal drums
- problems with lid closure

Paperboard/fiber drum

+lightweight
+ inexpensive
- can not be handled with common devices
- not nestable
- vulnerable to external moisture

INDIRECT COMPETITORS: INTERMEDIATE BULK CONTAINERS (IBC) WITH A HIGHER CAPACITY

Flexible IBC, BOC's Orca



Plastic foldable (Horen)

Metal cage

Steel container (Goodpack)

Wooden crate

Cardboard (Octabin)

Figure 16. Competitors (Cary Company, 2017) (BOC, 2017) (Goodpack, 2017)

Bulk containers

Juice can also be transported in much larger containers of 20.000 liters (Figure 20). This saves a lot of packaging material. However this quantity is too large for most customers. Also the truck, specifically design for transport of liquids, is often driven back empty. The container of the Flexibag can however be transported back with another non-liquid content (Figure 18). However the Flexibag does not currently work well in an active cooling Reefer. It is possible to transport a cooled juice in a Flexibag, in an insulated container, for a limited amount of hours, without the temperature rising too high.

Figure 20. Tank-truck (Transway, 2017)

Figure 19. Isotank (Tanksupply, 2017)

Figure 18. Flexibag (Almishipping, 2017)

Plastic drums

The N55 is not the only plastic drum on the market, there are multiple designs by many different suppliers, which are all quite similar (Figure 21). The main variation is whether or not the drum is tapered (has a smaller diameter at the bottom) allowing the drums to be nested (stored inside one another, reducing the volume of storage when empty). There are three tapered drums easily available on the market, these are very similar. The N55 can however be ordered with a plastic lid fastener instead of metal.

All drums and IBCs are use in combination with a plastic inner liner when transporting food (Figure 17). In most cases two liners are used, this depends on the wishes of the customer.

Figure 17. Plastic drums with liners (CDF, 2017)

Takeaway

In the current market, the plastic drums main competitor is the metal drum. Metal drums are the standard, however plastic drums are more durable and lightweight. There is very little variation in plastic drums. They are either tapered or non-tapered. Tapered drums can be nested when empty. Very little innovation takes place in the drum market. The IBC market has some more interesting variants.

TAPERED (CONICAL) PLASTIC DRUMS (200 LITER / 55GALLON) :

U.S. Coexcell
N55 drum

HDPE, plastic lid and fastening rings

Eagle 55 gallon labpack

Blowmolded HDPE, metal ring

56WT55

Blowmolded high molecular weight HPDE, metal ring

NON-TAPERED (200 LITER):

BEST SELLER
OPEN HEAD

RECONDITIONED
(SLIGHTLY LESS EXPENSIVE)

NARROW HEAD
(SMALL OPENING)

Non-tapered drums resemble metal drums in their shape. This allows for them to be handled in the same way; manually and by machines. However they are not nestable.

OTHER DRUMS (VARIOUS SIZES):

The square 15 gallon drum makes the most of the space on a rectangular pallet.

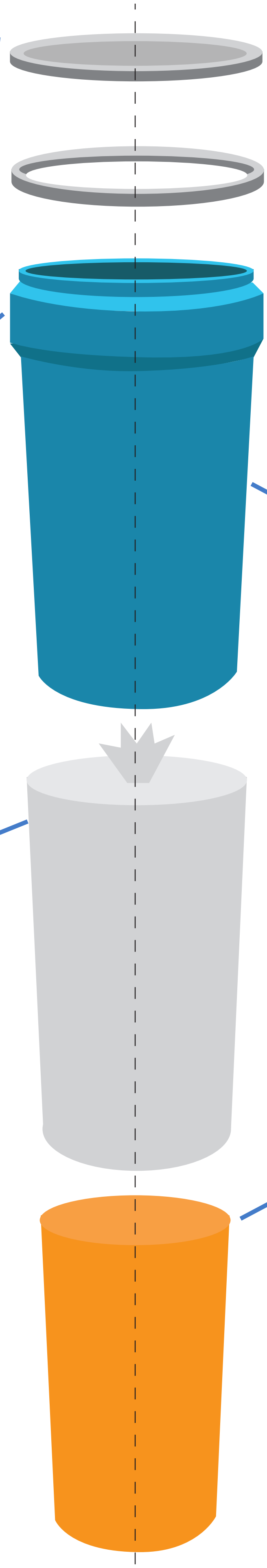
HDPE drums of 55 gallons also exist as rain-drums.

LLDPE 55 gallon,Non UN rated for wide range of non-regulated solid materials.

Figure 21. Plastic drums (U.S. Coexcell, 2017((Cary Company, 2017)

Analysis of plastic drums

The configurations in which plastic drums are transported is depicted in Figure 22 & 23. The tapered plastic drums currently on the market consist of of the following components:



LID

There are two types of containers openings. Closed head containers have a small opening in the top lid. Whilst in open head containers the entire top lid comes off, creating a larger opening. For the dumping of content an open head is required.

DRUM RIM

The rim allows for easy denesting of the drums, so that they do not get stuck in each other when nested in a high stack.

The N55 has a patented strapping channel which allows the drums to be strapped together for proper restraint on the pallet (U.S. Coexcell, 2017). However the drums coming in at Kloosterboer these were not used, they were also held together with plastic wrap.

LINER

All containers used for the transport of juice use a disposable inner liner, for hygiene reasons. This can be a plastic bag or a metalized aseptic liner (CDF, 2017).

In some cases two liners are used. One lines the container and the other, inside this, contains the liquid content. CDF Corporation is the supplier used by Maia Global.

U.S. Coexcell (N55 manufacturer) claims that the drums can be reconditioned to be used without a liner, meaning the juice is in direct contact with the drum (Coexcell, 2017). However this is is not common practice.

LID FASTENER RING

Drums with a removable lid use a ring with a metal lever lock for sealing the lid. Some also use a ring with a bolt. The N55 drum uses a plastic ring. The current plastic rings sometimes open when handling with a "pincher".

DRUM BODY

The tapered shape allows for the nesting of empty drums.

The round shape allows for rolling of the drum, if there is no forklift to use for moving. This is sometimes the case in the country of origin of the juice.

The existing drums are all blowmoulded HDPE.

CONTENT

The main content of the drums used by Maia Global is juice or juice concentrate. This must be transported in a cool supply chain. Sometimes in frozen form. The content is then melted, sometimes using heaters, while it is inside the drum.

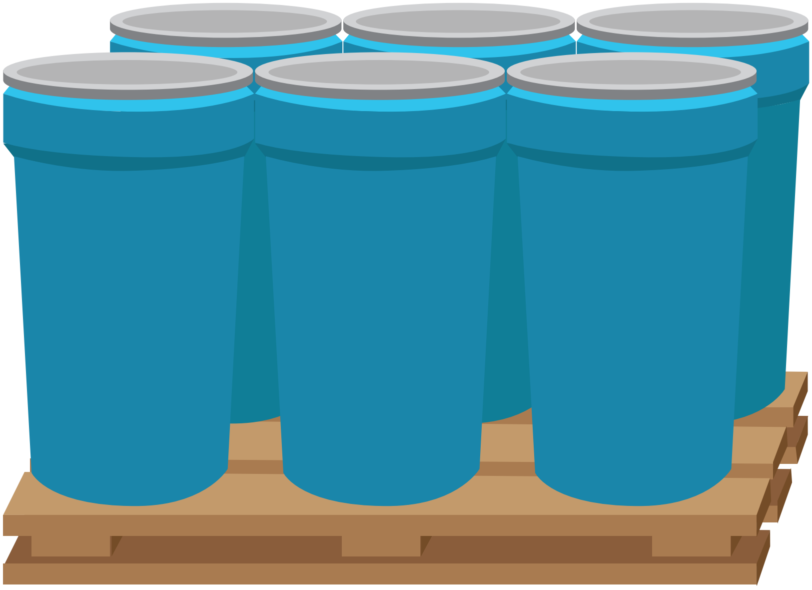


Figure 22. Plastic drums on an extra large custom made pallet approximately 1200*1800*144mm) used at some cold storages. The N55 drum has a maximum diameter of 60mm.

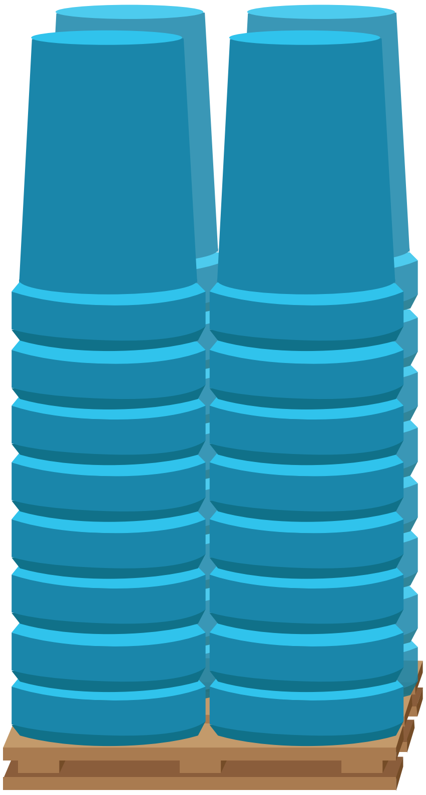


Figure 23. Nested plastic drums are turned upside down for stability

Figure 24. Lids and fasteners are placed on *a seperate pallet*

Common drum handling methods

The tools which are commonly used to handle drums are depicted on the right page. Preferably the new drum can be handled using each of these methods.

Takeaway

The most common types of handling devices are based on the principle of a "pincher" (which grabs hold of the rim of the lid) or "hugger" (which puts its arms around the drum).

Figure 25. A forklift with a "pincher" tool (ELE, 2017)

HANDLING OF DRUMS

FORKLIFT/CRANE WITH ATTACHMENTS

Forklift "Pincher": The "eagle claws" clasp hold of the rim of the drum and a support pushes against the body.

Hanging "Pincher": Slips in between drums to pick them up from the top, using a crane .

"Hugger": Arms at two sides surround the body of the drum. The rings of the drum prevent it from slipping down.

FORKLIFT WITHOUT ATTACHMENTS

On a pallet

Without a pallet

DUMPING

To empty the content the drum, it is placed on the "frame" of a tilting device and clamped in place, then tipped upside down.

MANUALLY (TO BE AVOIDED)

Rolled vertically, dropped out of a truck on an old tire

Pushed vertically (sliding), onto a hydraulic truck latch

Stacked on its side, rolled sideways down ramp

Figure 26. Methods of handling drums (ELE, 2017) (Vlogger, 2017) (Diggler, 2017)

11. IDEAL REUSABLE DRUM

In this chapter guidelines will be provided for designing a reusable drum.

Why reusable?

From the start of the project, the option to create a reusable drum has seemed like an obvious choice. This is due to the assumed reduced carbon footprint compared to disposable packaging (this is explored further in Chapter: Sustainability), the opportunity of exploiting the existing infrastructure Maia Global has for container pooling (reuse) and the cost savings for the company (the fee charged for reusable packaging, over its entire lifetime is beneficial compared to using disposable packaging).

From the company perspective, ideally a reusable drum would be used an infinite number of times, whilst remaining property of Maia Global, charging a fee per use.

Currently the Orca is used for 5-10 lifecycles, depending on how the customer treats them (the amount of wear varies). On average one lifecycle takes three months, but this can be up to six months (Lutzu, 2017).

Additionally, in this industry customers are accustomed to the idea of using remanufactured drums. Remanufactured metal drums have already been on the market for many years (CaryCompany, 2017). Typically for B2B markets, where parts are specified and tested, the perceived image problem (of reused products being inferior) is lower, since tests can show that the quality of a remanufactured product is equal to the new product (Vogtlander, 2017). In this specific case, the plastic liner inside the drum reassures the customer that the product will be safe for use (with regards to hygiene).

Guidelines

Not all products are suited for reuse in the system introduced in Chapter: Supply chain. In this section, guidelines will be provided for designing a drum which is suited. To start off, the process described earlier, which takes place at the service center, could be defined as remanufacturing. "Remanufacturing is an industrial process whereby products, referred to as cores, are restored to useful life. During this process the core passes through a number of remanufacturing steps, e.g. inspection, disassembly, part replacement/refurbishment, cleaning, reassembly, and testing to ensure it meets the desired product standards" (Sundin, 2004).

Eight criteria for remanufacturing are (Gallo et al., 2012)(Lund, 1985):

a.
the product is durable

b.
the product functionality can be recovered

c.
the product design is standardised and modular

d.
the value at end of life is high enough to prevent discarding

e.
the cost to obtain the core is low if compared with the potential intrinsic value

f.
the product's basic hardware technology is relatively stable over a period of time that exceeds the product life time

g.
the consumer should be informed about the opportunity to return the core and about the availability of remanufactured products, in order to create an adequate supply and demand

h.
the product is 'designed for disassembly'.

From this list, the criteria (a, c &h); durability, and design for disassembly, will be addressed further, as these are directly linked to the design of the drum. The other topics are not relevant for industrial packaging or have a larger (system) scope than the product itself. Criteria B, of recovering function, is quite evident which such a simple product. It must securely contain the (liner with) juice and allow for stacking. Criteria C is not relevant for this context, the drums will always pass through Maia Globals own service center, where custom-made parts are provided, the customers do not need to replace parts themselves. Criteria D and G, of preventing discarding and marketing reused drums, is currently covered by implementing the rental fee (which is attractively priced compared to disposable drums) and penalties if containers are not returned. For criteria E, the value is not directly in the drum, however it is in the cost saving of not purchasing and transporting new drums from a far away drum producer. Criteria F is not relevant for such a simple product.

Durability

To design a durable drum, we need to look at different types of damage which could be caused to the drum. These can occur from:

- Transport: The drum should be designed to withstand the norms for sea/road/ transport.
- Handling: Drums are not handled with much care, they should not break or dent easily. Or dents should be easily removed.
- Weather: The drums are often stored outside. Therefor they should be resistant to moisture and sunlight.

Product durability depends on durability of all respective parts. Not all parts have to be equally reliable as long as the ones that wear out can be replaced in time, either preventively or in a repair procedure (Bakker, 2014).

Design for disassembly

Some wear and tear of drums is inevitable, however it should be possible to undo this, to a certain extent (for example: if rips occur in the Orca these are stitched again). Another option is to replace parts of the drum which are broken, without discarding the entire drum.

Disassembly can be done manually at the service center. To improve disassembly, mechanical joints should be used rather than glue or other irreversible connections (Yang, 2013). In this way parts can be removed and replaces, and eventually materials can easily be sorted for recycling.

Additional criteria

Criteria which have not yet been mentioned, yet are relevant (specifically for reusable packaging) include:

- Compact dimensions (high return ratio of volume): When the drums are empty, they can be transported back to the service center compactly. This reduces the amount of truck rides, reducing costs and fuel emissions.
- Lightweight: The lower the weight of the drum, the lower the weight of packaging material, in ratio to juice, which needs to be transported.
- Easy cleansing: After each use cycle the drums are cleansed, so that the next customer receives a “neat & tidy” drum. Hosing down the drum (or other simple cleansing) should be facilitated.
- Simple inspection: It must be simple to evaluate whether a drum is still up to the required standards or not.

Takeaway

When designing a product the main topics to pay attention to, in this specific context, are durability and design for disassembly.

Due to the fact that product is type of industrial packaging, some additional topics should be addressed, to ensure the ease and efficiency of reverse logistics. These include minimizing weight and volume as well as facilitating cleansing and repair.

12. SUSTAINABILITY

The initial design assignment was formulated as designing a "low carbon footprint drum container". In this chapter the definition and possibilities of this goal will be explored, within the specific context.

Definition of sustainability

Lowering the carbon footprint can be seen as part of a larger goal of sustainable development . In its classic definition this is "development which meets the needs of current generations without compromising the ability of future generations to meet their own needs" (Brundtland, 1987). This will be set as the ultimate goal during this project.

To achieve this, the three pillars of sustainability, also known as the triple bottom line should be taken into account: people, planet, profit (Elkington, 1998). How these could be addressed within each pillar, has been illustrated in Figure 28.

The social pillar includes topics which improve the wellbeing of humans. These humans can be the handlers working with the drums, customers who order juice, or even people who are not in direct contact with the product.

Economic sustainability refers to the feasibility of the business model. Maia Global should be able to provide the drum at a resonable price for their customers. This will be discussed at a later phase of the project (see Chapter: Embodiment).

The main focus of this design project, with regards to sustainability, will be on the environmental impact. To reduce the negative side effects of the drum and the supply chain, on the environment. This will be explored with the aid of the EcoDesign Strategy Wheel.

The indicator which will be used is the carbon footprint. In this way the impact of the different use phases (including transport) can easily be compared. However other impacts, which are included in values such as eco-costs (Figure 28) should not be neglected, for example during material selection.

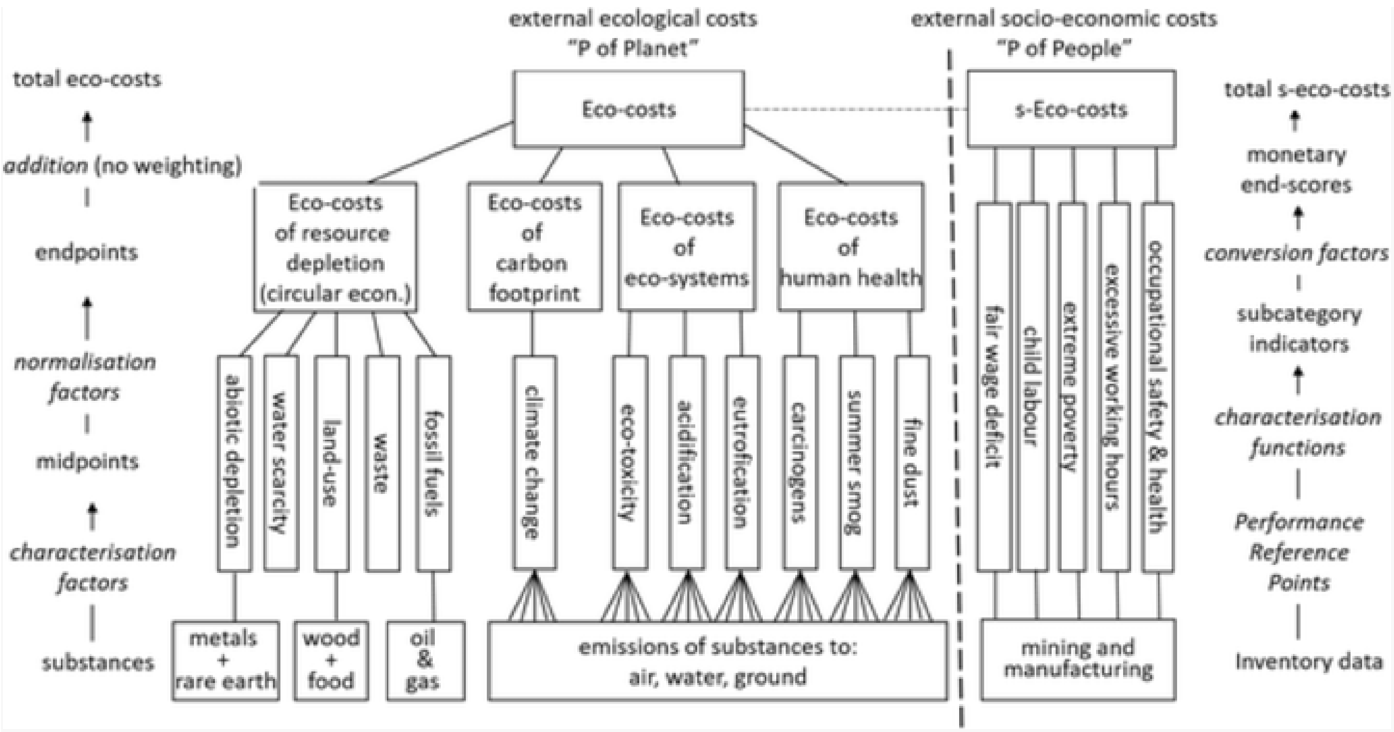


Figure 27. Composition of Eco-costs and s-Eco-costs (Van der Velden & Vogtlander, 2017)

SUSTAINABLE DEVELOPMENT		
SOCIAL	ENVIRONMENTAL	ECONOMIC
- Collaborate with suppliers and partners who guarantee good conditions for their workers (ex. use fair trade material suppliers, production in countries with strict regulations) - Improve working conditions at the plantations (ex. set up a scheme to provide forklifts, improved ergonomics of manual moving) - Charitable contributions from company profit - Provide quality checked products to customers (ex. only return products which have passed through the service center)	Reduced waste and carbon footprint throughout the phases of the life cycle phases: - Manufacturing - Packaging - Distribution - Usage (handling, transport) - Disposal Examples can be found in the EcoDesign Strategy Wheel.	- Savings in production costs (ex. with inexpensive design, by producing drums with a longer lifetime resulting in less products, increasing the return rate/speed of drums resulting in more drums available in the pooling system for next customer) - Savings in transport costs (ex. reduce weight/volume, strategic production and service locations, reduced use of consumables) - Savings in storage costs (ex. volume reduction by improved nesting) - Savings in handling costs (ex. ease of maintenance, use of existing devices for moving/dumping) - Increase amount of customers /order quantities of juice (ex. attractive (reliable/sustainable/competitive price) supply chain solutions)

Figure 28. The pillars of sustainability with some examples

Benchmark

A low carbon footprint of the new design implies that it is compared to a benchmark. The new design will be evaluated against existing drum designs. For this, the EcoDesign Strategy Wheel depicted in Figure 29, has been used. The drums have been scored, to show how they approach sustainability. The topics which will be interesting to approach in the new design have been printed in bold, and indicated in blue.

It is clear that the tapered plastic drum, such as the N55, scores the best of the current designs. Due to this, the N55 drum will be used as the benchmark for the new design. The new design should be better than the N55.

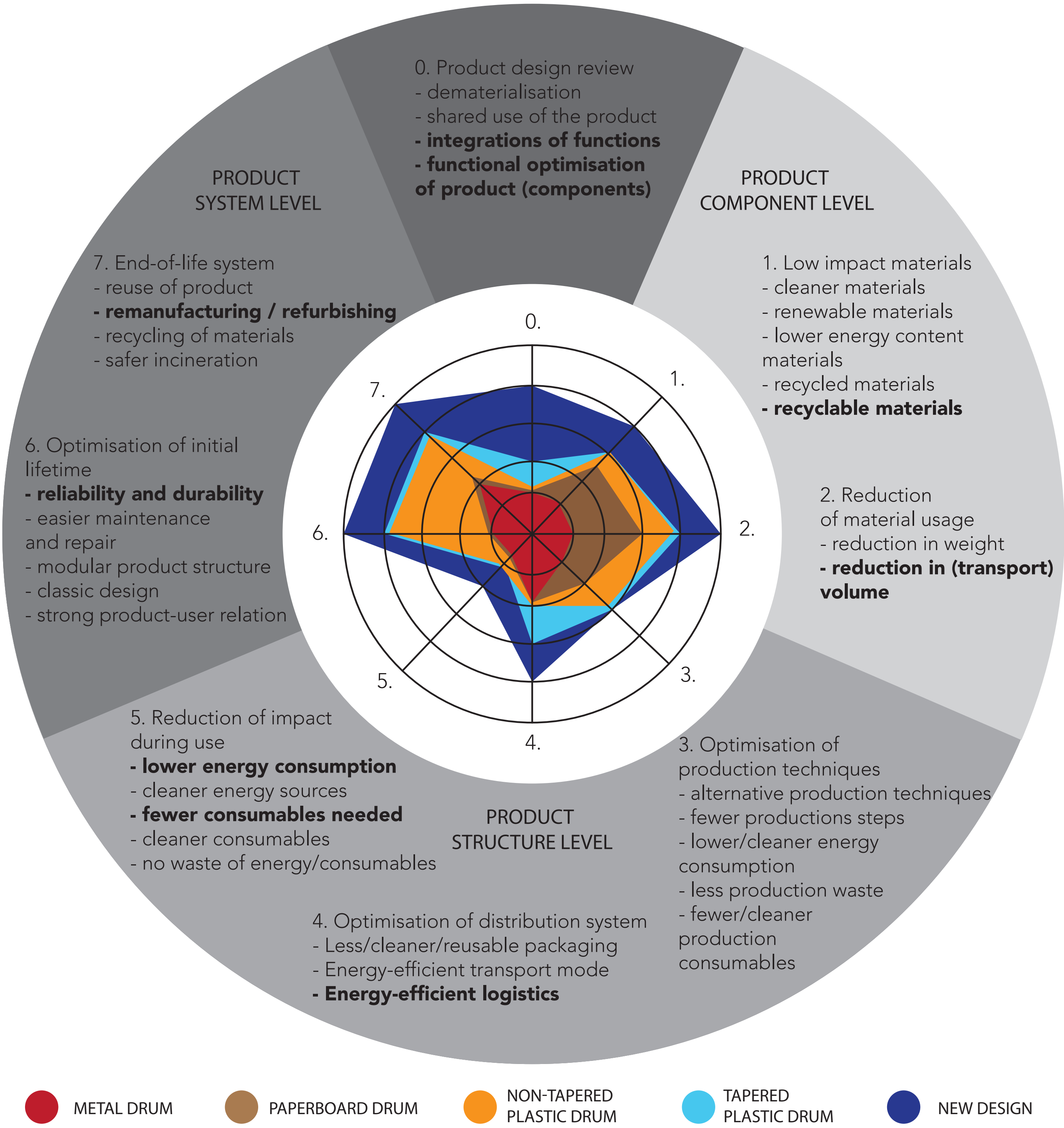


Figure 29. EcoDesign strategy wheel, based on (Brezet and van Hemel, 1997)

Life cycle analysis

Multiple Life Cycle Analysis studies about IBCs have been published and are used to promote specific types of containers (see Appendix: Sustainability ranking). The indicators used and assumptions made per study differ, however some general conclusions can still be drawn, see Figure 30.
The disposable, untapered, metal drum is the least sustainable alternative. This is due to exhausts from production and inefficiency in transport (seeing as it is not nestable/collapsible and relatively heavy).

Using reusable packaging for bulk liquids generally reduces the carbon footprint in the lifecycle (see Appendix: Sustainability). Emissions of return logistics and reconditioning are compensated by the decreased production emissions (the production emissions are spread out over mutliple lifecycles. The emissions of reverse logistics are comparable to those of the transport of virgin drums (and production materials) to the juice production location (unless they are entirely locally produced). However, the reduced carbon footprint is highly dependent on the specific context (locations).

Koskela et al. (2014), concluded that a recyclable corrugated cardboard box system was a more environmentally friendly option than the reusable HPDE plastic crate system in all the studied impact categories based on the defined boundaries and assumptions. Transportation played a very important role in the environmental impacts of the analysed systems. Therefore, changes, e.g. in the weights of products and their secondary packaging or the transportation distances could affect the results considerably.

A comparative lifecycle assessment of mango packaging made from a polyethylene/natural fiber-composite and from cardboard material, demonstrates the importance of context (Bernstad Saraiva, 2016). In the Brazilian scenario, after four uses the composite packaging greenhouse gas emissions became inferior to those of the single-use cardboard box. In the European scenario, break-even was attained after 29 or 35 reuses, depending on the fibers' content. The present study shows that use of natural fibers can be environmentally beneficial in relation to some impact categories, but not to others.

My personal preference is to create a drum which can recycled, without downgrading by mixing materials. If the drum passes through the service center, it can easily be sorted into the correct collection bin, as a pure/fully identified material for high grade recycling. Recycling of composites can be tricky.

Recycling of (wood plastic) composites would be the ecologically preferable pathway. Yet, incineration of the composites is the predominant EoL pathway due to current recycling directives and lack of markets for secondary WPC material (Sommerhuber et al, 2017).

Apart from the carbon footprint, using reusable packaging reduces the total amount of packages which need to be produced. The total amount (volume) of product, which will eventually become waste, if decreased.

The differences between reusable packaging types is more difficult to compare. The available information about the Goodpack study did not provide much insight into all the assumptions which were made. Volume reduction when empty is an important contributor, as marketed in Figure 32. As well as the assumed lifetime of ten years of the Goodpack container.

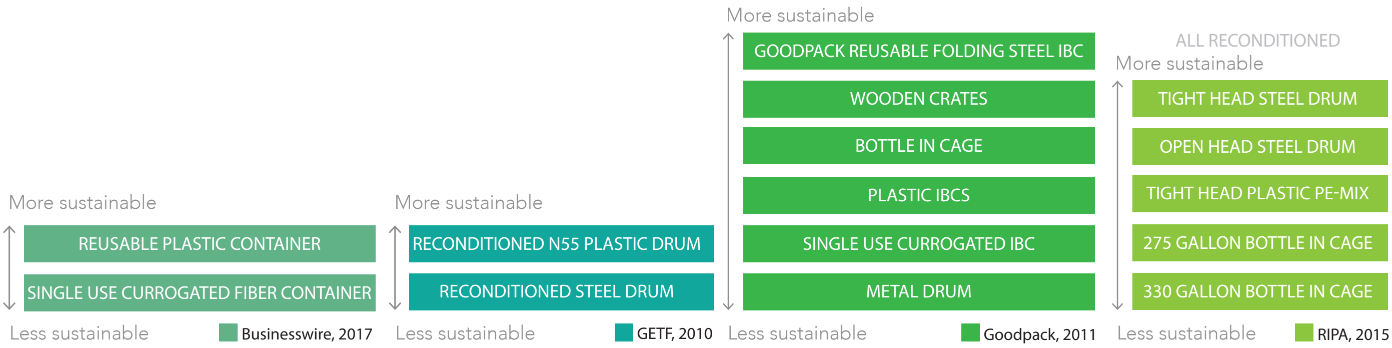


Figure 30. Ranking of different solutions based on sustainability indicators. Each study has been conducted differently, therefor they can not be compared directly.

Transport

As mentioned earlier, volume reduction plays an important role in the total emissions in a Life Cycle Analysis. For example: by fitting all required empty drums in one container instead of two, the amount of trips can be reduced. This means that the weight of the second container does not need to be transported.

Seeing as the supply chain of juice is a global operation, the container travels long distances, mapped in Figure 31. A rough calculation of the transport CO2 emissions per step of the supply chain has been made (Table 1). The functional unit in the calculation is a tonne weight being transported, the volume has not been taken into account.

As seen in the calculation, the emissions of the transport to the service center are negligible compared to that of the sea transport. For the highest impact, focusing on the sea transportation between plantation and cold storage or service center, should be considered.

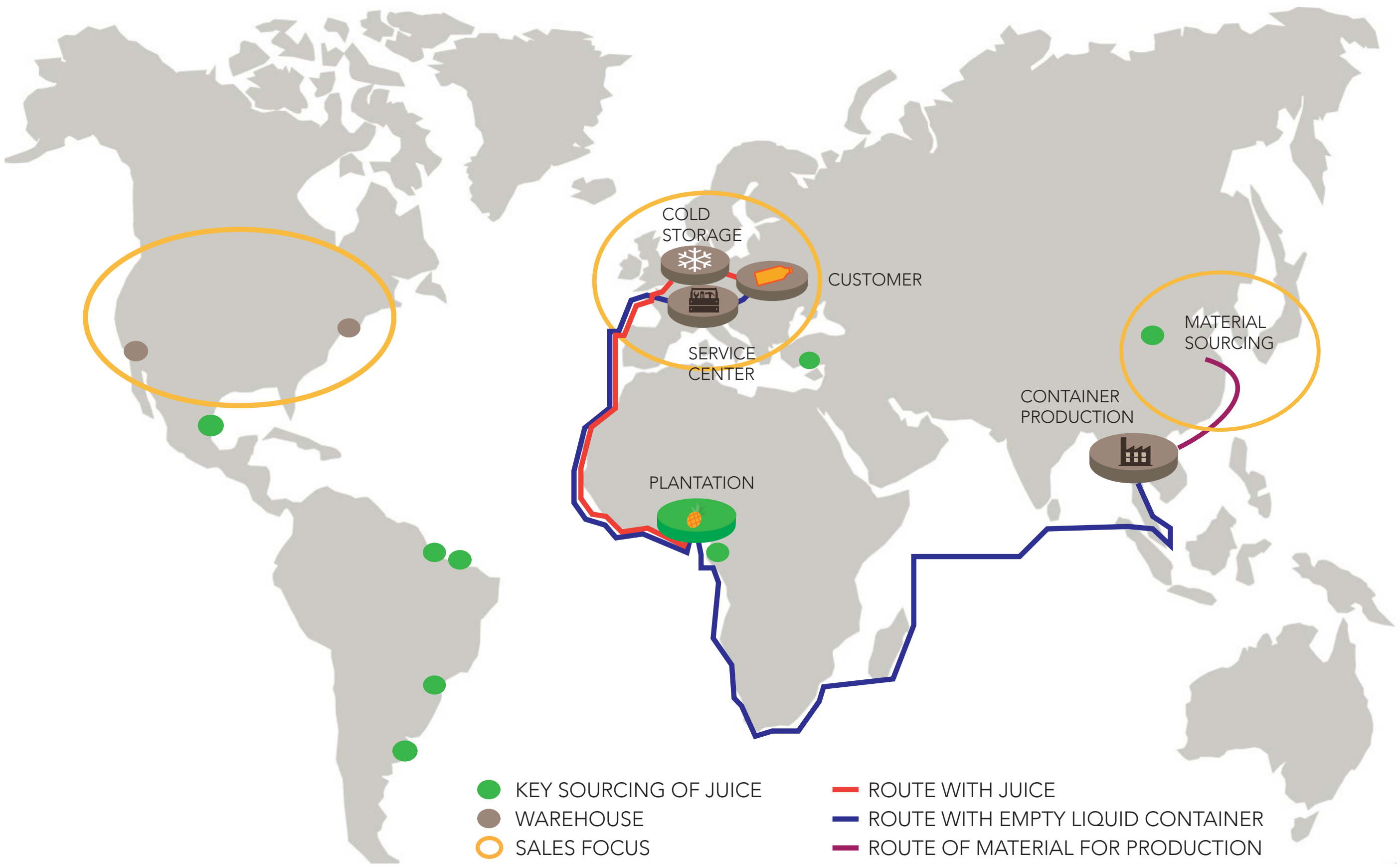


Figure 31. World map with with key locations of Maia Global and the routes in the supply chain of pineapple juice *Based on (Sono Global, 2017).*

Table 1

Calculation of the CO2 emission in transport of IBCs per step in the supply chain

TRANSPORT						
Location	Transport distance to next step in supply chain (km)	Transpor t method	Number of trips in entire lifetime	Emmission factor / g CO2 per tonne-km (McKinnon, 2010)	Total emission / g CO2 during entire lifetime	Container empty or full?
Thailand: Container production (Thai masterpack)	20000	Sea	1	16	320000	Empty
Ghana: Pineapple plantation and juice production	8400	Sea	10	16	1344000	Full
Rotterdam, Netherlands: Cold storage (Kloosterboer	200	Road	10	62	124000	Full
Moers, Germany: Customer (Niederrhein-Gold)	150	Road	10	62	93000	Empty
Turnhout, Belgium: Service center	8400	Sea	10	16	1344000	Empty
				overall total:	3225000	

Assumptions and definitions:

The functional unit is the distribution of a tonne of IBCs over a period of 5 years.
In this calculation the volume is not taken into consideration, only the weight of the IBC.
Lifetime: From the moment the container has been produced, until it is disposed/recycle. This is assumed to be 5 years.
Lifeycle: Leaving the juice producer until entering at the next juice producer. The assumed length is 6 months.
The shipping distances have been caluculated using the calculator on: www.ports.com (accessed on 27-03-17)
Some additional road transport may take place between the plantation and harbour, as well as Turnhout and the harbour, this has been neglected
The emission factors used are those of road transport and short sea transport (not deep sea crossing) as proposed by:
McKinnon, A., Piecyk, M. (2010). Measuring and Managing CO2 emissions. CEFIC
The return trip of the method of transportation has not been taken into consideration (after the truck has dropped off a load of containers, no more km are counted)

Competitors

Maia Global is not the only company in the liquids logistics industry to focus on sustainability. Being able to promote the design/service as the "most sustainable" alternative, is what many competitors aim for. Focusing on sustainability often leads to improved brand reputation, amongst other benefits (Haanaes, K., 2011).

There are many drivers for a sustainability (Mann, H. ,2010). These include drivers from a idealistic starting point, thinking of the social and environmental benefits, however in the end the economics are often the main driver for a company. Legislation, customer satisfaction and improving the internal business process are also drivers, which apply aslo in this design project.

Certification

Competitors use ISO 14000 certification to validate their sustainability towards customers. A less popular, stricter certification is the EMAS. These certifcations are used as promotional material, to set a company apart from others.

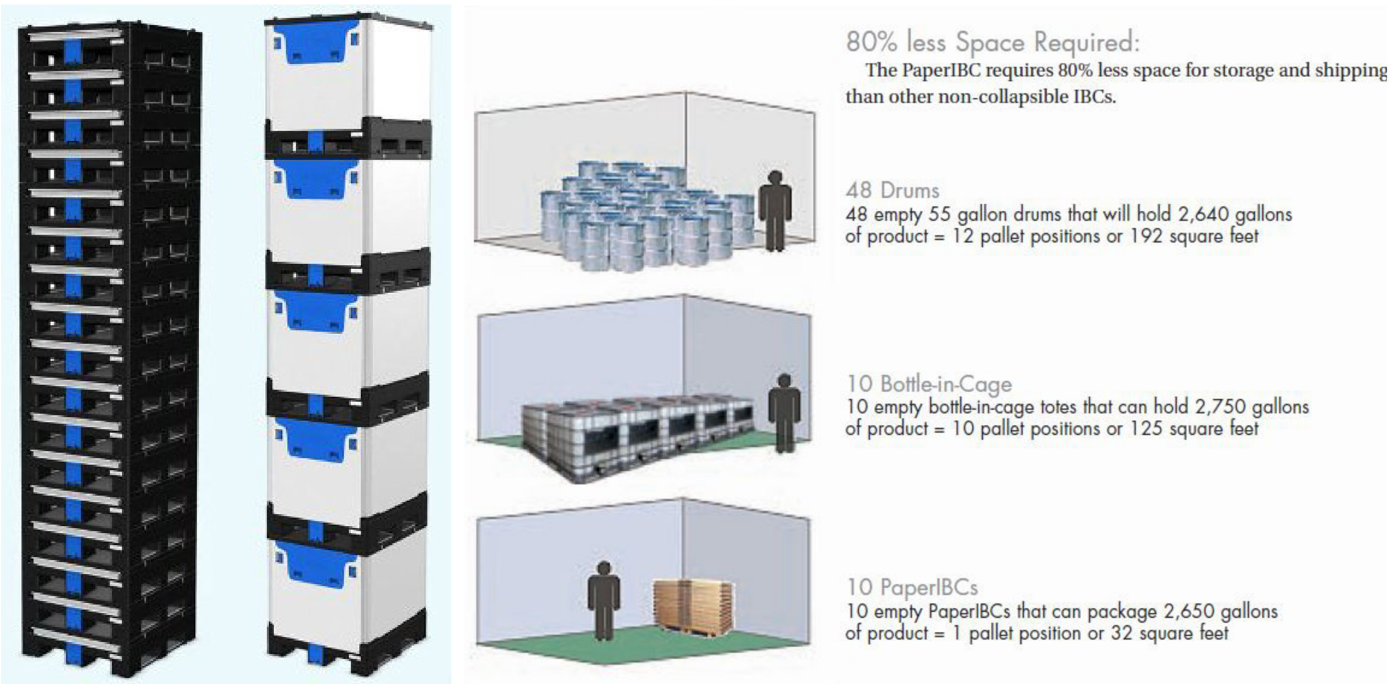


Figure 32. Marketing material used by companies to emphasize the volume savings in transport and storage. (Horen, 2017)

Goals

To summarize the remarks made in this chapter, I made a list of the most interesting ways to lower the carbon footprint (Table 2). These will be considered throughout the project, at the moment when they are relevant. Towards the end of the project the achieved result will be measured.

Table 2
Suitable ways to reduce the carbon footprint during this project

Goal	Effect	Beneficial side effect for Maia Global	Design implication
Reusable packaging	By increasing the amount of cycles a drum can be used, fewer will need to be produced.		Durable design Increased return ratio to make return logistics feasible
Increased return ratio	More empty drums can be loaded in a transport container, lowering the amount of required trips.	The space needed for storage of empty drums will decrease, lowering storage costs. Less trips means lower transport costs.	More compact nesting
Lightweight	Reefer containers have a very limiting maximum weight restriction. By making the drum lighter, relatively more juice can be transported.	More juice per trip means less trips.	Prefer lightweight materials/ constructions
Low impact production	Less exhausts from production.		Material choice
Replacable parts	If one part gets damaged, the entire drum does not need to be discarded. The damaged part is replaced.	The costs or replacing a part is lower than replacing an entire product (seeing as the service center is present).	The different parts should be easily removable
Fully recyclable	The discarded drum is still useful as a material source and will not be wasted.	A clean materials source can be worth money.	Materials can easily be sorted

Takeaway

A table has been created with the most suitable ways to lower the carbon footprint. These will be taken into account in the design and the effects will be measured later on in the project.

13. PRODUCT LIFE CYCLE

A schematic overview of life cycle phases of a drum has been made (Table 3). The actions which are performed by handlers at each phase have been listed. Together with possibilities to improve the sustainability. The results from interviews with stakeholders about issues with the N55 drum have also been incorporated.

Interview insights

Interviews with stakeholders have been conducted to gain more insight into the current situation, issues with the N55 plastic conical drum and the reasoning of stakeholders to prefer a specific drum.

The full list of interview results and the interview set up can be found in Appendix: Interviews. The relevant insights have been incorperated into the list of requirements (Chapter: Design requirements).

The issues with the N55 have been explored, to find out whether there are severe obstacles have emerged in practice, which would discourage the use of plastic as the main material or a conical shape in the new design. The most relevant insights, which have been confirmed by multiple interviewees have been incorporated in the lifecycle Table 3. For each insight, the possible cause has been explored during the interviews and using my own insight. The implications that these insights have for the new design have also been listed. Solutions to this problems will later be explored in the Chapter: Product level ideation.

The instability due to the tapered shape and low weight of the drum is a big issue. The new drum must be more stable. Also the deforming of the plastic, due to insufficient strength when stacking, when gripped with the claw and strapping, should definitely be taken into consideration. However these obstacles will probably be able to be overcome, even without switching to another material.

From the perspective of the cold storage, the metal drum is preferred. It has been proven to work over many years and handling devices are made specifically to handle this type of drum. Stackability is said to be the main advantage of the metal drum. Plastic drums can not be stacked as high, as they will deform.

Figure 34. Drums wrapped and strapped in a Reefer (Maia Global, 2017)

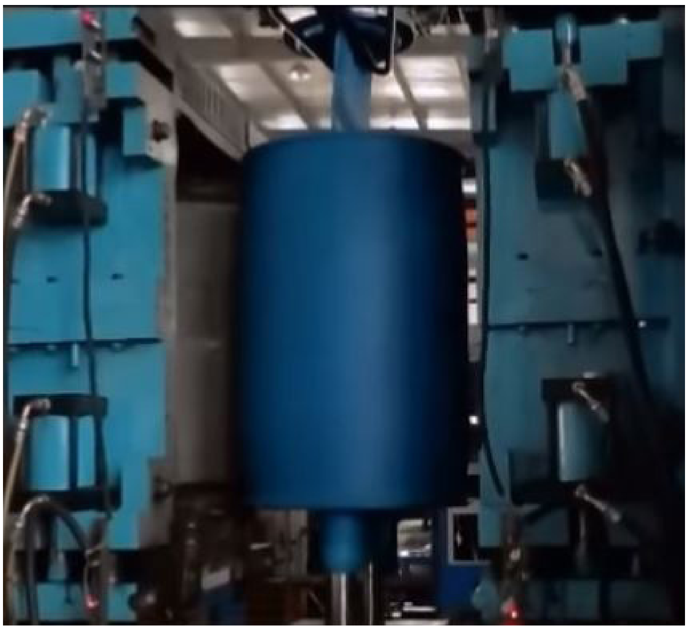


Figure 35. Blow molding of a plastic drum (Xu, 2017)

Figure 33. Empty plastic drums

Table 3
Life cycle phases of the plastic conical drum

Phase	Sustainability topics	Actions	Issue with plastic conical drum
Production (shown in Figure 35)	- low impact materials - low impact product processes - material/weight reduction by design	- produce drum - produce lid - produce fastener ring - sort drums, lids and fasteners	
Nesting (shown in Figure 34)	- increase return ratio of drums with compact nesting	- place drums on pallet - place lids and lidfastener on pallet and wrap in plastic foil	
Assembly		- insert the liner and fold over the edges	
Filling	- decrease the amount of liners used, or eliminate them completely	- place on roller conveyor - move conveyor - insert juice - close the liner bag - find lid and fastener - close the lid using the fastener - place tamper-evident seal	Empty drums often fall over on the roller conveyor. Because conical drums have a relatively small footprint and are extra light. Stability when empty should be taken into account.
			When a drum is filled with too much juice and then frozen, the lid can pop. The expanding liquid pushes the lid open. The maximum filling level should be clear for the filler and not exceeded.
			When a drum is filled with too much juice the lid fastener can become impossible to close. The pressure of the liquid deforms the neck of the drum. The lids fastener should be adaptive to deformation of the drum. Or deformation should be prevented.
Moving with pincher		- drive the forklift up to the body of the drum - pinch the lid fastener ring - lift up the drum	Pinchers can make the lid come off, if the lid fastener is on too loose, the pincher grabs hold of the drum instead of the fastener. This can cause the drum to deform and the lid to pop off. If an easily deforming drum is created, it should be made sure that the pincher only grabs hold of the lid fastener.

Moving with hugger		- drive the forklift up to the body of the drum - place arms around body - lift up the drum	
Moving manually		- tilt the drum a couple degrees - twist the drum so it rolls on its foot	
Dumping juice	- reduce the amount of energy required to melt frozen juices	- place on roller conveyor - open lid and inner liner - move conveyor - position drum in dumping frame - tilt dumping frame - remove/discard liners	
Stacking	- stack drums more compactly, making the required, cooled, storage space smaller	- cool/freeze the drum - place drums on pallet - move pallet to storage area - stack pallets - place empty pallet on top of stack for extra stability	Plastic drums can not be stacked as high as metal ones. This is an important factor for cold storages to prefer metal drums. The current blowmoulded shape of the HPDE drum with a minimum wall thickness of 0.32mm is not strong enough. The new drum should be stackable up to six levels high. Plastic drums with content are first frozen to be stacked higher. Freezing the drum and content makes it more rigid. The necessity to first freeze the drum could be prevented by design.
Reefer loading/ transport (show in Figure 34)	- decrease the weight of the drum, to increase the amount of juice which can be transported per truckload - decreased the amount of packaging consumables required, such as; plastic film to keep drums in place & boards/fencing in the Reefer - prevent the transport of empty shipping containers	Floor level of drums: - place drums on floor of Reefer without pallets, using pincher or hugger - place wooden H-profiles in container to prevent drums from sliding Second level of drums: - strap drums together - wrap drums in plastic film - place in Reefer in correct pattern	Drums fall over during transport. Straps used for transport sometimes slip down. When the drums are strapped too tightly, the lids pop off.

End of cycle	- reuse containers - low impact cleaning processes - repair containers - replace broken parts - recycle materials	- inspect (check for scratches/ dents/holes) - cleanse (with water) - repair (plastic welding) - replace parts (lids and fasteners) - send to next juice producer or - discard for recycling - dispose of non-recyclable materials	

Takeaway

The existing conical plastic drum is far from ideal. There are many issues with it, which need to be resolved if a similar drum is designed. The metal drum is preferred as it has been proven to work over many years. Stackability is said to be the main advantage of the metal drum.

14. COLD STORAGE

For a better understanding of the conditions in which the drum will be handled, Kloosterboer was visited at the Reeweg in Rotterdam. The tour was guided by a member of staff, Marco Jansen. This company specializes in the cold storage and processing of temperature controlled food products. At this location juice enters through the harbour, is processed and transported further.

The process at Kloosterboer

The steps which the juice and containers go through have been visualized in Figure 36 and will be discussed.

Sea:

Reefer containers filled with drums or IBCs containing juice enter the harbour by ship.

Harbour:

The drums and IBCs are unloaded from sea transport (Figure 39). They are briefly stored outside in the harbour and labeled with a sticker, which indicates the content and the location it should be stored inside the storage.

Cold & freeze storage:

Drums and IBCs are either stored in a cool storage or a freezer (-25 °C), depending on the content. The containers are moved there on pallets by forklift (Figure 37). They are stacked in rows (Figure 41) and labeled with another sticker to show which containers are stacked behind it. Some containers can not be stacked on top of themselves (Orca & Octabin), these are stored in shelves (Figure 42). Some juice is only stored for a while and forwarded in its original package.

Juice dump:

Inside a clean room, the content of the other drums is emptied into a tube system which pumps the juice to its next step in the process (Figure 44). At Kloosterboer their are two main types of dumping devices. One for tilting drums to empty them (Figure 45),most companies only have this device. For larger IBCs a larger device is required.

Blending:

The juices are pumped into barrels of 25.000 liter where they are blended.

Container sorting:

The empty containers are sorted by type. The next destination of these containers differs. Some are transported to the customer, others returned over sea.

Juice storage:

If the customer does not immediately require the juice, it is stored in large tanks, with a total volume of approximately 6.600 tonnes.

Container filling:

Most of the juice is pumped directly into 20.000 liter tank trucks. It can however, after blending, also be pumped back into the drums in which they entered.

Storage of empty containers:

Empty drums are stored outside (Figure 43), except the Orcas. Sometimes pallets are placed at the top of pile so they stay together, or plastic wrap is used.

Return sea transport:

Some drums are returned directly to the juice supplier, the next time they bring a shipment.

Road transport:

The juice and some of the containers leave the location by truck.

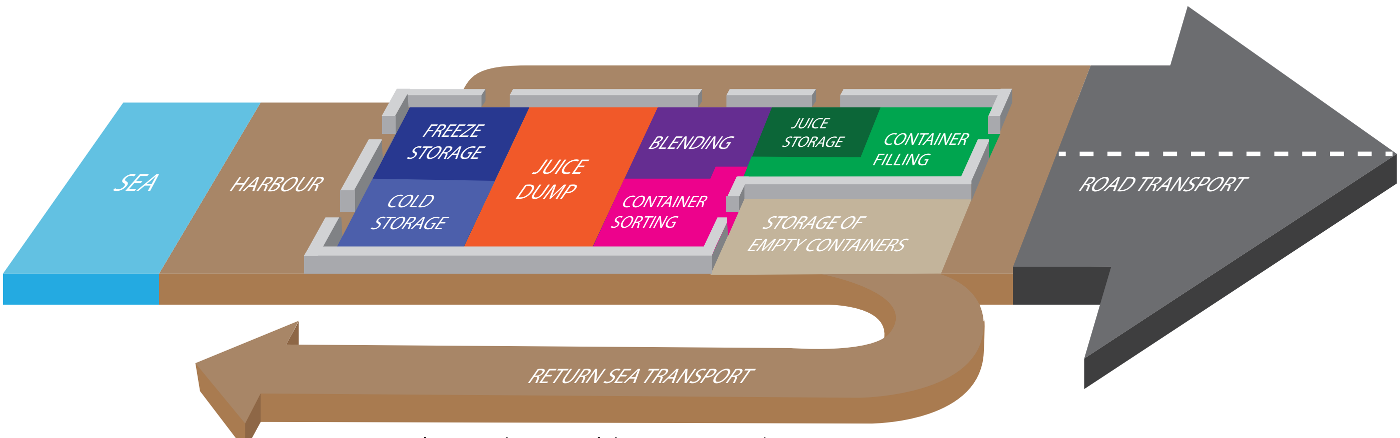


Figure 36. Kloosterboer cold storage and processing process

Figure 39. Drums being lifted out of a ship in Vlissingen. The drums are loose in the cooled belly of the ship (Kloosterboer, 2017)

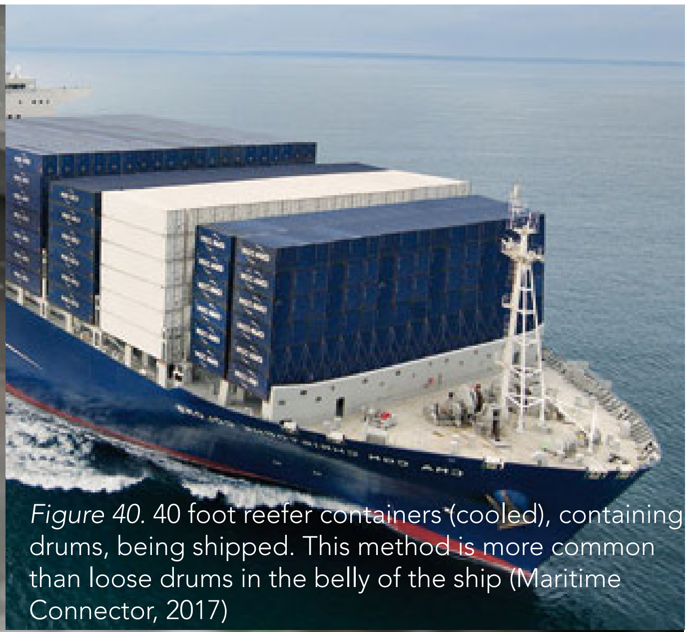


Figure 40. 40 foot reefer containers (cooled), containing drums, being shipped. This method is more common than loose drums in the belly of the ship (Maritime Connector, 2017)

Figure 37. Forklift moving drums on pallets

Figure 38. Forklift moving drums without a pallet, with "pinchers"

Figure 41. Cold storage of drums

Figure 42. Storage shelves

Figure 43. Empty plastic drums

Figure 44. Clean room, drum and IBC dumping lines

Figure 45. Dumping of juice at Kloosterboer (Kloosterboer, 2017)

What is done with empty containers?

When the contents have been emptied into the pipe system of Kloosterboer, the containers are:

- Collected by juice supplier at a next shipment, without cleansing. Ocean Spray does this with their branded plastic containers. Goodpack and Retropack containers are also all collected similarly, systematically. Citrofruit however picks up their wooden containers very irregularly, to dissatisfaction of the cold storage.

- BOC Orcas are transported to a third party in Turnhout, Belgium. Here they are inspected and cleansed for re-use in a pooling system.

- Non-branded containers which are still in good condition and are not recollected, are used by Kloosterboer to transport the processed juices to customers. Kloosterboer cleanses, then places liners and fills with juice.

- Unusable metal containers are flattened and sold as metal scrap.

- Packaging waste plastic is disposed or recycled. Clean liners are worth money in recycling. Dirty ones cost money to be disposed.

Takeaway

At Kloosterboer, in the harbour of Rotterdam,many different types of packaging are used simultaneously;multiple types of drums and IBCs. When full, the packages are stored in two ways. Stacked on pallets, up to 5 levels high. And if this is not possible, due to the package type, in shelves.

Once emptied, the packages are stored outside, before being transported to their next destinations; back to the juice producers, to a third party pooling company or to be recycled. Or containing juice, to the customer, if the customer does not want a 20.000L tank-truck of juice.

15. PLANTATION

The circumstance at the plantations (in Africa, South America, Asia) are often more primitive than those at the cold storages. The working regulations are not as strict and tools which simplify the process are not always present. This is compensated with manual labour, which is relatively inexpensive. However this should not be exploited. Some observations have been made based on footage from a plantation in Ghana where the juice is produced, information from Maia Global, as well as desk research.

The plantation in Ghana

The pictures on this spread have been taken at the plantation in Ghana. The location is slightly less sophisticated and smaller than for example the Kloosterboer cold storage. However the way in which containers are handled is similar. Similar equipment is used, including a forklift.

Most juice producer own a forklift, however not all of their local customers do. This means that drums will be unloaded from a truck manually, for such customer a drum of no more than +/- 200 liters is preferred.

The captions under each figure on this spread point out some interesting details.

Figure 46. The pineapple plantation in Ghana where the juice is produced. Juicing does not always take place at the same location, then fruit is transported to a juice producer. (Sono Global, 2017)

Figure 47. Discarded products have gained a new functionality. (left) N55 drums are used for storage of something else than juice, using a different lid. (right) Workers sit on empty crates instead of chairs.(Sono Global, 2017)

Figure 49. Cold storage of containers. This is a relatively small space for access with a forklift. Multiple types of containers are present, depending on the wishes of the clients. (Sono Global, 2017)

Figure 51. Overview of the facility. Including a "trench" for a truck, so that the mouth of the truck is at the same level as the factory floor. At some customers nearby juice producers, drum need to be "dropped" out of the truck.

Figure 50. Multiple types of packaging are loaded in a cooled container.(*Sono Global, 2017)*

Figure 48. Some containers being stored outside in the sun and weather.(Sono Global, 2017)

Conceptualisation

In this chapter the conceptualisation phase of the design project will be presented. The findings from the analysis phase will be brought together and solutions will be created for problems which have been discovered. The solutions will be combined to form the initial design of a drum. Which will be elaborated later in the embodiment phase.

Figure 52. Abstract visualisation of the creation of the new design

16. DESIGN REQUIREMENTS

The findings from the Analysis phase of the project, as well as from the interviews have been translated into design requirements, which the final design of the new drum must fulfill. Seeing as a low carbon footprint is the main selling point of the new drum, the requirements which contribute to this will be emphasized, these requirement have been highlighted in green.

Main function
- The container should have a capacity of 55 gallons (+/-208liters).
- When used in combination with a liner (a second one creates a backup) the drum should be suitable for containing juice (food-grade).
- The drum must be suitable for reuse for a period of 5 years, 10 use cycles.
- The drum should have a smaller volume when empty (nesting/collapsing etc.).

Company
- The drum should have a reduced carbon footprint, in grams of CO_2, compared to the N55 reusable plastic drum (see Chapter: Sustainability).
- The container should differ visually from competitors.
- The costprice of the drum should not exceed 40 euro (this slightly higher than the price of the N55 drum, 38 euro).

Materials
- The material should withstand temperatures varying from -30 to 60 degrees Celsius.
- The container should not weigh more than 10kg (to still compete with existing plastic drum with weigh approximately 8kg).
- The container should be made of recyclable materials, to compensate the carbon footprint.
- The different materials of the container should easily be sorted for good recyclability.

Production
- The production technique and materials should have a lower carbon footprint than that of a metal drum.
- The amount of separate components should be minimized to cut down assembly cost and make handling simpler (less parts getting lost and having to be sorted).

Handling
- The edge which is gripped, should not deform when using the “pincher” (Chapter: Mechanical calculations).
- The drum should facilitate handling with a hugger (Chapter: Existing products).
- The lid should not come loose unwantedly when handled (Chapter: Product life cycle).
- The container should be able to be handled with the current tilting/dumping device (Chapter: Existing products).

Transport and storage
- The drum must withstand the forces in sea/road/rail transport (see Chapter: Mechanical calculations).
- The drums should be stackable with a pallet, up till 6 layers high (see Chapter: Mechanical calculations).
- If the containers are nested they should not airlock (making denesting difficult), meaning a sufficient gap should remain between the wall of two drums when nested.
- The drum should make better use of the space in a transport container, than the N55; more drums on the floor level of a container (instead of on pallets on the second level).
- The containers should not fall over during transport. They should allow for secure strapping with a strapping band and plastic film if necessary.

Return system
- The container should be clearly recognizable as returnable and property of BOC/ Maia Global.
- The container should be easily cleaned for reuse, not necessarily for food grade, as liners are always used.
- Malfunctioning parts should be repairable/replaceable.
- The drum most be equipped with a unique identification code, preferably an RFID tag (see Chapter: The future system).

Regulations
- The drum should contain a tamper proof seal.
- The drum should comply with FDA standards.
- The drum should be eligible to be UN rated.
- The design should preferably be eligible for ISO 14040 and 14044 standards.

Wishes

- The carbon footprint is reduce as much as possible.
- The total eco-cost of the drum is minimized.
- The drum is more innovative than an incremental redesign, it is not a nestable plastic cup shape (Figure 53)..
- The use of additional, disposable materials, is minimized (liners, plastic film, caging).

Criteria

- Reduced carbon footprint
- Ease of handling (with pincher/hugger/manual)
- Suitable for extensive reuse
- Reduced empty volume
- Stability on conveyor and in transport

Takeaway

There many requirements for the drum, which in such cases are contradicting. Especially keeping the costs and weight as low as possible will be difficult, when creating an drum with a better performance than current drums.

The main criteria to keep in mind during designing are: reduced carbon footprint, compatibility with existing handling methods, suitability for reuse, decreased empty volume and security in transport. Complying with regulations will be address at a much later stage of the product development.

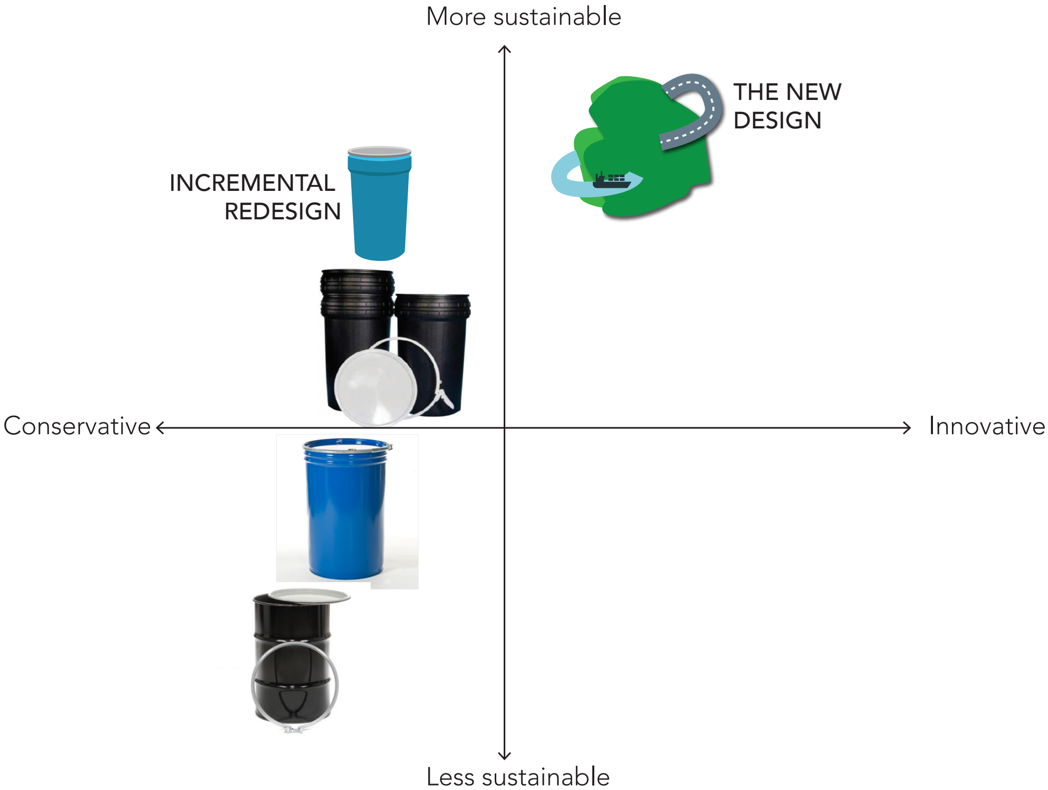


Figure 53. My design preference plotted in a matrix

17. PRODUCT LEVEL IDEATION

In this chapter the initial ideation phase of the design process will be discussed. The goal is to create ideas on how to solve the issues which have been discovered in the analysis phase.

Product feature level

The conclusions from the analysis phase consist of requirements and issues with current drums. The conclusions which have the largest influence on the design of the new drum, have been gathered in a morphological chart (Table 4). For each topic, solutions, in the form of product features, have been created. Less desired solutions, which increase costs or are not solved by the design of the drum only, have been highlighted in red. The trade-offs between the solutions will be discussed below per topic.

Space optimization

To reduce the carbon footprint of a drum, reducing the volume plays a key role. This is mainly relevant in two phases of the drum lifecycle; transport and storage.

During transport, the fuel emissions can be lowered, by reducing the volume of empty drums. If the volume is reduced, more drums will fit in a container. In this way, fewer containers need to be transported. Or it might become possible to fill the created empty space with another product, a third option is to use smaller containers. This depends on the order quantity of the customer (order quantities are discussed further in Chapter: System ideation).

The goal is to prevent "the transport of air", eliminating unused space in a container. This can be achieved by; nesting, collapsing, disassembling or direct reuse of drums (illustrated in the first row of the morphological chart). Nesting means that drums fit inside one another. In this method however, the volume of the bottom drum of the stack will always be "full of air". After the first drum, the denesting height determines the compactness of the stack (for more about nesting, see Chapter: Transport scenario). Collapsing or disassembling have potential for greater volume reduction. Collapsing have the advantage of having no "loose parts" which need to be sorted and may get lost.

A final approach would be to reuse the drums directly from the cold storage. By creating a logistic system in which drums (which have been emptied at the cold storage) are used for multiple customers, in different phases of the juice supply chain. To fully utilize the drums before shipping to a service center or all the way back to an overseas juice producer.

The scenario could for example be; drums with apple juice enter the harbour of Rotterdam and the content is dumped at the cold storage into large mixing tanks. The cold storage first inspect and cleanses the drums, depending on the desired drum quality (read more about the quality levels in Chapter: System ideation). The cold storage then fills the drums with a multifruit juice mix and sends them forward to a bottler. During this trip, the multi-fruit mix is unloaded and empty drums are loaded in the truck, to be returned and reused..

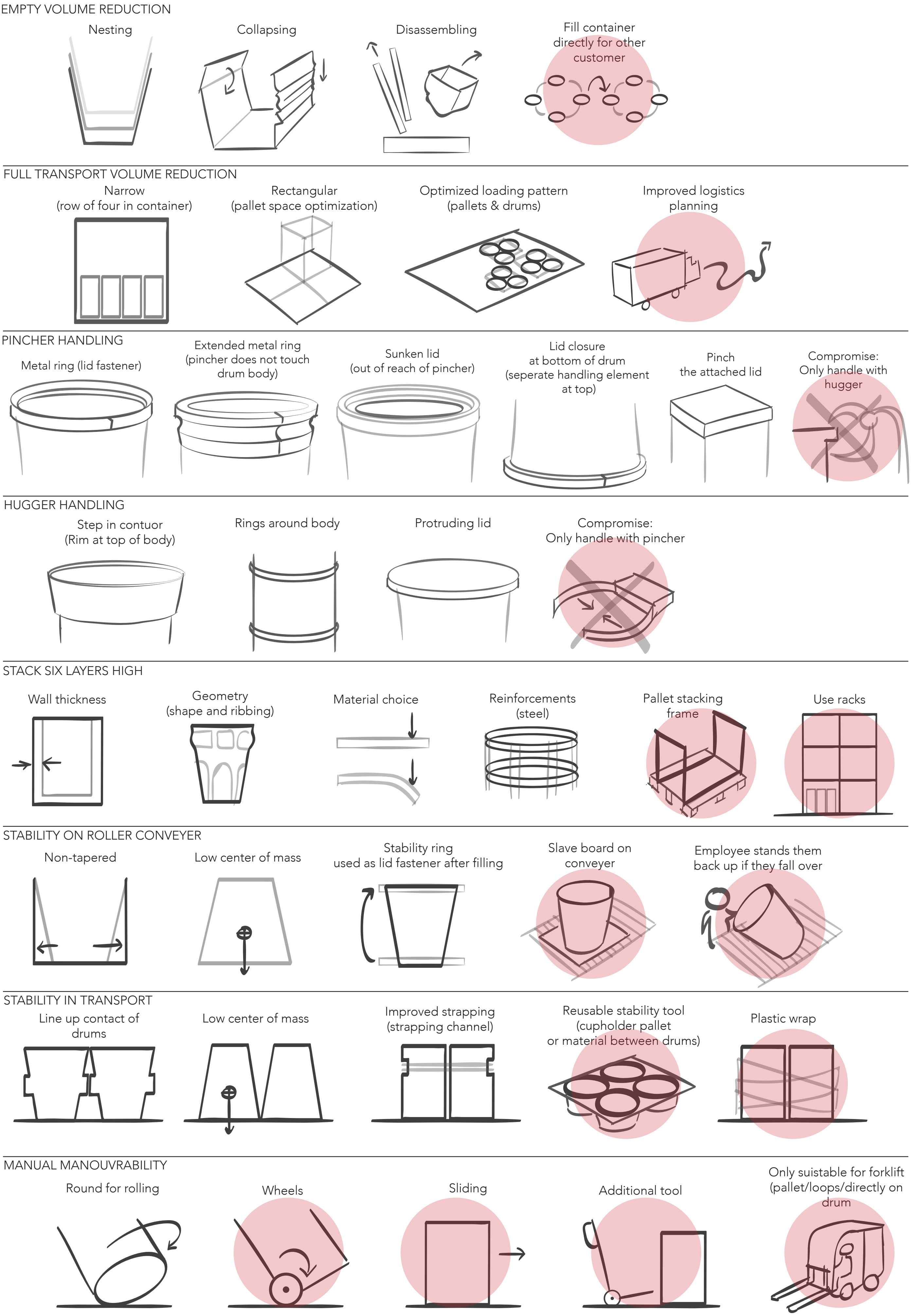
Reducing the volume of a drum when it is filled with juice (whilst keeping the content volume of juice the same), does not have benefits. This is due to the relatively low weight limit of cooled transport containers (read more about this in Appendix: Rectangular shape in a Reefer). Weight reduction of the drum however is desired in this situation.

During storage, in a space in a building which needs to be cooled, energy savings can be made by space optimization. If the drums, filled with juice, are stored more compactly, the size of the space which needs to be cooled is reduced. These spaces are often halls with high ceilings, up to 10 meters. Stacking of drums (up to six layer hight) should be enabled. It is preferred that the drums themselves are strong enough to be stacked on top of each other, with a pallet in-between each layer (see Appendix: Interviews). Using racks is also an option, however this is less space efficient (see morphological chart, row: Stacking).

A second approach is to minimize the footprint (amount of utilized floor space) of the drum, as explored in row: Full transport volume reduction. This can also have benefits in transport; if more drums fit on the floor level of a container, fewer pallets are required on the second level. Reducing the total weight of pallets, increases the available weight for drums of juice (read more about this in Chapter: Transport scenario).

A slightly smaller footprint can be achieved by creating a non-tapered drum. For a greater effect, the height of the drum will need to be increased. This is not an obstacle, as long as the drum remains stable and can be handle with the current handling equipment. In transport containers the vertical space is currently not fully exploited.

Table 4
Morphological chart (less desired solutions highlighted in red)



Handling

The devices used to handle drums have been explored in Chapter: Cold storage. The design features which allow for these types of handling have been explored in morphological chart rows: Pincher handling and Hugger handling.

To handle a drum with a pincher, a rigid top rim of the drum should be created. This should withstand the forces of the claw pinching and lifting the drum, hanging from the small claw. In existing drums, where the lid can be removed, a metal lidfastener is used which distributes the forces. This could also be applied in the new design.

One of the problems with the N55 drum is that the pincher claw sometimes gets in between the (rigid) lid fastener and the (more deformable) drum, causing it to pop open. To solve this the metal lidfastener could be extended downward over the body of drum, so the pincher is only in contact with the metal lid fastener. However, enlarging the metal part will make the drum heavier and more expensive. A balance should be found between improved performance and increased weight. The existing drums have been dimensions to minimize the weight (negatively influencing handling performance), creating a new design with a low weight and good handling will be very difficult.

To make a drum suitable for handling with a hugger is less complicated. Basically, somewhere towards the top of the contour of the drum, a protruding element is required for the drum to rest on the arms of the hugger. This force it spread over a larger surface (or at least two points instead of one), therefor less extreme.

Some solutions for the stability of the drum, affect the handling possibilities. Making the drum suitable for handling with a pincher does not prevent handling with a hugger, and vice versa.

Stability

It can be a nuisance if drums fall over on the roller conveyor when empty (before filling or after dumping). The light weight of plastic drum makes empty drums more at risk to fall over than a metal one (as mentioned in Appendix: Interviews). Solutions which may improve the situation as explored in row: Stability on roller conveyor.

Falling over in transport is a larger issue. If this happens, the drum may get damaged, and it is very likely that the juice will leak out the drum. Making it unsellable and requiring clean up. Solutions are explored in row: Stability in transport.

Currently N55 drums (on the second layer during transport), are strapped together and wrapped in plastic film to keep them in place. By creating a more stable design the amount of wrapping material may possibly be reduced. Resulting in reduced material and as well as handling costs for placing/removing/discarding the materials.

Manual handling

Some customers in the regions close to the juice producers (for example in Ghana) do not own forklifts and therefor manually unload trucks. In this case pallets are not used.

The simplest way to facilitate this is to create a round drum. Other options are also possible (see row: Manual handling), however these complicate the design and will most probably increase the price of the drum.

It may also be considered to take manual handling for granted, only making it suited for customers who work with forklifts. However, if manual handling can be solved in a simple way, the customer market does not need to be made smaller.

Takeaway

The are many ways to solve each of the issues discovered in the analysis phase. These are illustrated in the morphological chart. However, these solutions are not all compatible with each other. The possible combinations of solutions will be explored in Chapter: Initial concept development.

18. SYSTEM IDEATION

The design of a new drum does not limit itself to the function based features mentioned in the previous chapter, which are only focused on the physical drum. A broader exploration of the system and services provided by Maia Global is worthwhile, as this can possibly create a large impact and may affect the design of the drum.

Drum quality

The quality of the drum which Maia Global wishes to provide to its customers, largely determines the required return system and the design of the drum. Different options for drum quality are illustrated in Figure 54.

Seeing as Maia Global already has a system set in place for the reuse of containers (see Chapter: Supply chain), and reuse is the option with a lower carbon footprint (see Chapter: Sustainability), it is logical to design a drum which is reusable.

Directly reusing drums, without inspection or maintenance at a service center, may seem like the easy/cost saving option, however in this way, the quality can not be guaranteed and Maia Global has less insight into the condition of their fleet. Maia Global wishes to provide“neat and tidy”drums to all its customers, to prevent surprises (Lutzu G., 2017).

The design features which make a drum ideal for reuse have been discussed in Chapter: Ideal reusable drum.

Another interesting topic to investigate, is the fact that currently drums are all used with plastic liners. It may be interesting to create a drum which does not require a liner and is food-grade. In this way disposable plastic liners can be eliminated.

To achieve this, the drum must be entirely sealable and the cleansing/drying process must be altered to meet stricter hygiene standards. Based on industry insight, thoroughly drying the drums after cleansing will be an obstacle (Lutzu G., 2017). Studies have shown that repeated washing of refillable plastic article does not significantly influence the chemical, physical nor surface properties, however it is very likely that strongly flavoured products will cause flavour carry over (Jetten J.,1999). This might become an issue is the content of the drums varies.

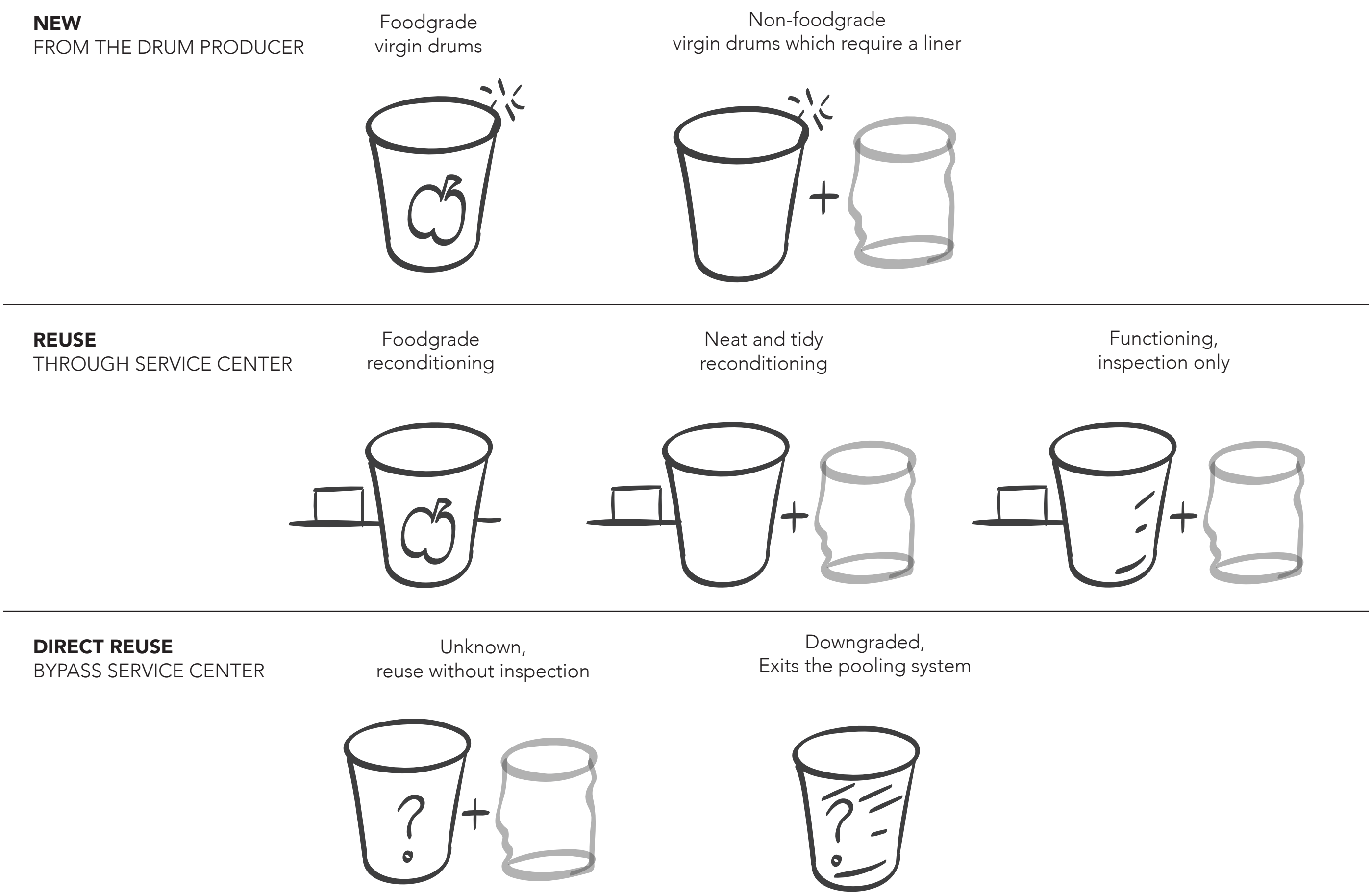


Figure 54. Drum quality levels

Demand

The demand for drums depends on the supply of the juice which will be stored or transported in it. The variations are depicted in Figure 55. In some cases juice is stored in drums for several months before it is forwarded to the next location (Appendix: Interviews). For Maia Global this creates difficulty in tracking their inventory, as this information is not shared.

In transport, the quantities of drums can vary. Sometimes a Reefer container is filled to its maximum weight load with drums. In this case the weight is the limiting factor. A lightweight drum is preferred, to allow for more weight of juice. However the dimensioning of the drum also plays a role, in limiting the amount (weight) of pallets required in transport. Read more about this topic in Chapter: Transport scenario.

In other cases, a Reefer is filled with different types of packaging. For example, a 1.000 liter IBC is placed next to 200 liter drums. By using standardized dimensions (as far as a standard is present, as these vary per region), allows for efficient loading of Reefers.

With regards to orders by customers; Maia Global currently allows different types of deployment for their Orca container. The main focus of the new design will be on the first two types in the illustration below. In this way optimal use is made of the drum (material and energy embodied in it), is not wasted.

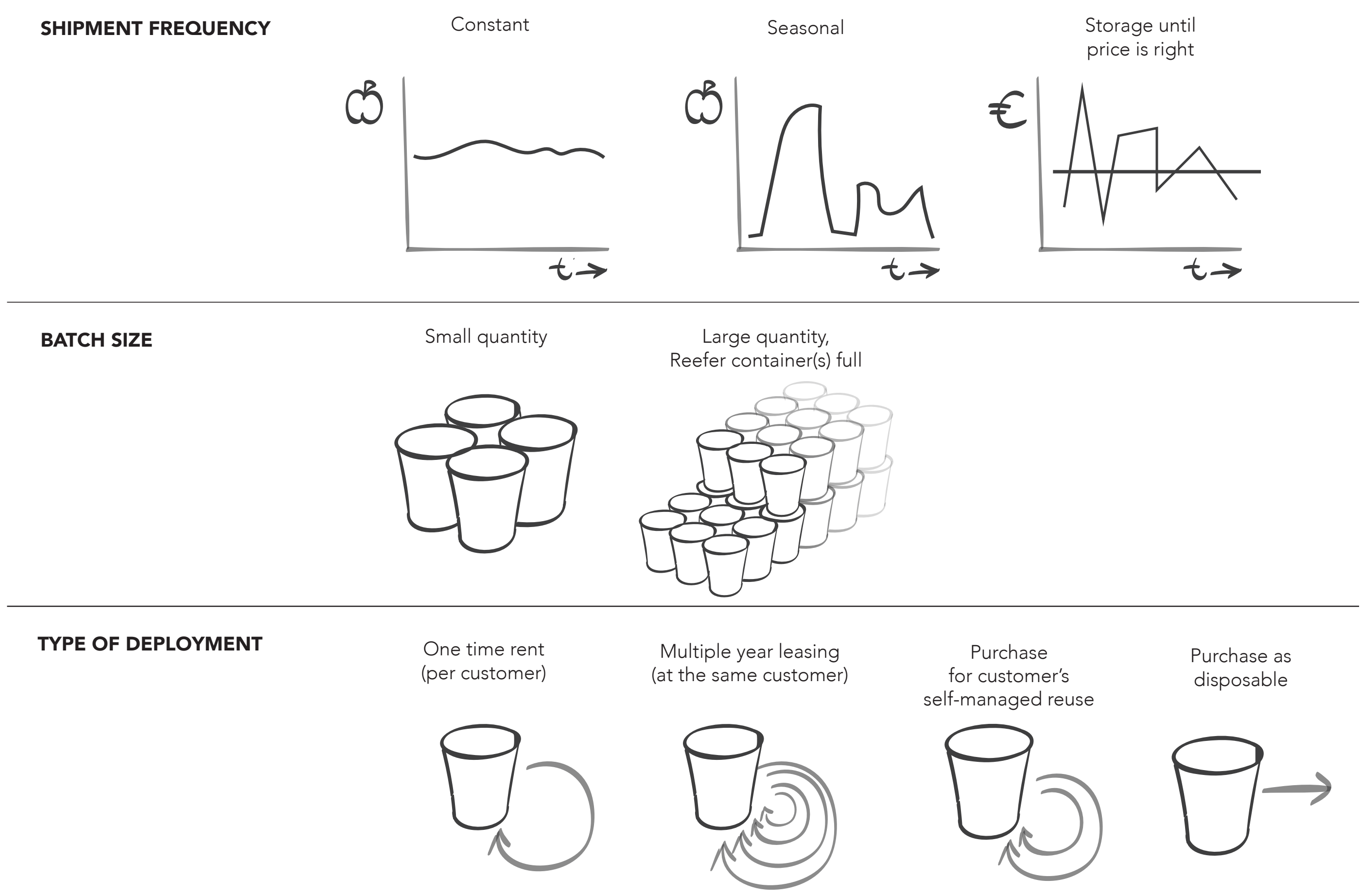


Figure 55. Types of demand for drums

Reuse system

With minor alterations the current reuse system which Maia Global has created (see Chapter: Supply chain), with service centers for maintenance, for their Orcas could be used for the new drum as well.

Some alternatives for the current system have been explored in Figure 56. These ideas focus on reducing the amount of trips made by trucks which are not fully loaded/empty, to reduce fuel emissions.

By combining delivery trips with pick up trips, delivering juice and collecting empty drums in one trip. Delaying pick up moments until a full truckload can be collected would also help. However, for such systems constant monitoring and sharing of information between parties is required.

With regards to maintenance; the possibility of not using a service center at a fixed location, but one on the go (at the customer or cold storage), would eliminated the kilometers drive to and from a cold-storage. However this is quite a complicated system to set up. Also an added bonus of having a service center is that is can be used as a storage location, for buffering drums between deployments. Also the use of dedicated staff, who frequently works with the drums is beneficial, to ensure the job is done correctly.

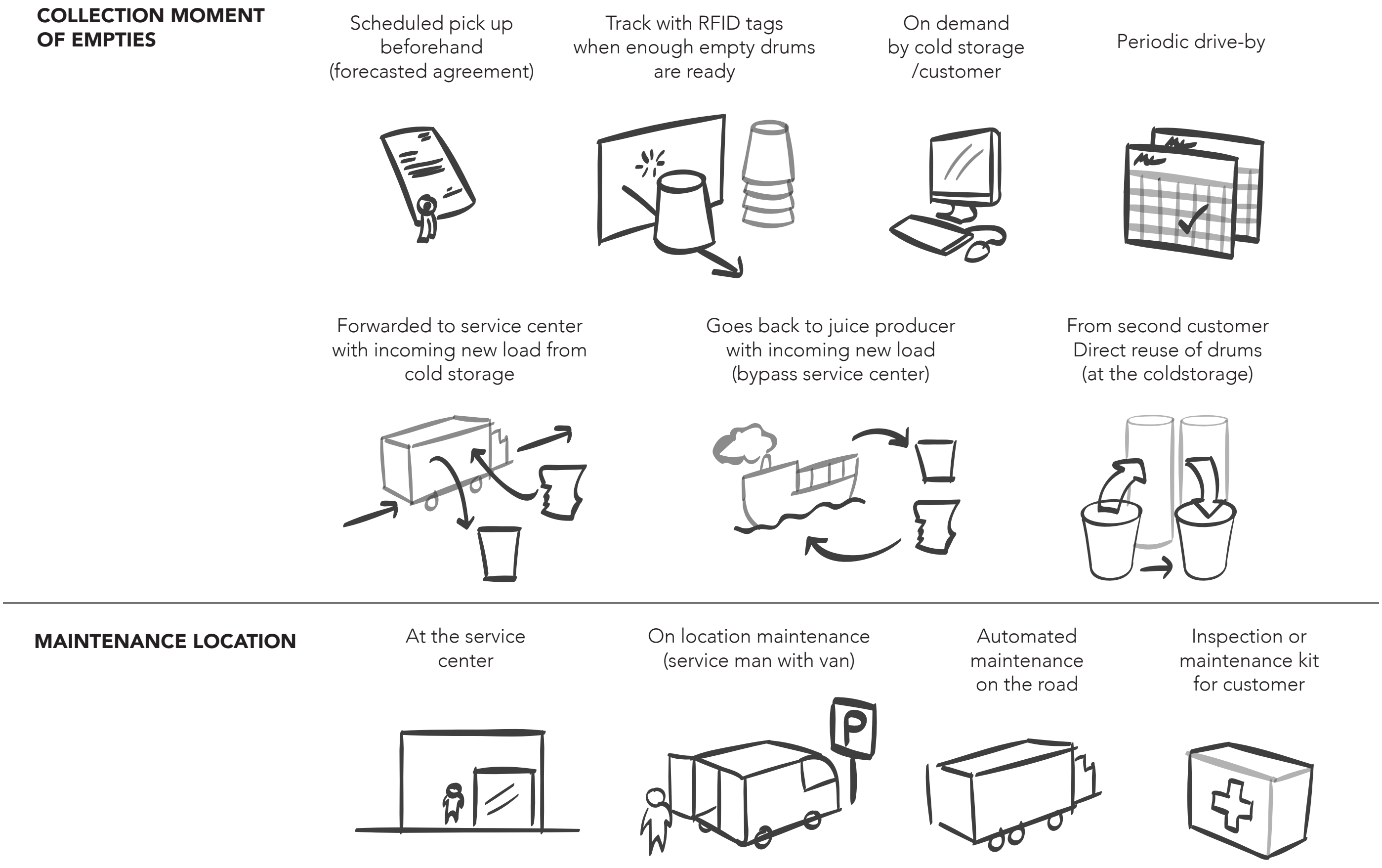


Figure 56. Reuse system possibilities

Information

Within the system of drum use, transport and pooling, there is a lot of information which needs to be transferred between parties in the supply chain. There are multiple ways to do this. Also some new opportunities for gathering useful information have been identified in Figure 57.

RFID-tagging or bar-coding drums allows for useful, up to date, insight into the inventory of drums. Each drum receives a unique code, which can be linked to information about its journey and content. For the most effective system sharing of information would be desired, for example: when a drum arrives at a cold storage this information should be forwarded (read more about this in Chapter: The future system).

Figure 57. Types of interesting information in the system

Sustainability

In the prior ideation sustainability has been approached by focusing on reducing the empty volume of drums and the volume in transport when full. However there are still multiple other solutions which can also be applied, these are listed in Figure 58.

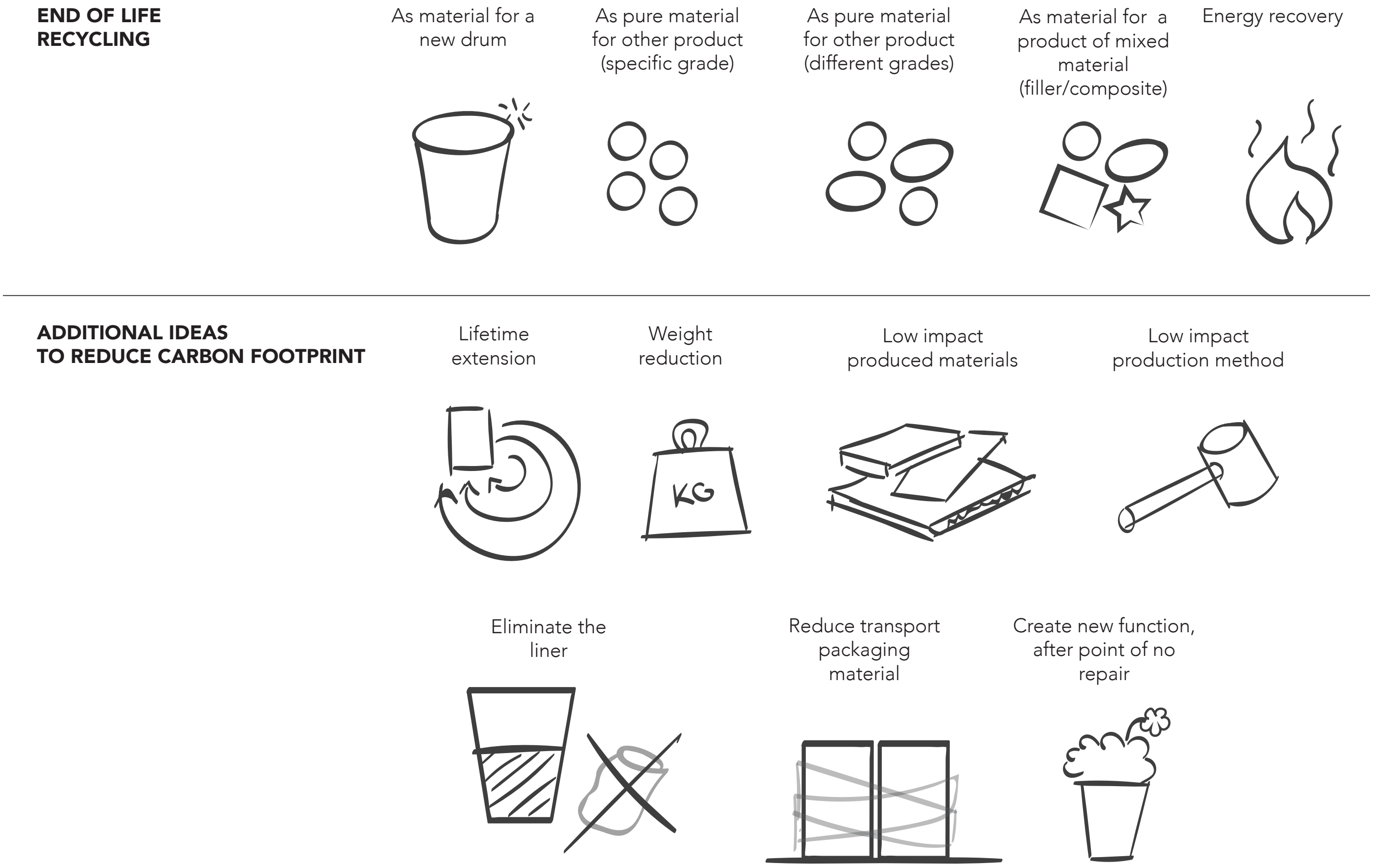


Figure 58. Additional ideas to improve sustainability

Takeaway

A broader has been taken into consideration, looking at opportunities for the system surrounding the drum. The main new topic introduced, which reoccurred on many levels, are the possibilities provided by using information from the supply chain in a smart way. This can increase the efficiency, mainly in transport, which in turn reduces operation costs (after an initial investment in technology) and the carbon footprint.

19. INITIAL CONCEPT DEVELOPMENT

Five initial concepts of reusable drums have been created, putting together elements from the morphological chart in Chapter: Product level ideation, and opportunities introduced in the Chapter: System ideation. Each concept has its own unique benefits (+), shortcomings (-) and points which require further investigation (o). These will be discussed on the following pages. These are still rudimentary concepts, however they provide a direction for further development.

The morphological chart has been used to indicate the features which have been incorporated in each concept. The opportunities for further embodiment of each concept have also been indicated in the chart.

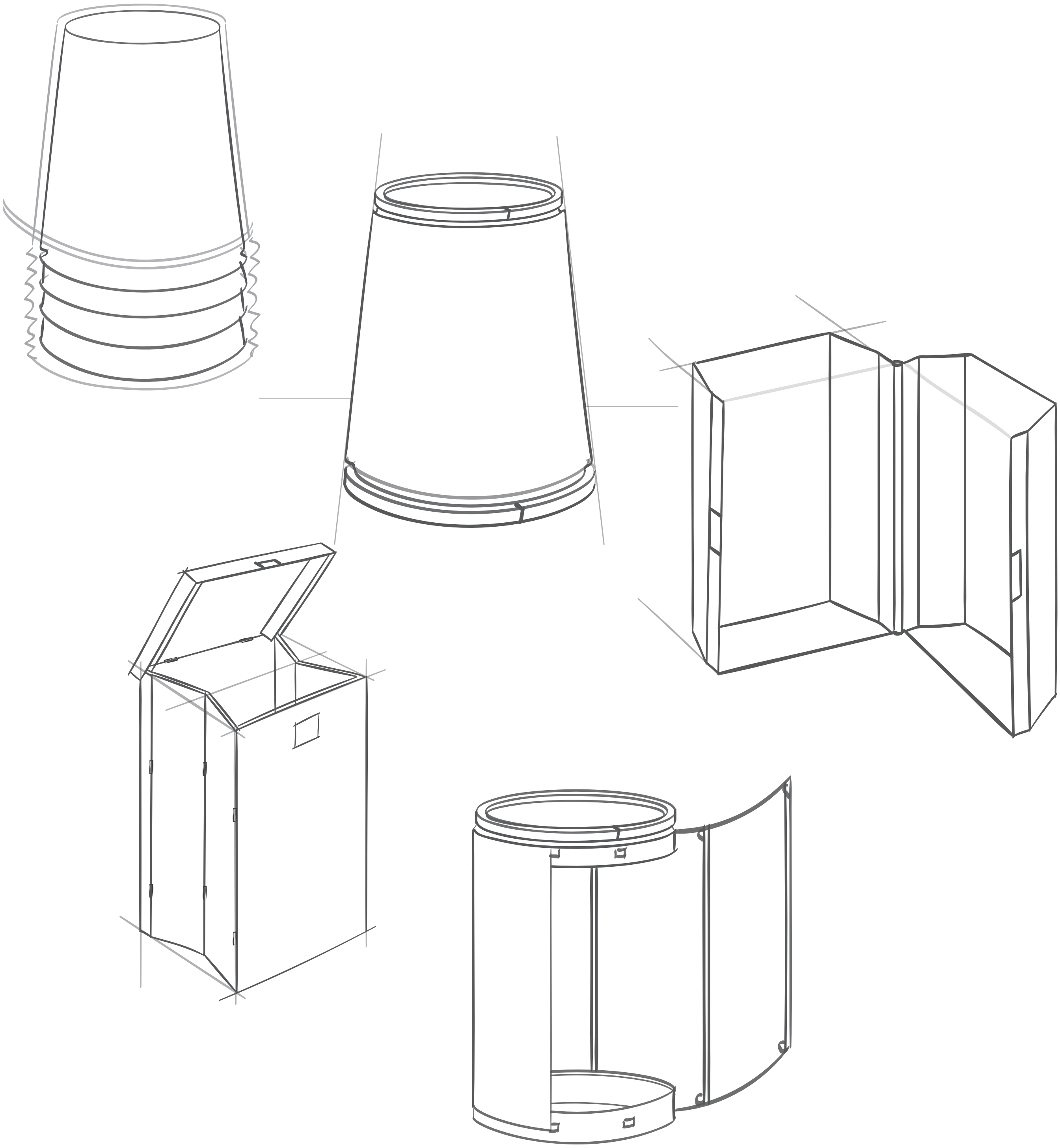


Figure 59. The initial concepts

20. THE NO LINER

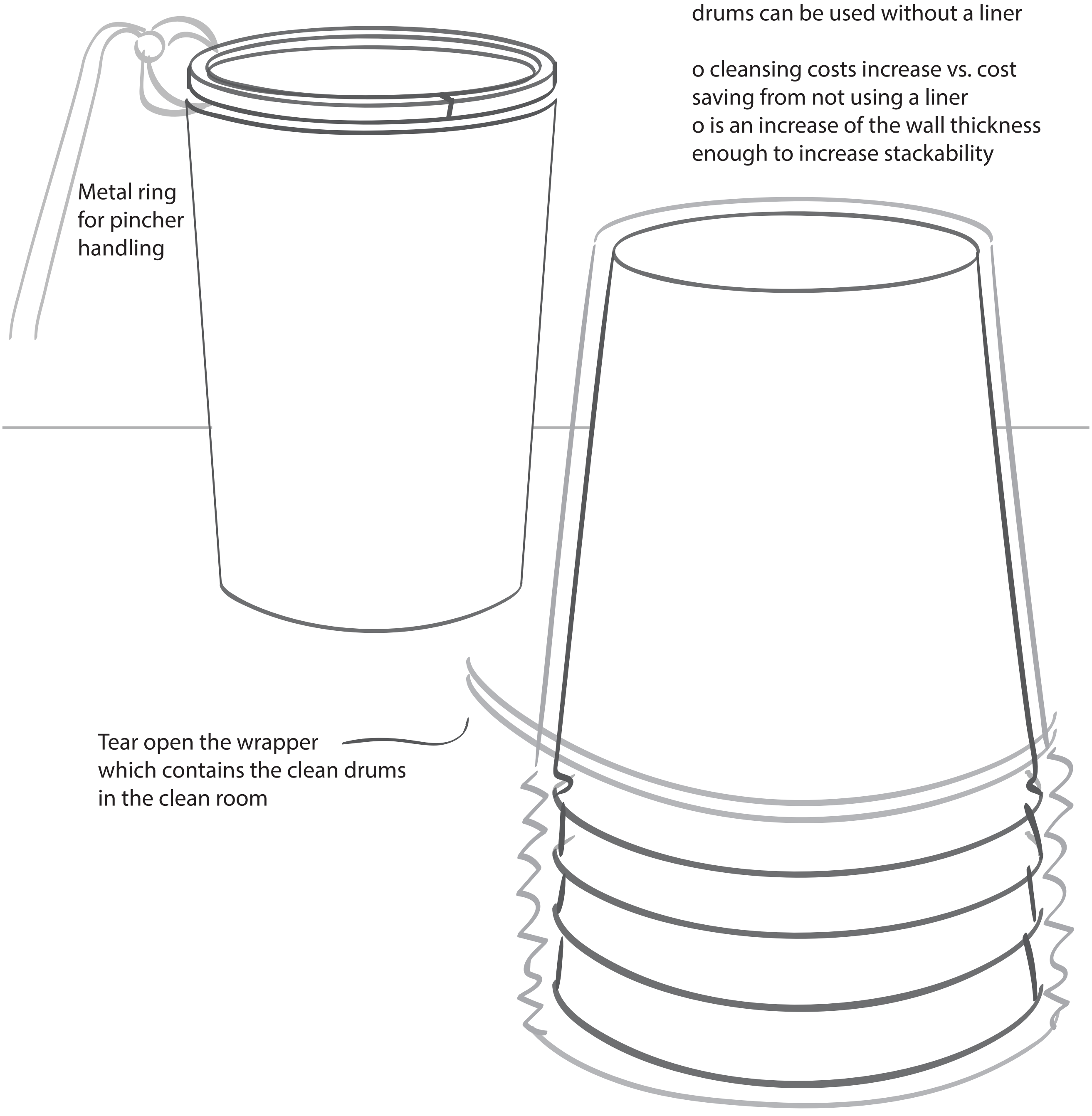
Elimating the liner cuts down waste. The existing N55 plastic drums are already airtight and Coexcell claims they can be cleansed by Contraload for reuse to foodgrade level without a liner. This should be further investigated.

A blowmoulded HDPE drum, which has been optimized for handling and cleansing will be created. An element will be introduced which clearly distinguishes a drum which can be used without a liner from one which cannot.

+ less packaging waste
+ nestable
+ distinguishes itself as foodpackaging, not an oil drum

- liability shift, the drum cleanser must assure the drums are foodgrade, not the liner producer
- it must be very clear that only specific drums can be used without a liner

o cleansing costs increase vs. cost saving from not using a liner
o is an increase of the wall thickness enough to increase stackability



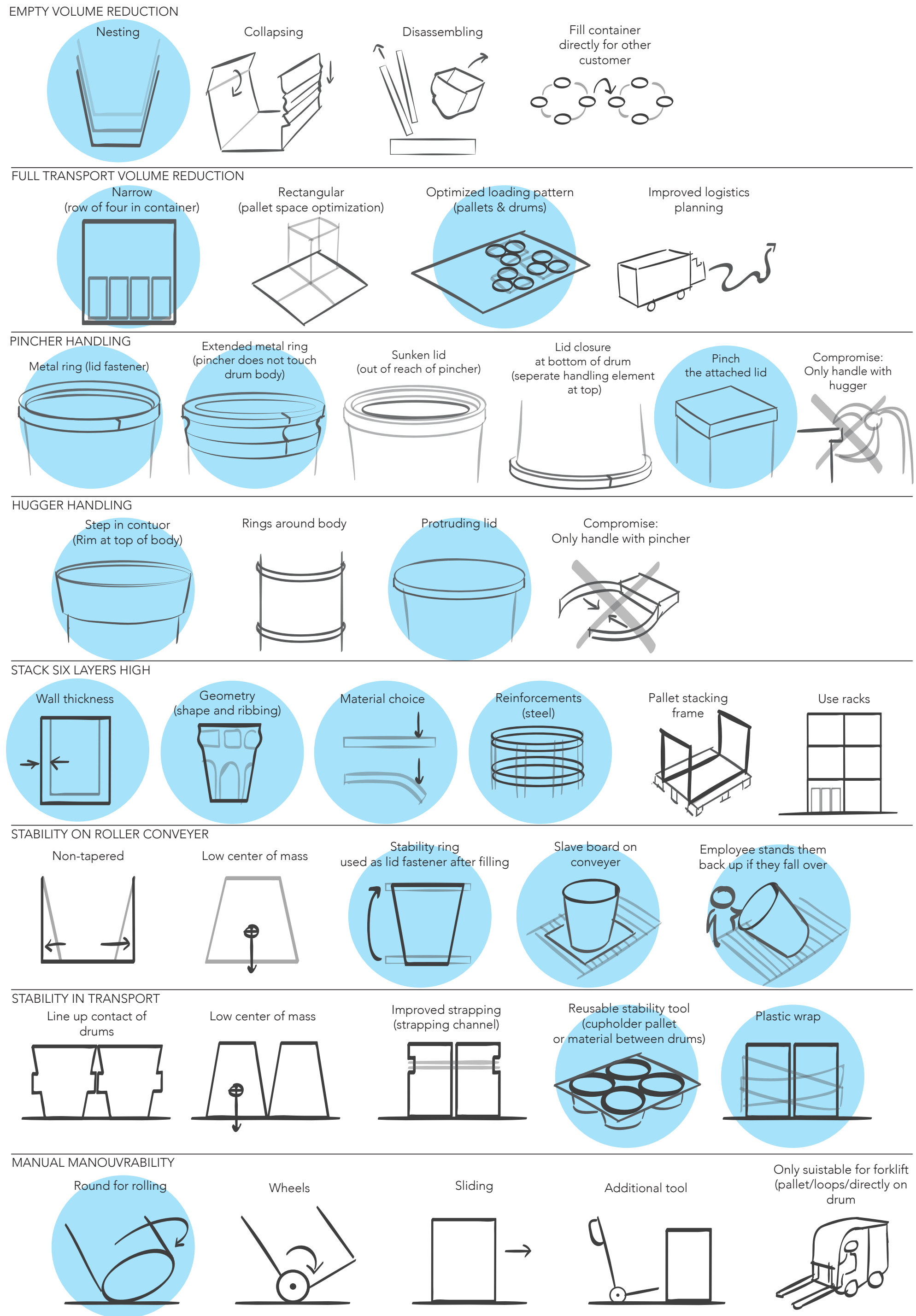


Figure 59. Morphological chart, possible/promising solutions highlighted for: The no liner

Elaboration

The main focus of this concept is to eliminate the necessity to use disposable liners inside the drum. With each use, a liner is thrown away in the mixed waste bin. The liner not clean enough to be collected for plastic waste recycling, as it is covered in juice. The function of the liner is to ensure that the juice does not get contaminated and remains safe to drink. Some customers prefer to even use two liners, to second acting as a back up is the first one tears.

A drum which takes over the functionality of the disposable liner would need to be; airtight and sterile when taken into use. To be airtight the amount of seams (possible openings) should be minimized. Achieving a sterile drum is more complicated, especially when reused. It should be possible to wash and dry the drum completely (or use another method), without residue. For this a smooth inner surface without corners, where build up of dirt can occur is preferred. Also the drum must be delivered to the clean room of the juice producer without getting contaminated. The liability for being food-grade will no longer be with the liner producer.

The smooth inner surface and airtight design can most probably not be achieved with a collapsible or drum which can be disassembled. Therefor only nesting is an option, if a reduced return volume ratio is desired. This means the drum must be tapered. This is a restricting factor for the stability functions shown in Figure 59.

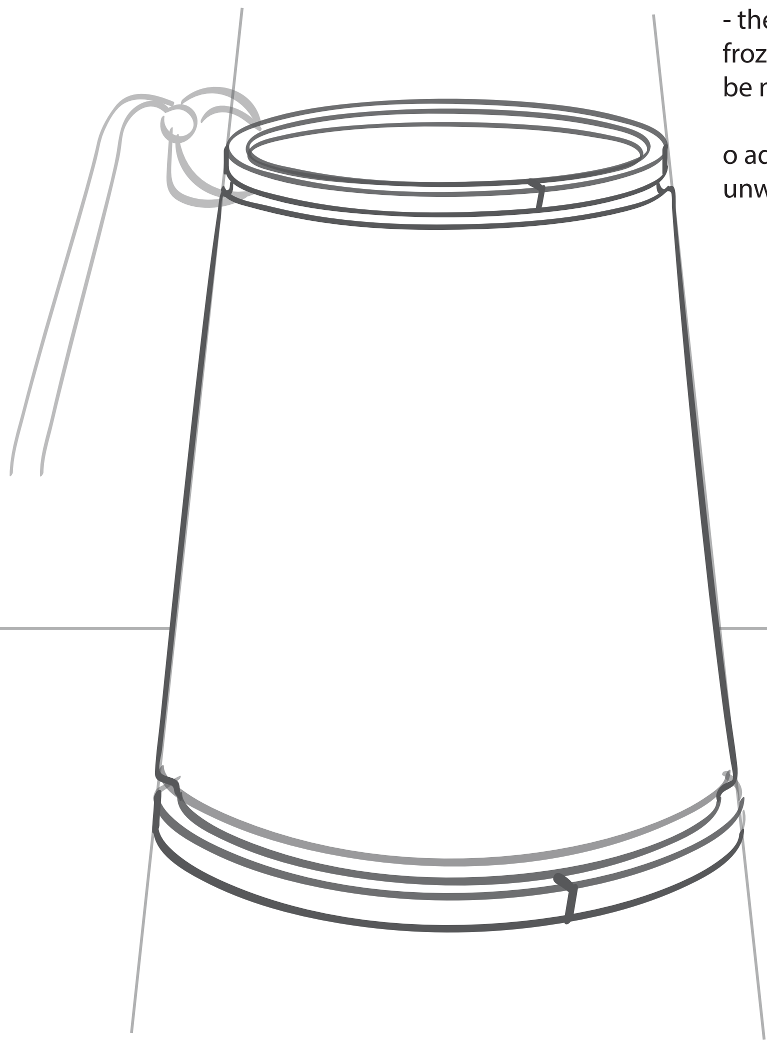
21. UPSIDE DOWN DRUM

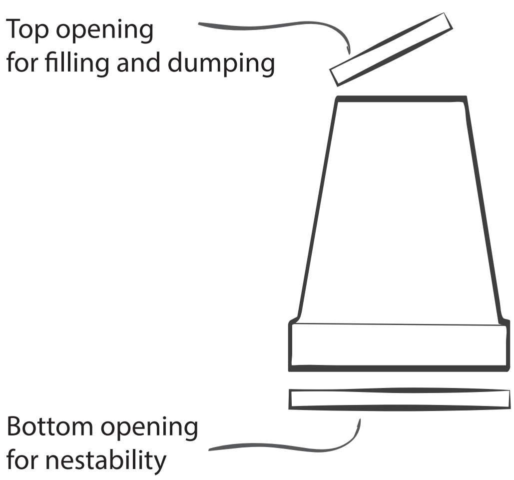
A blowmoulded HPDE tapered drum with a new orientation. The bottom of the drum is wider, for increased stability, in transport and on the roller conveyer.

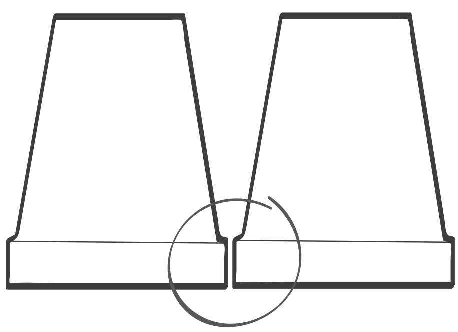
+ stability in transport and filling
+ nestable

- two openings to close (one before and other after filling, other for nesting)
- the top opening is narrower than the frozen content, the content needs to be melted sufficiently

o adapt lid fastener /drum to not open unwantedly







Allignment of bottom edge
Rim for easy denesting and strength

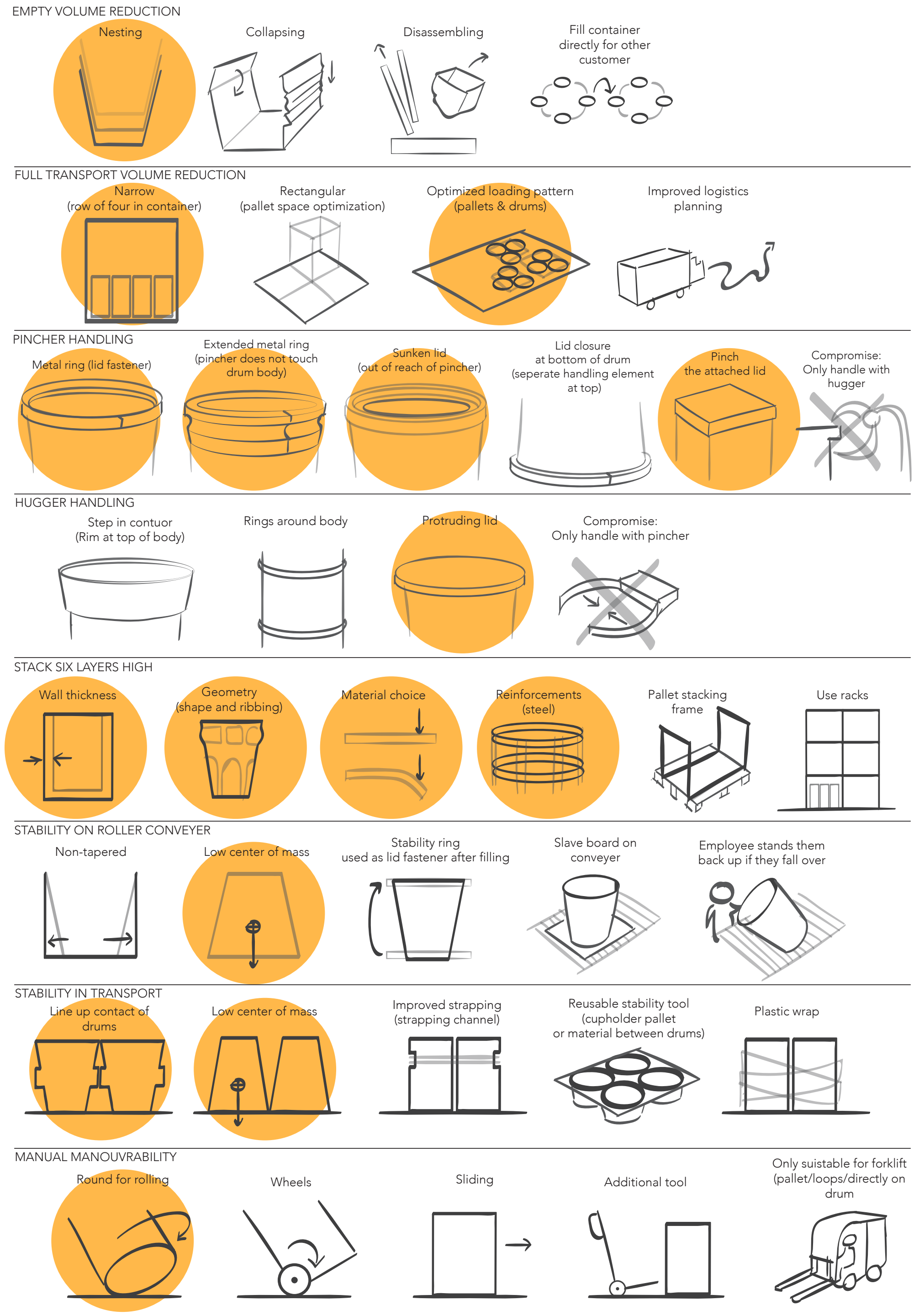


Figure 60. Morphological chart, possible/promising solutions highlighted for: Upside down drum

Elaboration

This concept addresses the stability issues of tapered drums, as shown in Figure 60. By flipping the conventional tapered drum upside down, a more stable design is created, the foot is wider than the top. Also the bottom edge has been made straight (vertical) so that drums align more securely and can support on each other at the foot.

To be able to nest the drums, the wide mouth, now the bottom, must be openable. However, for filling with juice, the smaller end at the top must also be openable. This is because the extra stability is required on the filling line (therefor the drum can not be flipped the other way around on the filling line).

The main challenge of this design is the fact that the drum will have two lids which must be opened nd closed. This means one additional handling step, and one extra pile of lids when the drum is nested. The bottom lid should also be strong and secure enough to prevent it from opening from the weight of the juice, or if two drums are stacked very closely and step on each others foot.

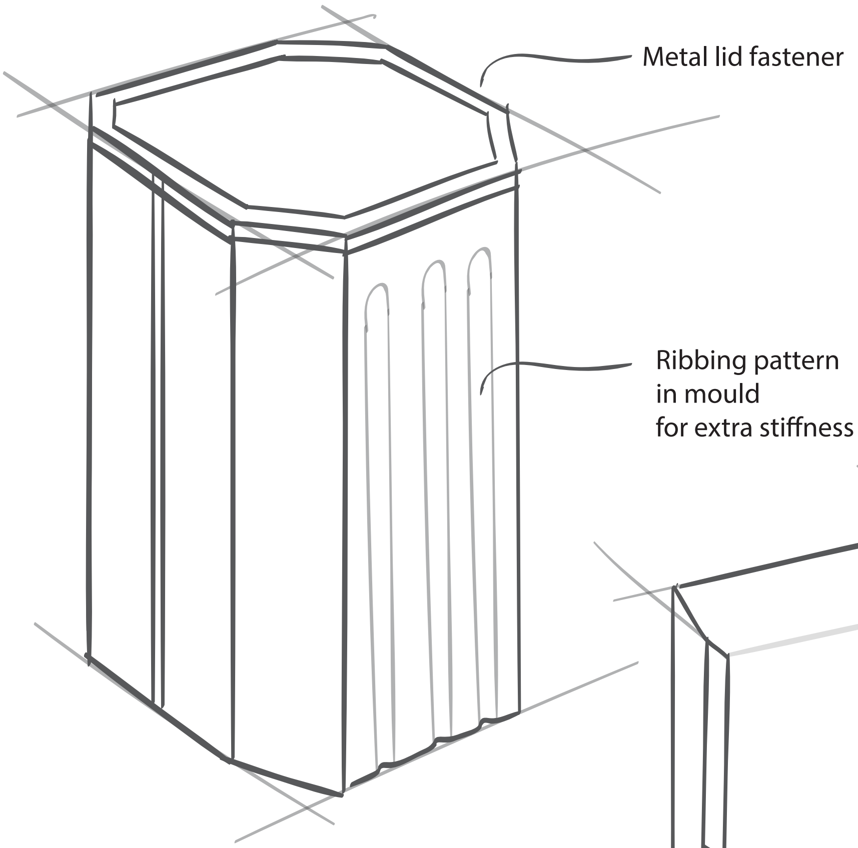
22. CLAMSHELL

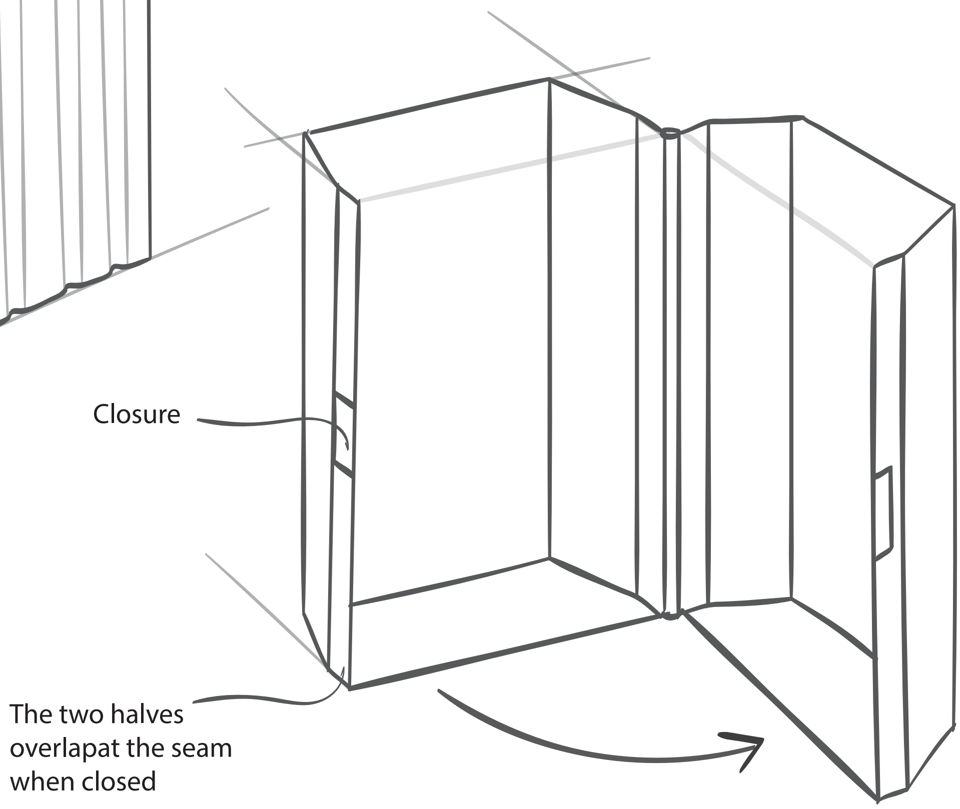
A clamshell, suitcase like structure, consisting of two thermoformed, blowmoulded or injection molded halves which hinge open. Creating a drum which can be opened for nesting.

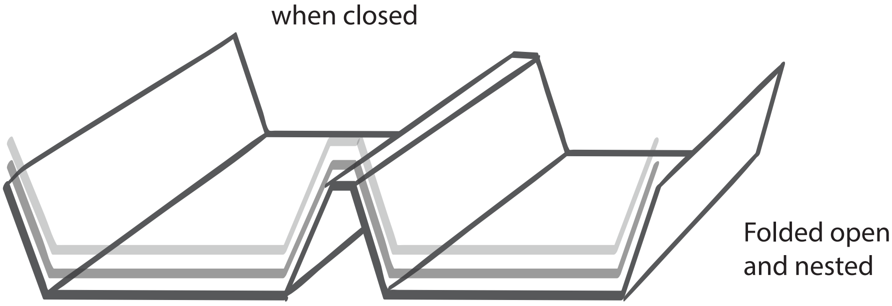
+ stability in transport and filling
+ nestable

- hinging element will fail over time (requires maintenance)
- an additional action of opening the drum is required when it has been emptied

o create a closure which prevents the clamshell from opening unwantedly







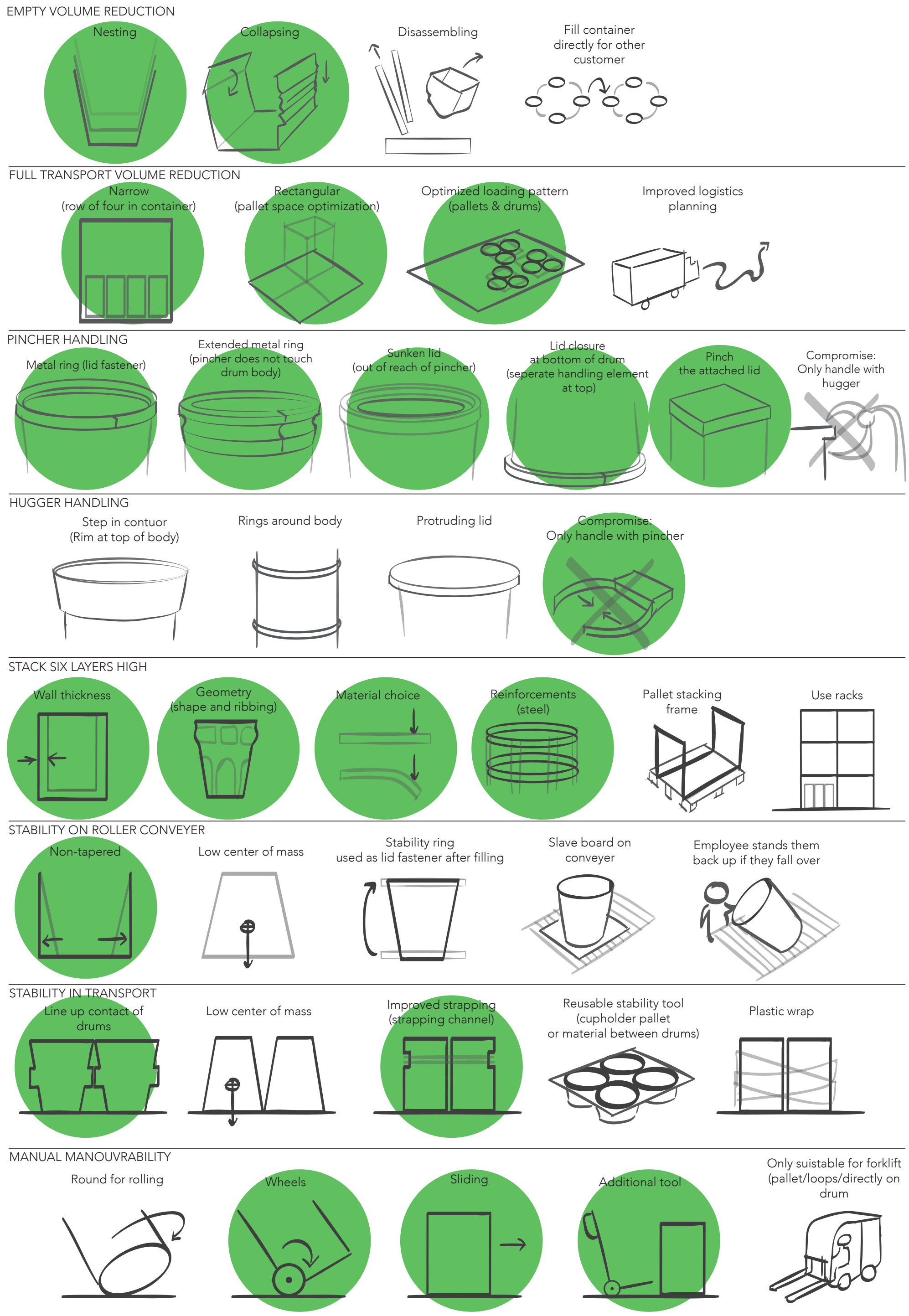


Figure 61. Morphological chart, possible/promising solutions highlighted for: Clamshell

Elaboration

The clamshell concept consists of two halves which are connected together with a hinge, this allows the drum to be folded open and then nested.

The octagonal shape, with straight (non-tapered) walls allows for the drums to line up securely in transport. This shape also uses the space on the pallet more efficiently. There is no loss of space due to tapering, and the octagonal shape is closer to the rectangular shape of the pallet, whilst still being nestable when folded open (a perfect rectangle would not be nestable).

However, choosing not to make the drum round has some negative effect for hugger handling and manual maneuverability, as shown in Figure 61. The arms of the hugger can not reach in-between the tightly packed drums. And rolling an octagonal shape manually may not be possible.

To make this design feasible a suited hinging system must be created. This might be an "external hinge" which works with a pin which slots into the halves of the body. Or it could be a "living hinge", which is produced together with the two body halves in the same mould, from the same material. The durability of the hinge is an important factor, as it is the most prone component to fail in this concept.

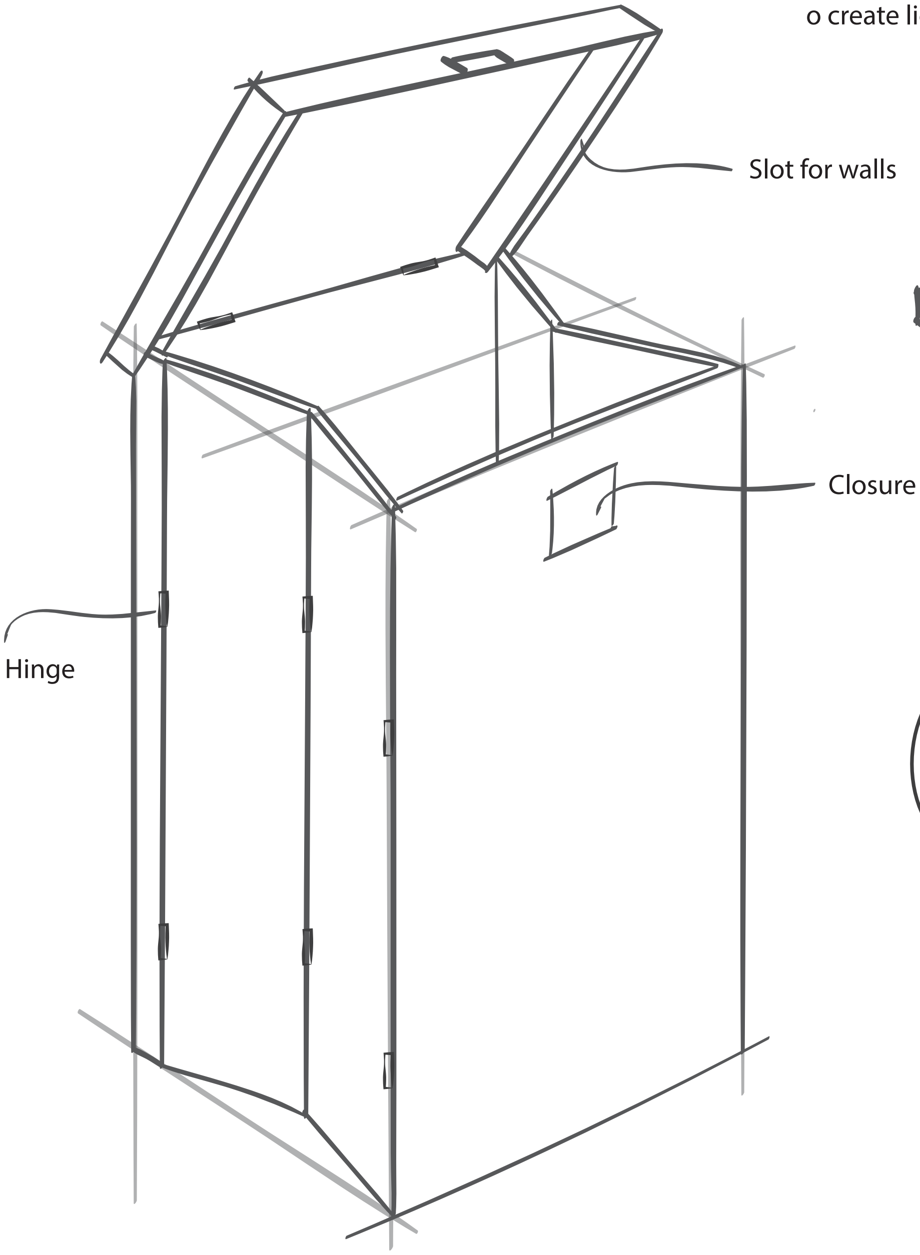
23. RECTANGULAR COLLAPSIBLE

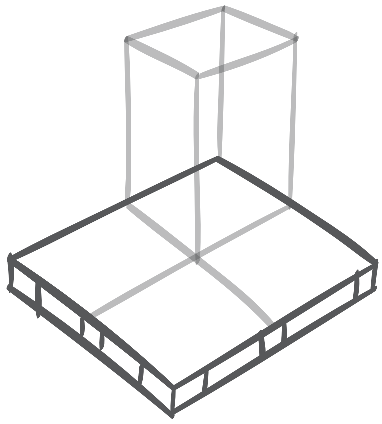
A rectangular shape is more space efficient in transport. Rigid injection moulded plastic panels with ribbing create a crate which can be collapsed to save space when empty. The lid and bottom aid to prevent the crate from folding inward unwantedly.

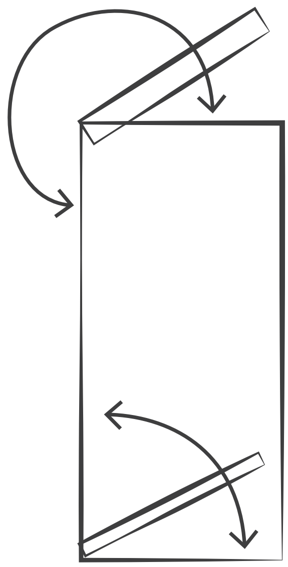
+ makes optimal use of pallet space in transport and storage
+ low empty volume
+ no loose parts (integrated lid)

- hinges will fail over time
- folding empty crates is an extra handling step

o create a hinging method with a long lifetime or easy repair
o create lid closure







The lid and bottom keep the crate in its desired shape. When flattened the lid is flipped to the back and the bottom is pushed inward.

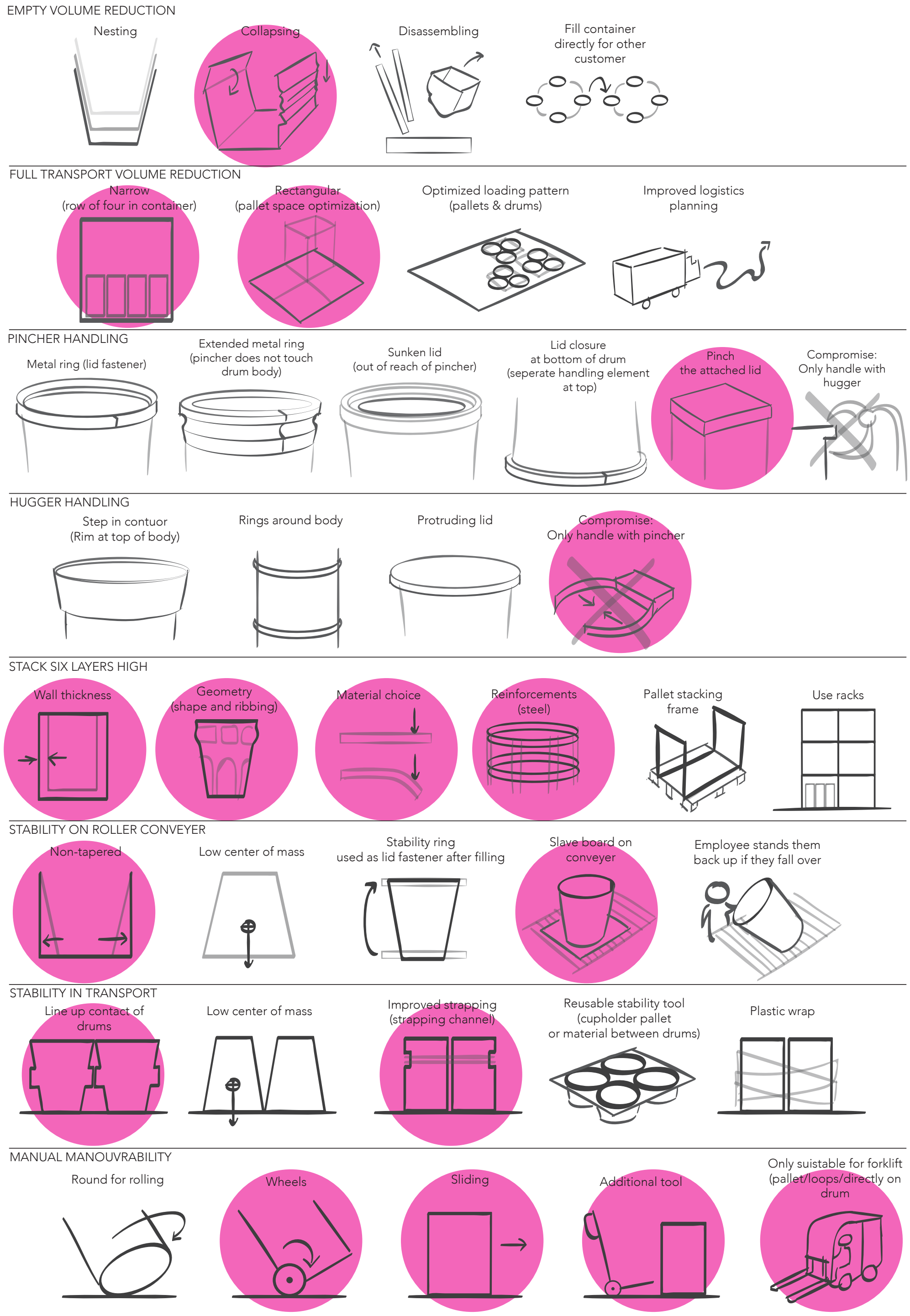


Figure 62. Morphological chart, possible/promising solutions highlighted for: Rectangular collapsible

Elaboration

The goal of this concept is to create a drum which makes the most efficient use of the space on a pallet. Drums are transported and stored on pallets are used throughout the supply. The main type of pallet used is 1.200*1.000 mm. To create a drum with similar dimension to current drums, to make it suitable for current handling equipment, the pallet should be split into four parts.

This rectangular shape is space efficient on a pallet when filled with juice. The efficiency in a transport Reefer will be explored in later chapters. Also when the drum is empty, it can be folded/collapsed into a space efficient form. This collapsed shape has potential to be more space efficient than a nested drum, seeing as a pile of nested drums always has the volume of one empty drum unused at the top of the pie. In this design the size of the empty drum is determined mainly by the wall thickness and hinging method. Incorporating a lid, which is attached to the body will decrease the amount of loose parts to handle (store neatly/package for transport).

The rectangular shape however does not only have advantages. The drum can not be handled with a hugger or rolled manually, as shown in Figure 62. The drums should also be designed in such as way that the amount of hinging elements is minimised, as these are the most prone to failure.

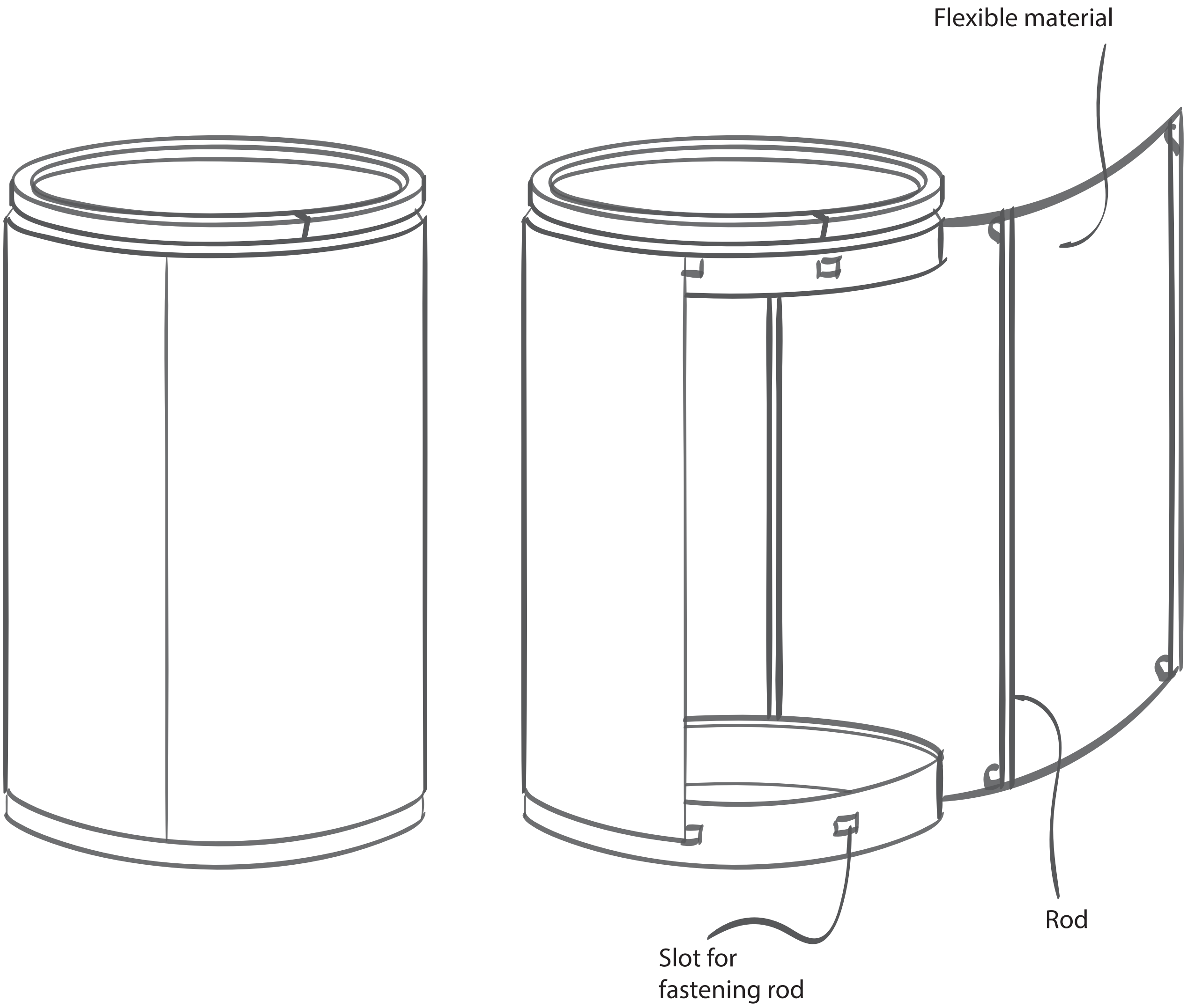
24. WRAP AROUND WALL

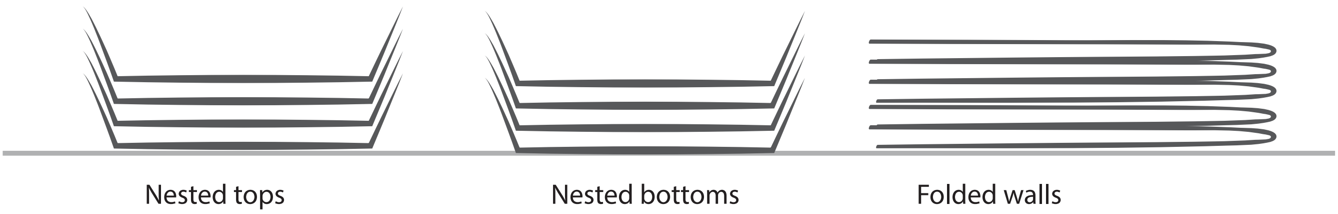
This drum can be dissambled into three pieces when empty; the top, bottom and sidewall (and lid and lid fastener). The wall consists of a flexible material, keeping the liquid in place and with rigid metal rods, for stackability. The top and bottom are rigid caps with slots where the rods can be fastened.

\+ low empty volume
\+ differentiating

- disassembly into multiple parts
- flexible material may be vulnerable to wear and tear

o fastening method of wall to top and bottom





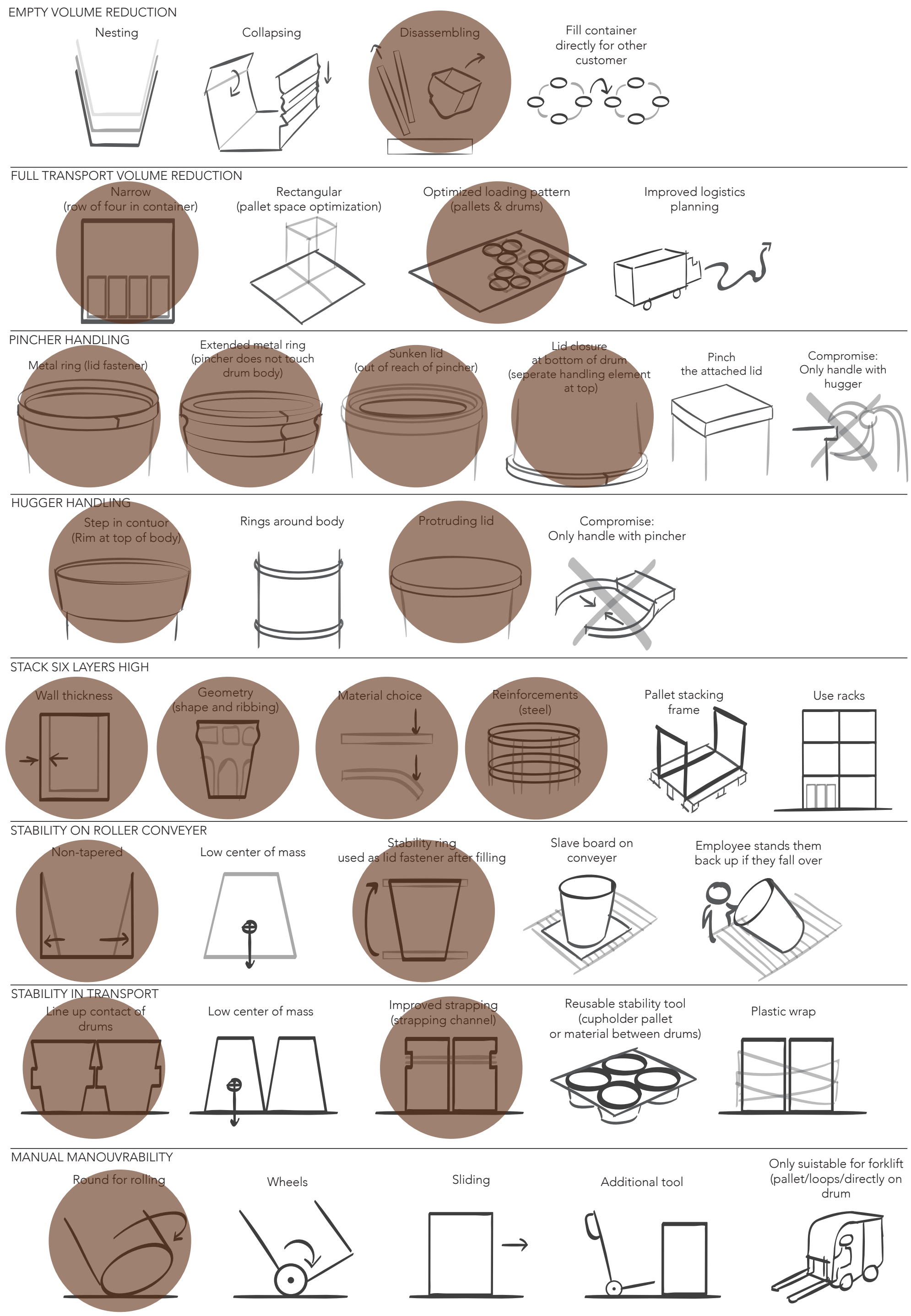


Figure 63. Morphological chart, possible/promising solutions highlighted for: Wrap around wall

Elaboration

The essence of this concept is to create a drum which has a flexible side wall which can be removed and takes up very little space when empty. This side wall has incorporated metal rods to give it structure for stacking drums on top of each other. It also consists of a top and a bottom.

When embodying this concept, handling the drums with a hugger should given extra attention (Figure 63). The walls of the drum should withstand the inward force on the walls, caused by the hugger and the flexible material should not tear if the drum is handled with brute force.

In its current form each drum consists of five parts; the wall (in which metal the rods have been fastened during production), top, bottom, lid and lid fastener. This is two more than current drum (body, lid and lid fastener). This means that there is more work involved in disassembly after use and preparing for transport, parts may even get lost. However this full disassembly of the drum creates potential for maximum empty volume reduction.

25. COMPARISON OF CONCEPTS

In this chapter the five concepts will be compared and reflected on, to find the most promising direction to continue in.

A visualization, Figure 64, has been created in which the different concepts, represented by a coloured line, are rated on the main design criteria. The grey zone is the benchmark, the score of the N55 drum. These criteria, presented in random order, have been formulated based on the findings from the analysis phase and interviews. The scores have been given based on design insight into the possibilities, when these concepts would be elaborated further, as explored in the morphological charts in the previous chapter.

The criteria which have been used are:

- Potential carbon footprint reduction: At this phase the drums have only been developed to a minor level of materialisation. The main effect on the carbon footprint is evaluated by the reduction of waste (for example: no plastic liners used) and a reduced volume when empty.

- Handling once empty: Once the drum has been emptied at the cold storage the empty drums, lids and lid fasteners need to be collected. Some concepts require an additional step, like disassembling or collapsing the drum. The reverse applies when filling the drum. These handling steps (time and effort) should be minimized.

- Suitable for extensive reuse: The goal is to create a reusable drum. In such a system, a drum is preferred which requires little maintenance and has a long lifetime. This can be achieved by for example; minimizing moving parts/hinges and making a drum easy to repair.

- Handling with pincher: For a drum to be handled with a pincher, it must have a top edge which can resist the clamping force of the claw, without the drum opening (see Chapter: Existing products).

- Handling with hugger: A hugger wraps around the body of a drum and needs a top rim, which prevents it from slipping down. Either handling with a hugger or pincher must be possible, preferably both.

- Empty volume reduction: The "transport of air" should be prevented. When there is no juice in the container is should take up less space. This is also beneficial to save storage space.

- Stability on conveyor and in transport: Drums should not fall over easily.

- Manual handling: For markets in the region of the juice suppliers, being able to handle a drum without a forklift is desired. For customers in more developed countries this is not required.

When presenting the concepts to the company, it was agreed that the "No Liner" would not be continued with. This is due to the complicated issue of reliability; the food safety would need to be ensured by Maia Global, instead of the plastic liner producer as is currently the case. This was seen as a large obstacle.

There is not one concept which scores the highest on all criteria. However, the clamshell concept scores consistently high on all criteria. Unlike the other concepts it does not have criteria which is scores very low on, which indicates an obstacle which I evaluated as very difficult to overcome. The clamshell concept will be worked out in the next phase of this project. Combining the positive elements from other concepts and making the most of the features which were highlighted in the morphological chart in Chapter: Initial concept development.

Takeaway

This comparison makes it clear that the concepts, each have their strengths. However the features which contribute to this, sometimes create a direct disadvantage on other criteria. The clamshell is the most promising direction, as it scores consistently high on all criteria. This concept will be continued with and improved.

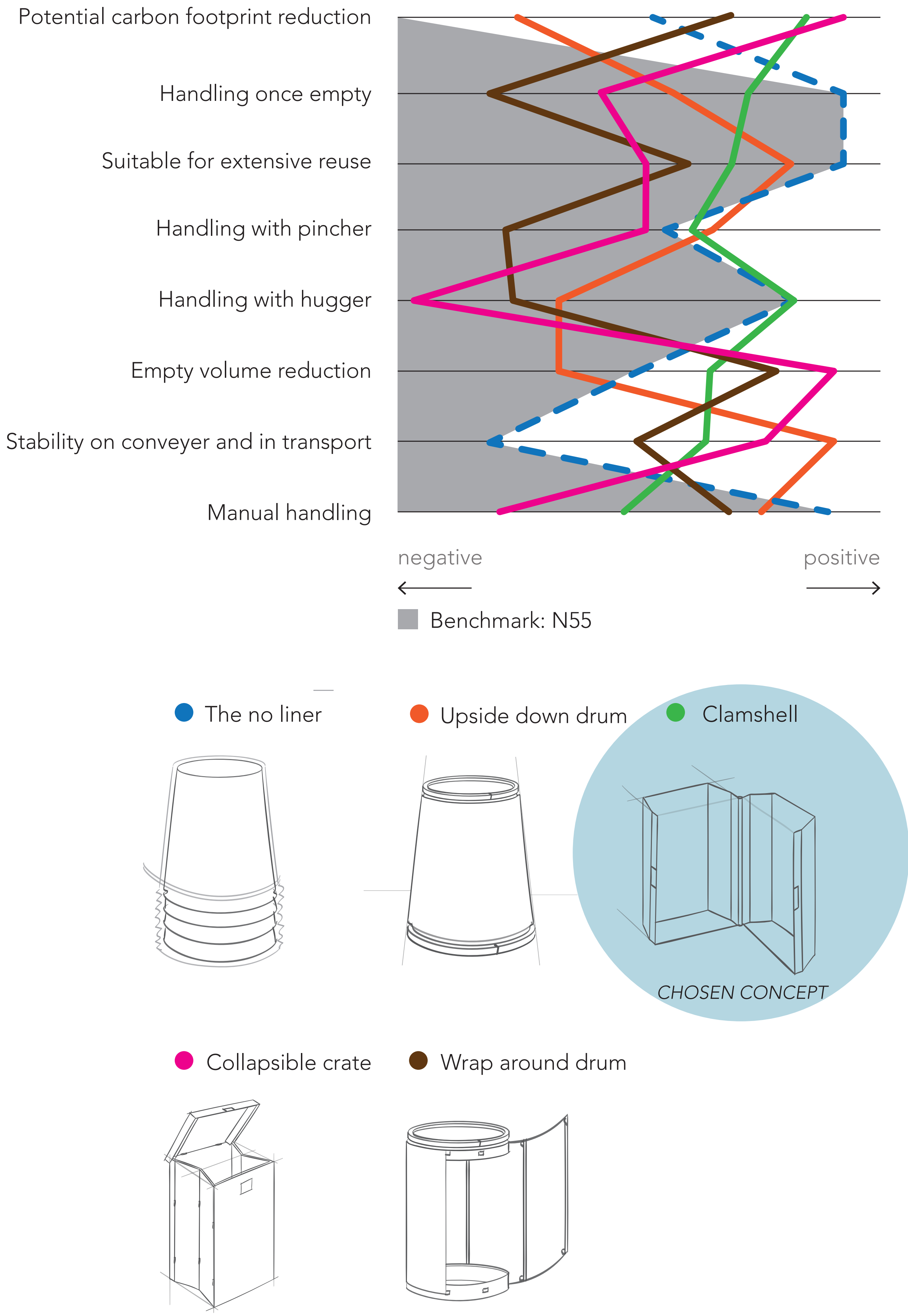


Figure 64. Comparison of the concepts

26. CHOSEN CONCEPT

In the previous chapter the Clamshell was found to be the most promising concept to continue with. However some recommendations for improvement can me made already at this point. These alterations will be introduced here and elaborated in the Embodiment phase of this report.

Feedback session with Maia Global

The concepts were presented to members of Maia Global and they gave their insights into what, based on their experience with the industry, would be an interesting direction to continue in. It was agreed that the clamshell concept was most promising. After useful feedback on the limitations of the concept Rectangular Collapsible, which was initially chosen (read more in Appendix: Rectangular shape in a Reefer, Initial chosen direction, Folding mechanism and Use scenario rectangular concept)

Alterations to the concept

The comparison of the concepts in the previous chapter, and a decomposition of the specific design features which are/are not beneficial, concluded in alterations which would be beneficial in the new design. These are closely intertwined but can be described as:

- Make it round: The space saving benefit of a square drum in transport is minimal due to weight limits in Reefers (see Appendix: Rectangular shape in a Reefer). The benefits of a drum with a round shape are: no vulnerable corner points (the round shape distributes forces), it can be rolled by a worker and it is non-directional (when loading a truck the direction which it is placed in does not matter).
- Simplify the closure system: Implementing additional parts to the design, such as external hinges, could increase the production and assembly costs. And a living hinge may not be as durable as desired. Using the shape of the body to keep to two halves together, with a form fit using the pressure of the liquid which pushes outward, would be ideal. And could keep the weight of the drum to a minimum.
- Add external band: The two halves must be securely locked in place, to be assured of this, an external band may need to be added. For example a metal ring which is closed with bolts.

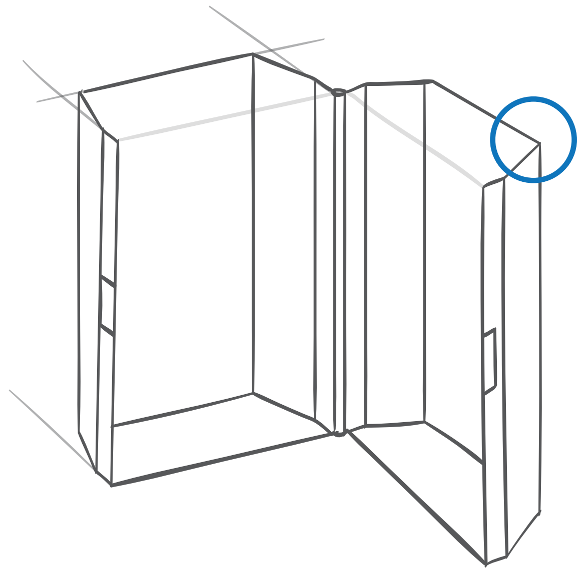


Figure 66. The original clamshell concept. A drum existing of two hinging halves which can be nested when folded open. One of the vulnerable corner points highlighted in blue.

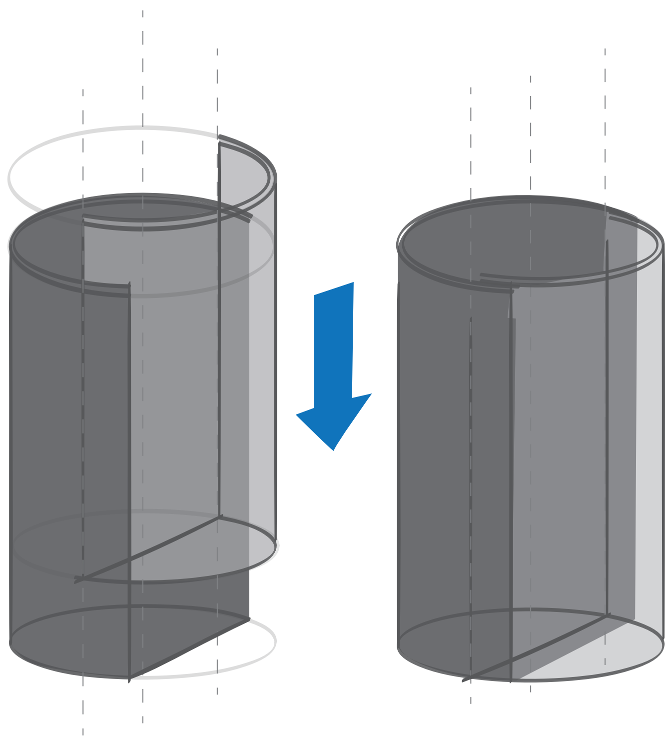


Figure 65. An initial iteration sketch of the chosen concept. The hinge has been removed and the drum is made up of two independent round parts which slide into each other and interlock. See chapter: Embodiment, for further iterations.

27. THE FUTURE SYSTEM

While designing the new drum, paying attention to the larger system and not only the physical design, some additional opportunities arose. The benefits of tracking containers were first introduced in Chapter: System ideation. In this next chapter these will be discussed further, seeing as they have implications for the new drum design.

Tracking

Maia Global currently works with bar-codes on their containers and is doing trials into replacing these with RFID tags. The current reason to use these tags is to be able to identify each container with a unique code. This code allows for the monitoring of inventory (containers). These codes are currently only scanned at the service center, to know which customer returned how many containers and in which condition.

The use of RFID tags could however be taken much further, to perform to its full potential. The most obvious example would be to expand the current inventory monitoring to track the containers with more accuracy. Providing a specific location at each moment in time, which can be useful for scheduling. This information can be valued for Maia Global, cold storages as well as the customer. In Figure 68, a warehouse suitable for precise tracking of inventory, with the aid of the required software, has been depicted.

An RFID tag can however be provided with more information than an identification code (number). They could be equipped with information about the contents, instructions for storage/blending/ transport etc.

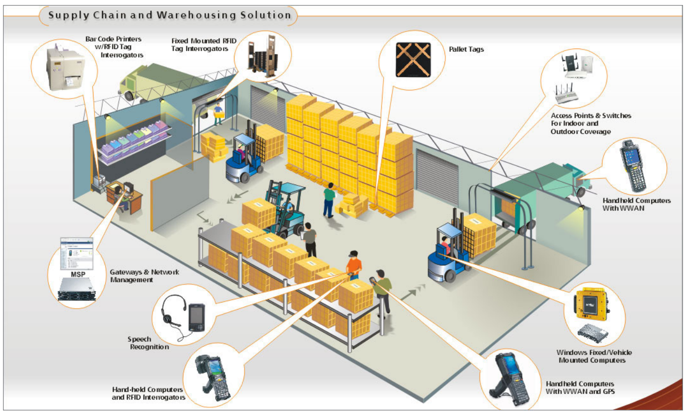


Figure 68. An example of RFID tags being used in combination with "scanning portals" in a warehouse, in the medicine industry. (Tecoid, 2017)

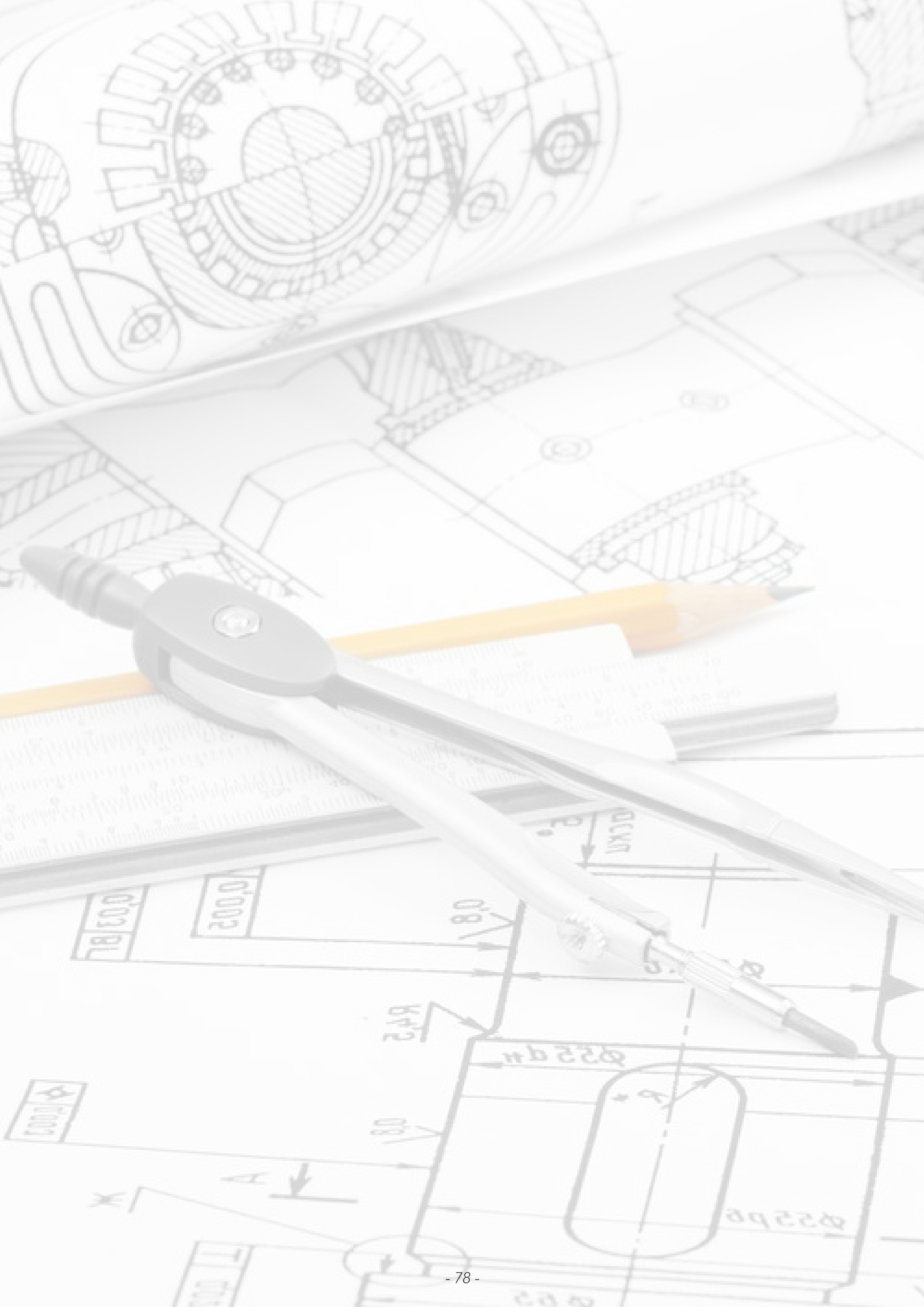
For most of these solutions, collaboration is required from different parties in the supply chain. This may be the largest obstacle, therefor it is important to consider what each party has to gain from these solutions. A customer may for example be interested due to end-consumer marketing purposes, as done by CoolBest in Figure 67.
Also tampering with information should be prevent, for example with block-chain technology (Forbes, 2017).
Due the scale of the project, the tracking of drums will not be elaborated further. A little more on the topic can be found in Appendix: Tracking.

Figure 67. Juice marketing emphasizing the coldness of the supply chain (CoolBest, 2017)

Takeaway

The three main elements which will be incorporated in the design will be:

- Rectangular shape: For optimal use of the space on an industry standard rectangular pallet, in transport and storage.
- Collapsible: The drum should be collapsible to reduce the volume when empty.
- Tracking: Using technology to track drums and their content can bring new added value.



Embodiment

In this chapter the embodiment phase of the design project will be presented. The concept which was chosen at the end of the conceptualisation chapter will be elaborated further to create a feasible design.

Figure 69. Typical embodiment design setup (NuturEnergy, 2017)

28. STARTING POINT

The starting point for the embodiment phase is the improved concept (fig. 70), introduced in Chapter: Chosen concept. The main idea of this concept is that the round plastic drum is made of two halves which interlock and can easily be separated again for compact nesting. In this chapter the main pros and cons of this idea, compared to existing drums, will be listed.

Pros (+) and cons (-) compared to the N55 drum

+ Increased stability: The drum does not need to be tapered, which would make it more instable.

+ Possibility for higher stacking: The new design allows more freedom to increase the strength/ stiffness, which could allow for higher staking, due to the possibility of other production techniques and the different way of nesting allowing for example more ribbing.

+ More compact truck loading: The floor level of the Reefer is loaded without the use of pallets. By giving the drum a smaller maximum diameter, four drums fit next to each other per row (see Chapter: Transport scenario).

+ Volume reduction empty transport: The nesting of the new drums is more compact (see Chapter: Transport scenario).

+ Repair: If one of the halves of the drum is damaged, it can be replace, instead of replacing the entire body.

- Extra assembly step: This drum is made of four parts (two body halves, lid, lidfastener) instead of three.

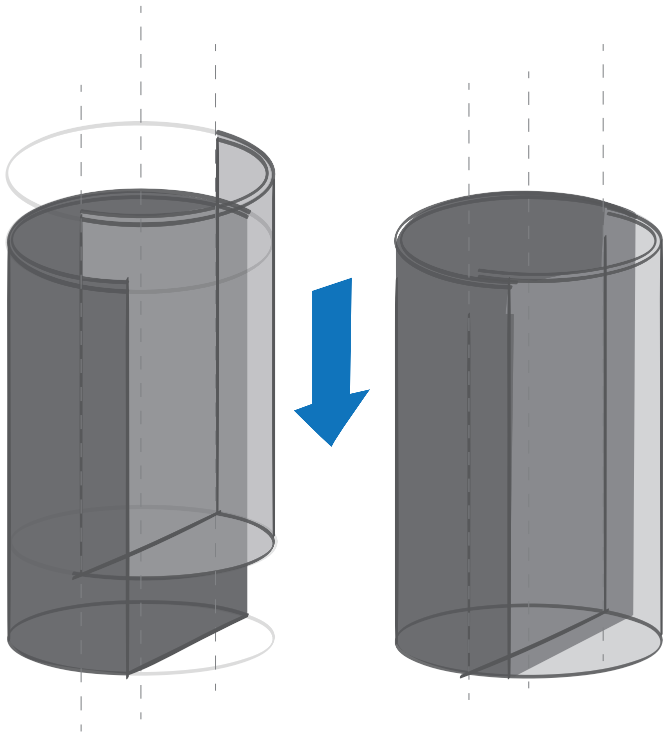


Figure 70. Starting point: An initial sketch of the new concept direction

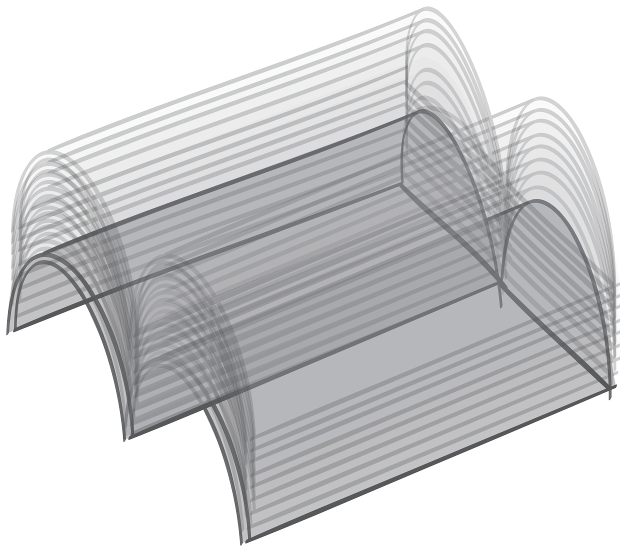


Figure 71. New concept direction, empty and nested

Figure 72. N55, conical plastic drum (U.S. Coexcell, 2017)

Figure 74. Empty N55 drums nested. 4*8=32 per pallet

Pros (+) and cons (-) compared to the metal drum

+ Lighter design

+ Lower carbon footprint of production

+ More durable (against corrosion and denting)

+ Nesting of reused drums is improved. Non-tapered drums are not nestable at all. Tapered metal drums, which are less common, have a low relatively low volume, however they often get stuck together due to rusting when stored outside.

- More parts and extra assembly steps

- A new design which will still need years to prove itself to more hesitant customers

Figure 73. Metal drum (Newpig, 2017)

Validation

The pros and cons discussed in this chapter are an estimation of what could be achieved. During the embodiment phase these points will be validated.

Takeaway

The starting point is still a very rudimentary sketch, however a lot of thought has gone into creating the underlying principle. The new design has many advantages compared to the existing metal and plastic drum, if embodied well. The disadvantages should be minimized. Later in the embodiment phase the assumed advantages of the new design will be validated.

29. PRODUCTION TECHNIQUE

The chosen material and production technique largely influences the design which can be achieved. In this chapter the alternatives and decision will be discussed.

Basic material selection

The chosen concept has initially been envisioned as a blow molded product. This production technique is suitable for thermoplastic polymers, for relatively inexpensive production of unibody hollow products (CES, 2016). This production technique is currently widely used for producing plastic drums. These are commonly made of HDPE with a minimum wall thickness of approximately 3 mm, such as the N55 (U.S. Coexcell, 2017) and a similar tapered drum (CC, 2017).

For this design other production techniques may be more suited and will be discussed later in this chapter. However at this point it can be said the drum will be made of a polymer. The main advantages are:

- Lightweight: The amount of juice which can be transported in a Reefer is limited by weight restrictions of the Reefer (see Appendix: Rectangular shape in a Reefer). If the drum weighs less, more juice can be transported (assuming the volume of the container is the same). When transporting empty drums, fuel savings may be possible. A typical plastic drums weighs about 7 kg, whilst a metal one weighs between 17 to 25 kg, depending on the wall thickness (CC, 2017).
- Water resistance: Plastic drums are not vulnerable to rotting or rusting, when they are stored in a moist environment or outside (unlike other materials introduced in Chapter: Competing products). Additives to the material can also make them resistant to degradation from sunlight.
- Durability: Reconditioning of metal drums for reuse is an intensive process. Dents are removed from the walls and sprays/paint are added against corrosion (CC, 2015). A well designed plastic drum is less prone to denting and does not require anti-corrosion spraying.
- The more specific polymer material choice is also restricted by the temperatures it will be used in, ranging from -20 to 60 degrees Celsius.

Production techniques

The basic shape of the concept, when made from a polymer, makes it suitable for the following production techniques:

- Blow molding (Figure 75): To create the two halves, the shape which comes out of the mold would be cut in half.
- Rotation molding: Here also, to create the two halves, the shape which comes out of the mold would be cut in half.
- Injection molding: Will not be feasible at the relatively small quantities in which the drum will be produced (ProductivePlatics, 2017).
- Thermoforming (Figure 77): The two halves of the drum are formed in separate moulds.
- Twin sheet thermoforming (Figure 76): This method of thermoforming allows for increased strength and rigidity (Spencer Industries, 2017) It is also possible to create a smooth inner wall of the drum, to prevent tearing of the liner, whilst creating the desired closure solution in the outer wall.

I will explore the possibilities of producing the drum by twin sheet thermoforming, due to the possibility of creating a double walled design, with an extra rigid wall (which is a problem with current drums, as introduced in Appendix: Interviews).

Another approach to produce a double walled design could be by using a prefabricated, corrugated HDPE pipe, produced using a combination of pipe extrusion and blowmoulding Figure 78. This might cut down the production costs. However it limits the design freedom for design features required for handling.

Figure 75. Blow molded products (Alibaba, 2017)

Figure 77. Thermoformed products (Conlet Plastics, 2017)

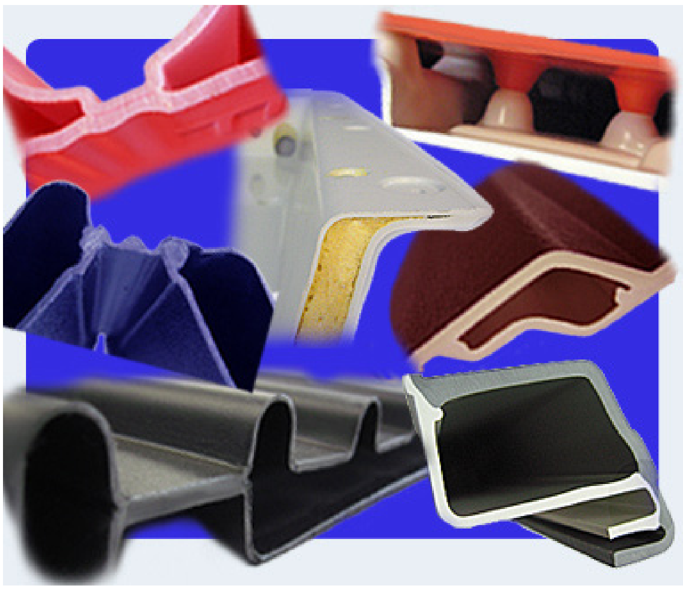


Figure 76. Twin sheet thermoformed samples (Spencer Inudstries, 2017)

Implications of thermoforming

The principle of twin sheet thermoforming is explained in Figure 79. The process is very similar to traditional thermoforming, however with two shapes being formed at once and being sealed together.

The maximum wall thickness which can be achieved with thermoforming is approximately 6mm (Custompartnet, 2017). Thermoforming is a production technique suited for thermoplastics (CES, 2014).

Figure 78. Corugated HDPE produced using a combination of pipe extrusion and blowmoulding.

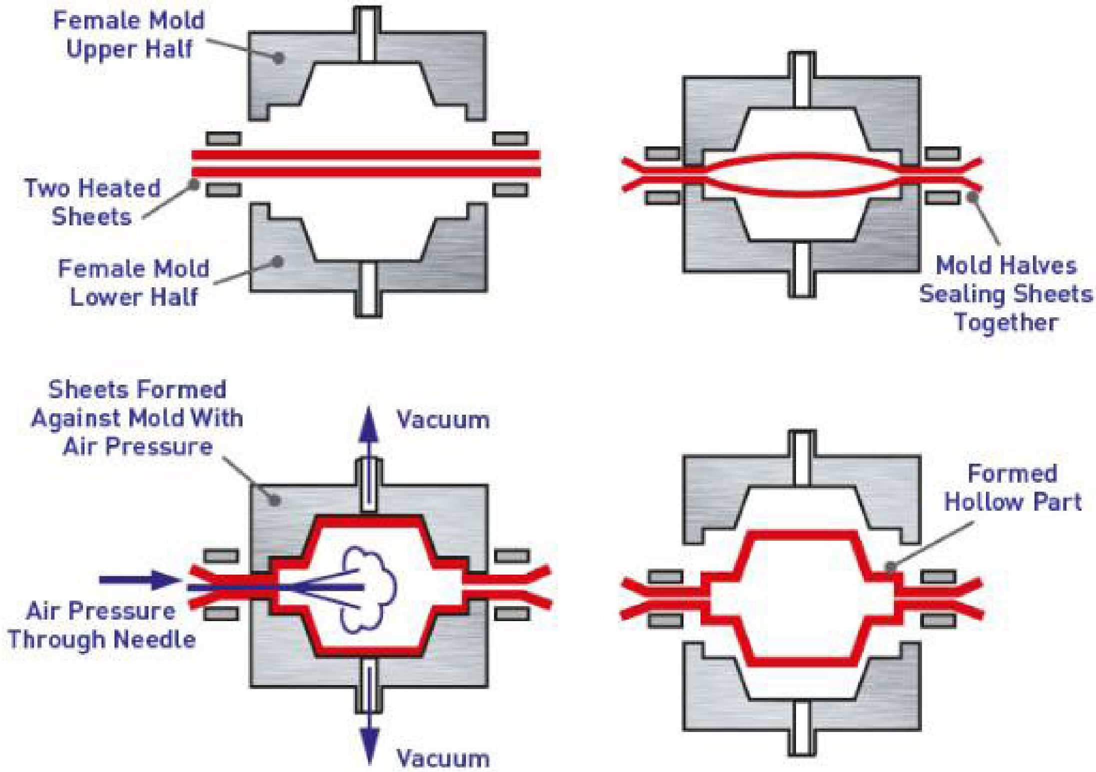


Figure 79. The process of twin sheet thermoforming (Cannon, 2017)

Material choice

The chosen production technique entails that the drum will made of a thermoplastic polymer. Common thermoforming plastics, applicable to high-volume production, simple shapes, low surface quality requirements pressure forming(thermoforming is a type of pressureforming), include PS, PVC, ABS, HDPE, PP and PC (Tempelman, E. & Eyben B.N., 2012).

Using the Cambridge Engineering Selector, Level 3 Ecodesign, (CES, 2014) I made an initial selection of materials using the following filters):

- Material family: Thermoplastic polymers
- Processing level for thermoforming: Acceptable/ Excellent
- Thermal properties, Maximum/minimum service temperatures must be beyond: -20 and 60 degrees Celsius (based on requirements discovered in Chapter: Cold storage).
- Materials must be recyclable (read more about this in Chapter: Sustainability).

The materials which meet these requirements are plotted in Figure 80, based on their CO2 footprint during primary production and their yield strength. These axes were chosen seeing as the goal is to create a design with a low carbon footprint. The CO2 footprint during processing (thermoforming) varies less per material (CES, 2014), therefor the primary production was chosen as the indicator.

The yield strength (indicates the maximum stress a material can endure before permanent deformation) is used because it gives an indication of the attainable mechanical performance of the drum. Deformation of the drum is allowed as long as it is not permanent. A higher yield strength can result in a lower required wall thickness, resulting in less material material being used. The difference in density between the polymers is negligible.

The materials which have a relatively low CO2 footprint and high yield strength (highlighted in orange), are different grades of: ABS, HDPE, PETG, PP, PS and PVC. These will be explored further, based on their "eco-impact" and general properties.

It is interesting to note that biopolymers (non-petroleum based polymers) did not make it through these selection steps. LCAs of biopolymer materials show reduced environmental impact and energy use when compared to petroleum-based materials (Narayan, 2004). Which would have made them interesting to apply in this project.

First of all PVC will be eliminated from the list. Due to reasons, summarized by (Thorton, J., 2002); "The manufacture, use, and disposal of PVC poses substantial and unique environmental and human health hazards. Across the world, governments, companies, and scientific organizations have recognized the hazards of PVC. In virtually all European nations, certain uses of PVC have been eliminated for environmental reasons, and several countries have ambitious programs to reduce PVC use overall".

This example of PVC, illustrates how focusing only on CO2 emission data can tricky. Therefor, during material selection, other eco-indicators will also be taken into account. Relevant eco-indicators of the remaining five materials have been collected in Table 5.

The different sources of data and ways of measuring make it difficult to determine which material is the most suited. Eventually I chose to continue with HDPE, as it scores well based on all sources. The plot made in CES, it has one of the lowest carbon footprints with a sufficient yield strength.

HDPE is a commonly used material, worldwide it is the third most used plastic, after PVC and PP (Tata Strategic, 2014). This large quantity of material, which eventually becomes waste. Thermoplastics, including PET, PE and PP all have high potential to be mechanically recycled (Hopewell et al., 2009).

Mechanical recycling: also known as physical recycling is the process where plastic is ground down and then reprocessed and compounded to produce a new component that may or may not be the same as its original use (Cui and Forssberg, 2003).

APME (2004) calculated that in western Europe, the amount of mechanical recycling of plastics increased strongly at a rate of approximately 7 per cent per annum. In 2003, however, this still amounted to only 14.8 per cent of the waste plastic generated. Together with feedstock recycling (1.7 per cent) and energy recovery (22.5 per cent), this amounted to a total recovery rate of approximately 39 per cent from the 21.1 million tonnes of plastic waste generated in 2003.

This is such a large waste stream that it can not be ignored, I see this as an indicator that the large scale recycling of HDPE will remain relevant and will keep improving. If a "niche" material would be chosen, the future economic recyclability might not be as assured.

Properties of mechanically recycled polymers do not remain the same because of degradation from heat, mechanical stresses and oxidation during their reprocessing. Thus the quality is the main issue when dealing with mechanically recycled products (Al-Salem, 2009). However, a percentage of the HDPE can be from a recycled source.

Most plastic drums currently on the market are made of HDPE, is in a indication that it is suited for this use environment (although their material choice was most probably made based on the good blowmoudling properties of HDPE).

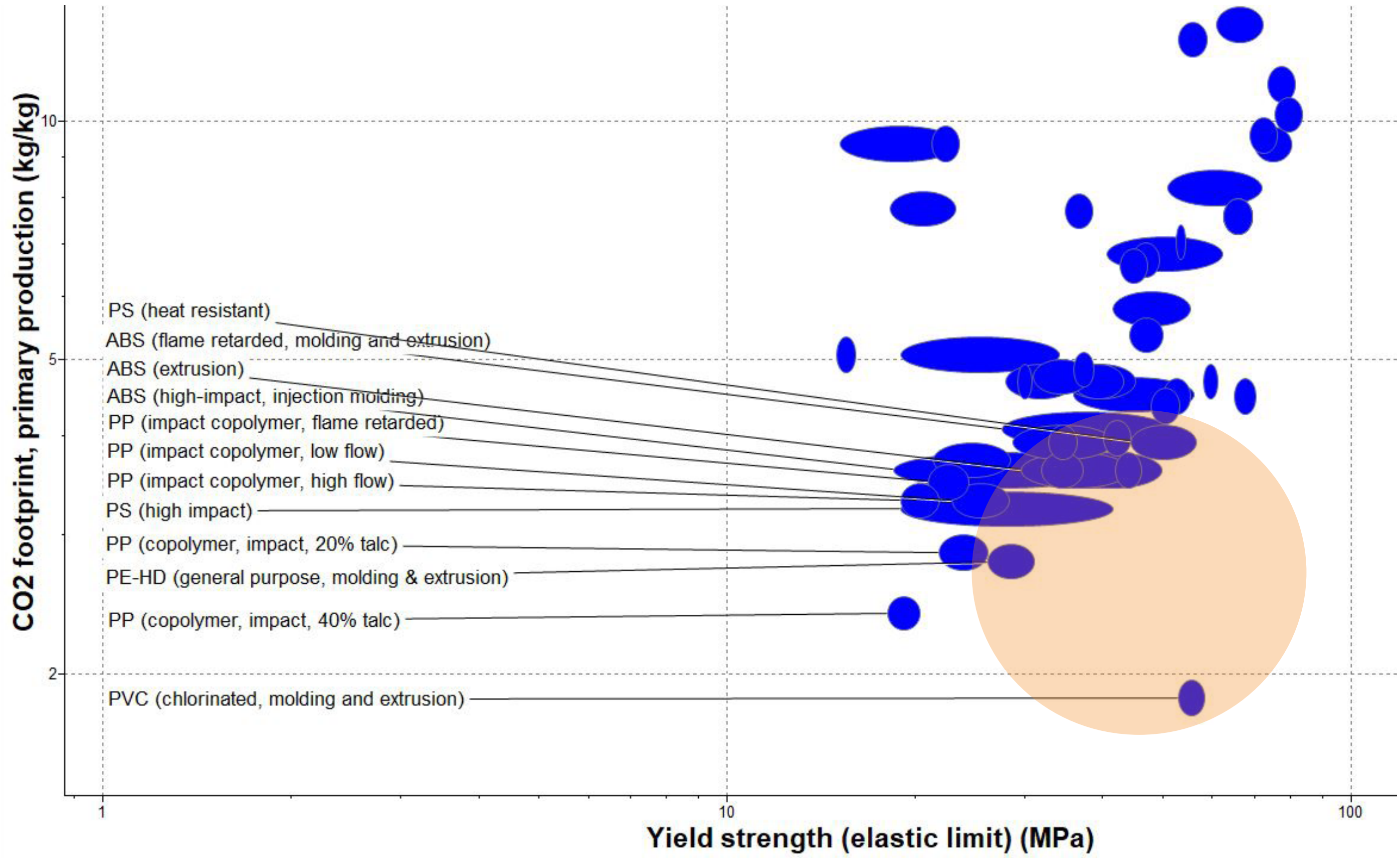


Figure 80. Plot of selected materials in CES, orange area indicates options which will be explored further

Table 5
Eco-indicator scores (low is good)

Information source	(CES, 2012) via (Idemat, 2012)					
	Recycled		Virgin		N/A	N/A
	Total eco-cost	Carbon footprit kg CO2 equivalent	Total eco-cost	Carbon footprit kg CO2 equivalent	Eco-indicator 95/99 (millipoints/ kg)	EPS value
ABS	0,53	3,47	1,41	3,89	400/352	N/A
HDPE	0,57	3,7	1,15	1,97	330/ N/A	730-806
PETG (amorph PET copolymer)	0,45	2,92	1,19	3,46	380/275	883-975
PP	0,57	3,74	1,06	2,01	330/254	804-888
PS (high impact)	0,55	3,59	1,42	3,57	360/319	960-1063

Durability

The durability of the drum can be improved further than only by choosing to use a polymer. Now that I have chosen to use HDPE, I will look at the specific material and its durability in some more detail.

In outdoor applications (empty drums are often stored outside), the life time of HDPE is determined by various environmental factors as solar radiation, temperature, thermal cycling, humidity, weather, pollutants, but most importantly by ultra-violet (UV) radiation (Husein I.A., 2007).

Common effects of weathering caused by ultraviolet radiation are discoloration, embrittlement, tackiness, loss of surface polygloss, and crazing or chalking of the surface (Fritscher C., 1994). These should be prevented.

Carbon blacks are the most frequently used pigments where long-term weathering performance is required (Jakan E., Blazso M., 2002). It is generally recognized (Allen et al,. 1998) that carbon black provides enhanced UV stability to the filled polymers. For this reason carbon black will be used in this design as well. In another scenario, where the packaging would not be sorted manually for recycling, carbon black pigments would cause issues. As stated by (WRAP, 2017), carbon black pigments do not enable the packaging to be sorted by the optical sorting systems being used widely in plastics recycling. As a result, black plastic packaging commonly ends up as residue and is disposed of in landfill or recycled into lower value materials where polymer sorting is not required.

The colour of the drum has no further aesthetic significance, in this B2B (business to business) industrial surrounding, customers are not typically preoccupied with the appearance of a drum.

Further improvements to the durability of the drum can be achieved by other elements of the design than material and production technique, as described previously in Chapter: Ideal reusable drum.

Takeaway

The new drum will be produced using twin sheet thermoforming. This is a process similar to traditional thermoforming, however two moulded sheets are sealed together. A design made with twin sheet thermoforming can have improved strength and rigidity, due to the double wall design. The maximum wall thickness for thermoforming is 6 mm. This thickness may not be required due to the double wall. Two thinner sheets will be used. The chosen material is HDPE.

30. SHAPE ITERATIONS

In this chapter the basic shape of the drum will be created. This basic shape will later be developed into a shape which can be produced (Chapter: Producible shape) and can withstand the forces which it will encounter in use (Chapter: Mechanical calculations).

Ideation

Iterations on the shape of the new drum took place parallel to the exploration of production techniques (see Appendix: Revised concept ideation). After having chose to continue with thermoforming a step forward could be taken in the embodiment. The morphological chart (Figure 81) was updated for the starting point concept and used as a reminder of which design elements to incorporate.

Process

In SolidWorks many 3D variations of the design were made. The most promising ones will be introduced in this chapter. The process is illustrated in Figure 82.

It is important to emphasize that amongst other, the required wall thicknesses and radiuses have not yet been incorporated in detail. These shapes are still very rough.

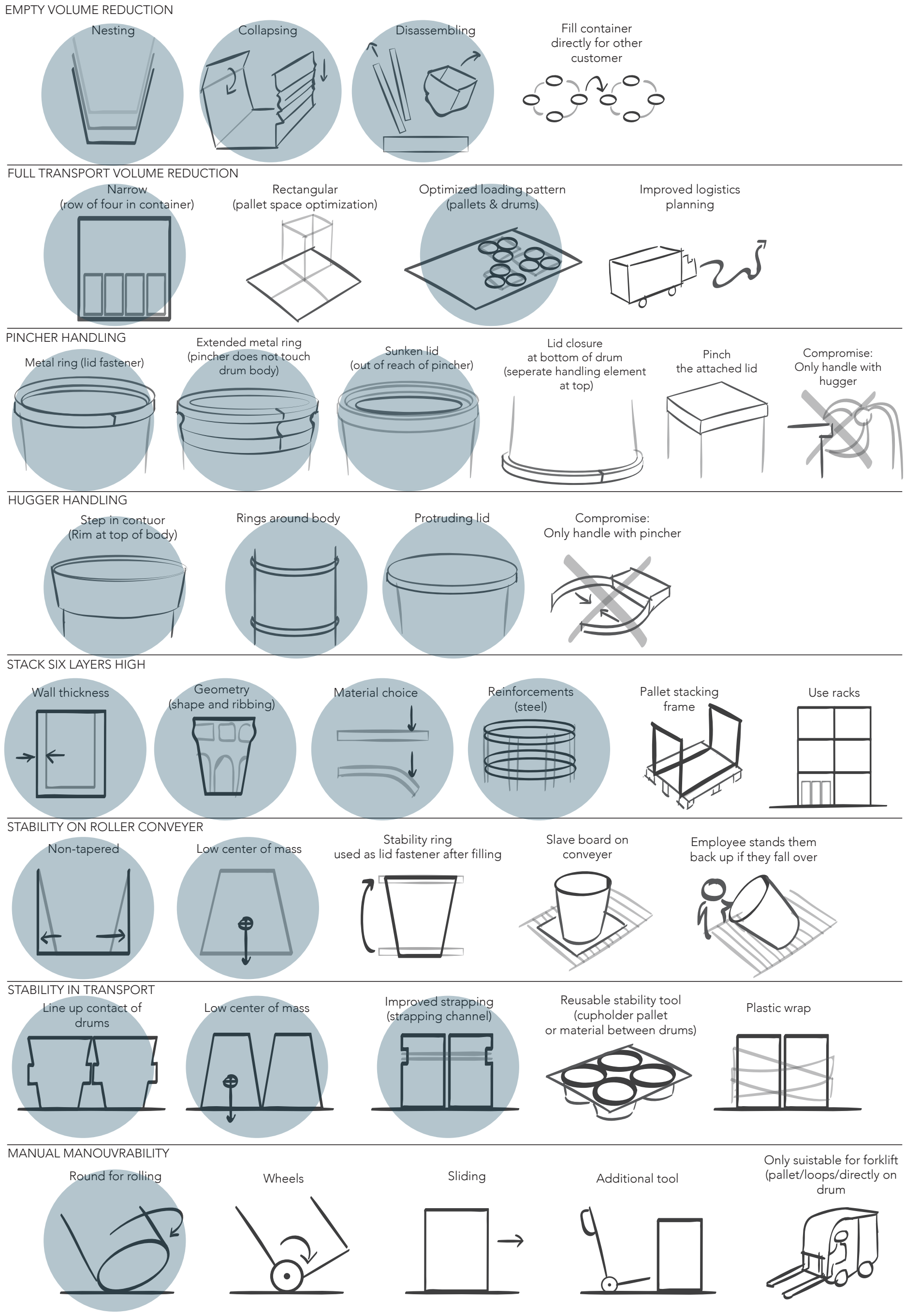
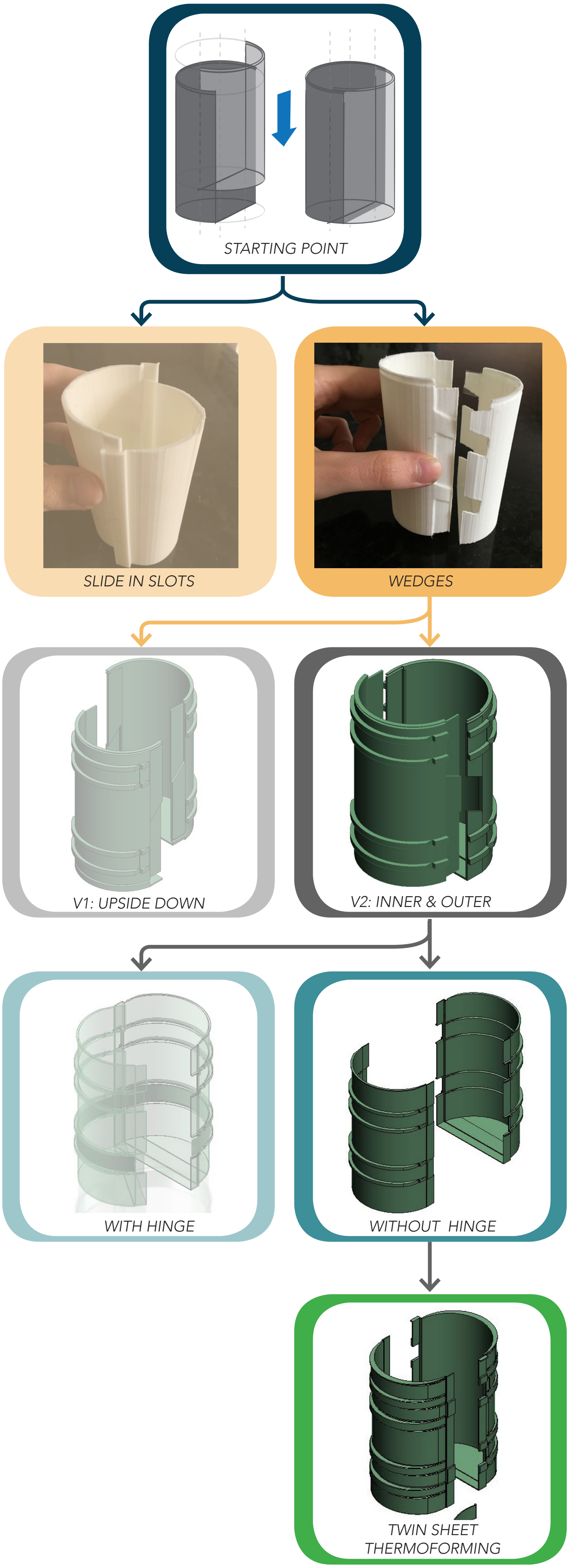


Figure 81. Morphological chart, possible/promising solutions highlighted for: Starting point



The starting point of this Phase of the design process is described in Chapter: Starting point.

Two initial 3D embodiments of the design were made and 3D printed. One with long vertical slots, the other with short diagonal wedges. The second concept has been chosen, as it has less chance of jamming and the Movement required by a worker to assembly it is less complicated.

The concept was embodied one step further, incorporating rings around the body for handling and strength. The producibility by thermoforming was also taken into consideration. Concept Inner&Outer was chosen as it the side flanges/wedges are less vulnerable and fewer seams are present on the inside of the drum (which could damage the liner).

The dimensions of the overlapping flanges of the drum were altered to 60 Mm, for compact nesting. An external support ring was introduced which keeps the two drums halves together. Due to ergonomic reasons the external support ring does not keep the two drum halves attached at all times, only when it is filled with juice.

The Final design is a drum which has been designed specifically to be produced by Twin sheet thermoforming. The main benefits are the improved strength/rigidity and the smooth inner surface.

Figure 82. The main steps of the process of creating the basic shape

SLIDE IN SLOTS

The drum is made of two identical halves, which slide into each other from the top. The ends of each half have a U-shaped profile. The left one is smaller and slides into the right one. A 3D print of the model has been photographed on the right. The top shows the assembly steps. The bottom row shows how the halves are nested.

For detailed drawings see Appendix: Technical drawings: Slide in slots.

Required improvements:

- The large length of the U-profiles creates a large distance in which the two halves can jam and get stuck. Very low tolerances and a very rigid profile would be required to prevent jamming.
- The U-profiles need to stick out more to assure they lock in place. However they should not stick out more than the rings on the body of the drum, which would make them vulnerable.
- This version of the drum, made of two identical halves is very vulnerable to sideways inward forces. By making two different halves, one is the inner profile, the other the outer, this can be overcome. Or by making the left and the right side of each half into both an inner (at the bottom) and outer (at the top) U-profile.
- The angle of the U-profiles needs to be adjusted to created a nesting stack which is straight (does not lean to one side).
- The inside of the drum should be made smooth to prevent tearing of the plastic liner.
- The slot in the bottom of the half drum creates a weak point.

WEDGES

The drum consists of an inner and an outer half. The inner half slides into the outer. This inner half slides into place in a diagonal movements due to the wedges which have been created in the sides of the drum. The wedge shape helps keep the halves together.

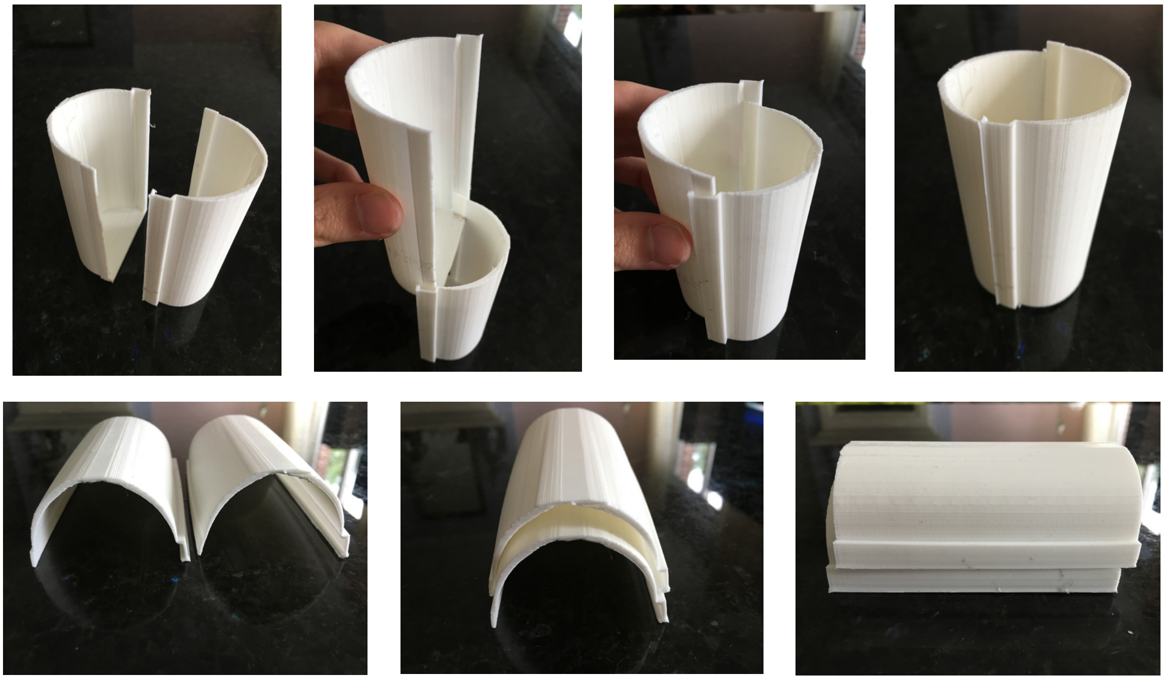
For detailed drawings see Appendix: Technical drawings: Wedges.

Required improvements:

- In this initial version the halves are not nestable. The large half currently starts curving inward, this can easily be prevented by creating the splitline (where the two halves part) in the center of the circle (top view) and not curving the overlapping surfaces inward, but making them straight.
- The amount of wedges could be decreased. Making the wedges longer. In the current design, the small top wedge flap, on the smaller drum half, is very vulnerable.
- Having halves which are not the same size will create stacks of different heights when nested. Imbalance in stacks will not use space efficiently. An optimal stacking pattern must be created, or the halves must be made the same height.
- Explore the possibility of using one production mould to save costs. By creating two identical halves or using the same mould for the body in different directions with different ends (top/bottom or left/right ends).
- Find the best angle and the required tolerances for the wedges.
- The lid fastener rim should continue onto the flap, to prevent a gap and create extra structural support.
- To disassemble the two halves, quite some force may be required. It would be good to incorporate an element which can be hit with a hammer to disassemble the halves.

1:10 SCALE MODEL: SLIDE IN SLOTS

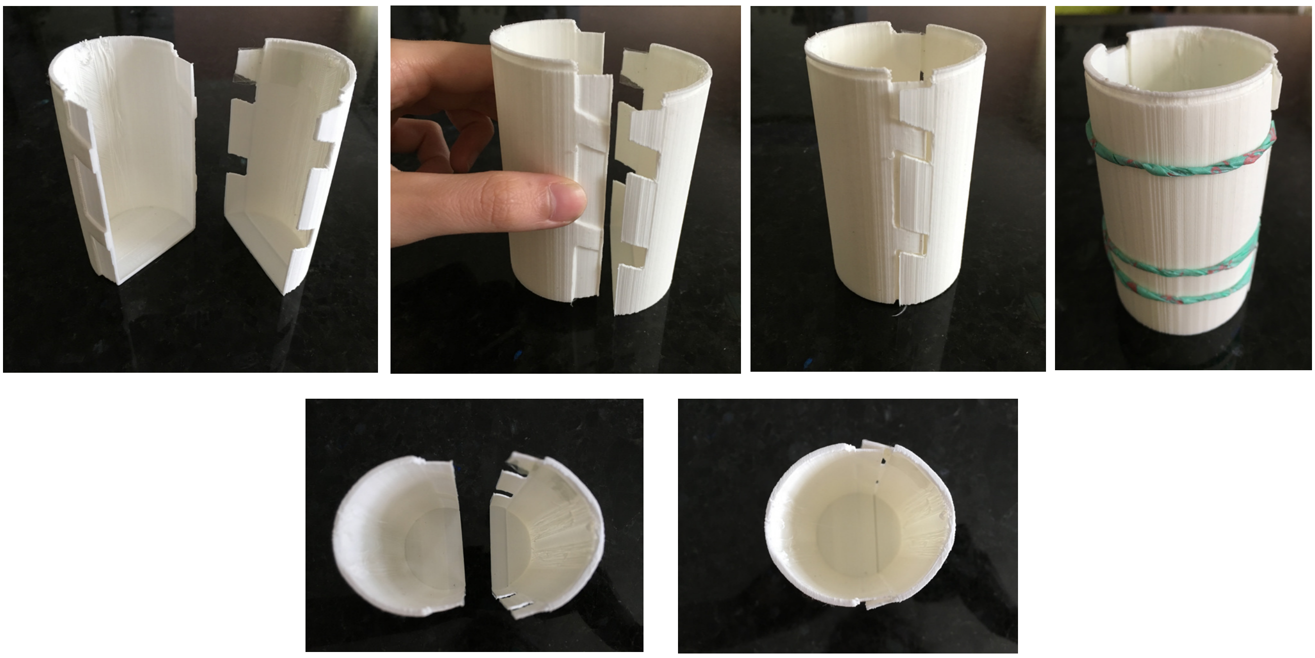
Top row: Assembly. Bottom row: Nesting



The two identical halves can be interlocked by sliding them into each other, from the top. The slots which the halves slide in, are used to prevent them from air-locking when nested.

1:10 SCALE MODEL: WEDGES

Top row: Assembly. Bottom row: Top view



The smaller half slides into the larger half, in a diagonal movement. The wedge patterns on the edges of both halves keep them together. This model is not nestable.

V1: Upside down

In the next round of iterations, I added rings to the body of the drum, which allow for handling with the hugger, as well as giving structural support to the drum (as shown in Figure 86). I also incorporated a rim at the top of the drum, which is used to fasten the lid, using a lid fastener ring (Figure 85). For more detailed drawings of the concept, see Appendix: Technical drawings: Upside down

These protrusions (rings and lid fastener ring) in the drum influence the nestability. If the rings would be continued around the entire body of the drum, the drums could no longer be nested. To solve this, indents have been created in the rings. These indents also act as an edge for the drums to rest upon while nesting. Read more about this in Chapter: Transport scenario.

The difference between this concept (V1), and the next one (V2), is based on the way they will be produced. I designed V1 to explore the possibility of producing the drum using only one mould, to cut down the investment costs in moulds. V2 requires two different mould or a mould with interchangeable parts for the wedges/overlapping flanges.

For V1, the difference between the two drum halves is the direction in which the wedges are pointed. To interlock two halves in a diagonal movement, the wedges in one drum half should point upward, whilst the wedges in the other half should point downward (Figure 83). This can be solved by creating a mould which can be used in two directions (Figure 84). The mould has a "drum bottom" at each end. If a sheet of plastic would be moulded over the entire mould, you would get a drum half with two bottoms (no top opening). By cutting off the material at one of the ends, one end of the drum is assigned to be the top (it has an opening).

A disadvantage of this design is that a gap must be created between the bottom wedge and the bottom of the drum. To allow the halves to be assembled to interlock. This makes the wedge quite vulnerable. In addition to this, the wedges can not be interconnected. Meaning the outer wedge is not connected to the inner wedge. They can not support on each other, making them vulnerable and creating an additional seam on the inside of the drum (which could tear the plastic liner).

Figure 85. Lid fasteners. The left has a lever lock and the one on the right has a bolt which must be fastened. (Yankee Containers, 2017)

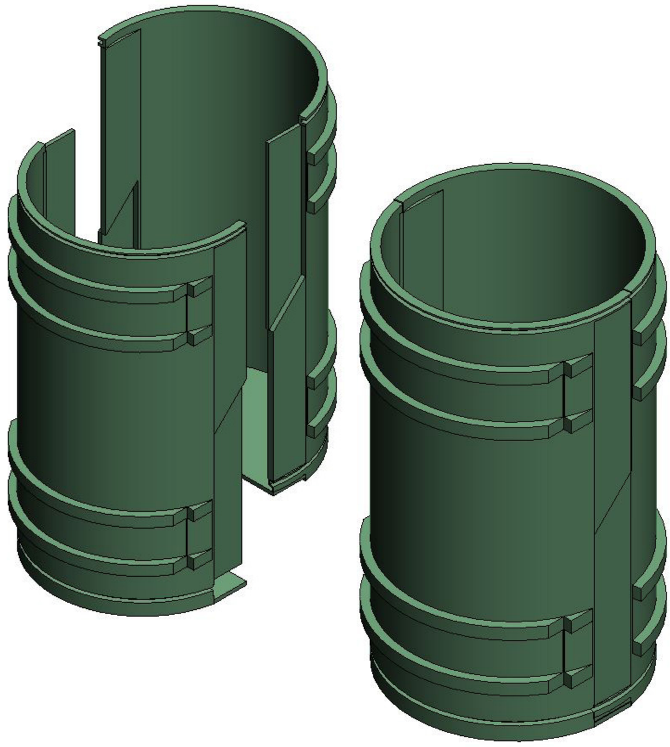


Figure 83. Left: The two halves connect in a diagonal movement. One half the slots point downward, on the other upward. Right: The two halves interlocked

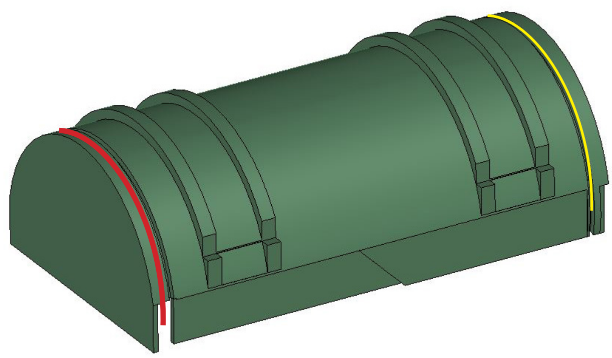


Figure 84. The same mould can be used for the two halves. Either cut off at the red or yellow line. This determines the direction in which the wedges are slanted.

Rings around body

To be able to use a hugger to lift the drum, a "bump" in the profile of the drum is require, at the top of the drum. This has been formed as rings around the body.

In total four rings have been incorporated in the design. The top two rings create a "strapping channel", in which straps used during transport to keep the drums together will be placed to prevent the strap from slipping down (read more about this is Chapter: Transport scenario).

The bottom rings create as channel in which an external support can be placed which keeps the drum halves together.

This rings around the body also has a structural purpose to strengthen the shape.

Lid fastener rim

The lid of the drum will be fastened with a commonly used metal lid fastener. This a U-shaped profile bent in a circular shape. This profile wraps around the lid and the lid fastener rim (a thin protruding rim at the top edge of the drum). The ring is then clamped closed with a bolt.

Wedges

Each drum has two flanges (edge of the drum which overlaps with the other drum half), which each have two wedges (the slanted protrusion used for interlocking).

When two drum halves interlock, two wedges of each drum are on the inside and two on the outside. This means that each drum half creates inward and outward support against forces.

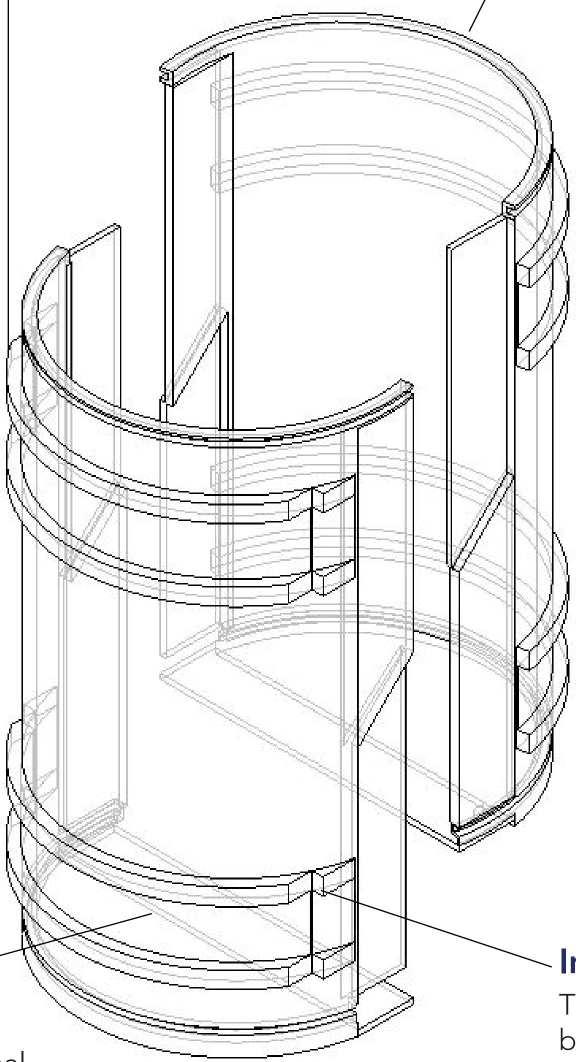


Figure 86. V1 The two halves seperate

External support

To ensure the two halves of the drum stay together, an additional metal "belt", will be used. This external support ring is made of two metal arches, with a hinge connecting them (so that it can be remove) and a bolt closure.

Together with the lid fastener, the external support keeps the two drum halves together.

Indents for nesting

The indents in the rings on the body of the drum, are required to keep the design nestable.

They also create a surface for drums to rest on each other when they are nested. This creates a more stable stack of nested drums and prevents air-locking.

V2: Inner & outer

This concept consist of two non-identical drum halves. The inner drum half slides into the outer drum half, as shown in Figure 87. For more detailed drawings of the concepts, see Appendix: Technical drawings: Inner & outer

This concept is similar to the previous one, however the wedges/overlapping flanges, are different, as described in Figure 88. One half the drum slides into the the other. The pressure of the liquid inside the drum, pushes the walls of the inner drum onto the walls of the outer drum, causing them to interlock more.

As mentioned earlier, this design will most probably be produced using two separate moulds; one for the inner and one for the outer half. However, it might be an option to create a mould with interchangeable parts for the overlapping flanges and using the same mould for main body.

Comparison of V1 and V2

Concept V2 is more promising to continue with. The main issue with concept V1 is that due to the requirements, set by creating a design which can be made with one mould, the wedges will be very vulnerable. The wedges can not be made to support on each other, or the bottom of the drum. This will be a weak point in the design. In concept V1 there is space for reinforcement of the wedges. Also in concept 1 there are less seams on the inside of the drum, which could cause the inner liner to tear.

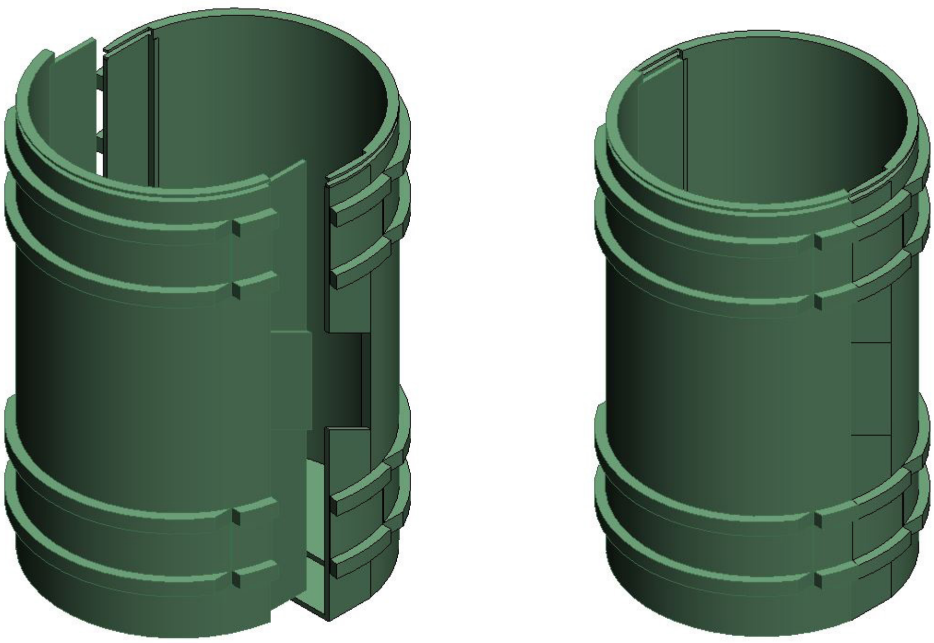


Figure 87. Right: V2 halves separate. Left:V2 Halves interlocking

The V2 drum is similar to V1, however the overlapping flanges between the drums are different.

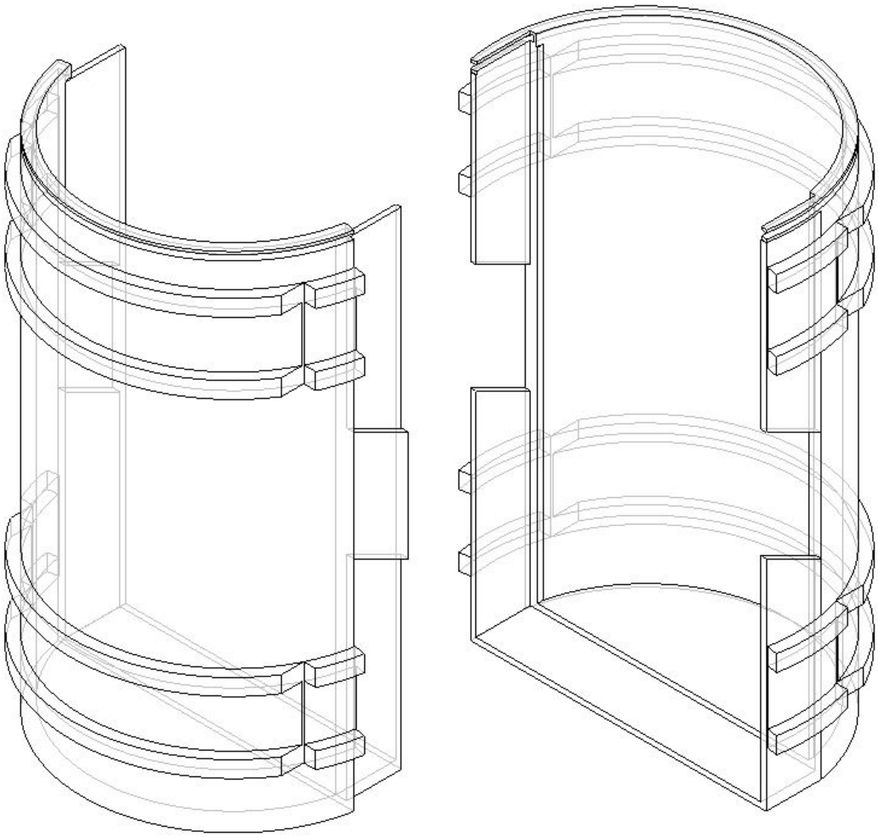


Figure 88. V2 The two halves separate

Wedges

The inner half of the drum slides into the outer half. The inner half has a " bump" wedge which fits into the gap in the outer half. To give the wedge on the inner half some support, a flange has been created along the entire length of the overlapping area of the two drum halves.

With hinge

In the previous concepts, the external support was introduced. This is a ring around the body halves of the drum which gives extra support to keep the two halves together. Introducing an additional part to drum, increases the complexity of handling. The drum is not directly ready for use (unlike the N55); the two body halves must first be positioned, then the external support must be positioned and fastened. The parts must also first be collected (gathered together from different transport pallets).

To simply this process, minimizing loose parts and the positioning of parts, it might be an option to create the external support as part of the drum. This support remains attached to both halves of the drum (Figure 92, Figure 90) and acts as a hinge of the "clamshell"(Figure 89, Figure 91) .

Because the drum will be closed like a book, a horizontal movement, the wedges can no longer be slanted/diagonal. The wedges will be horizontally oriented.

An added bonus of horizontal wedges is the simplified producibility. When thermoforming this shape, the sheet of plastic will be "draped" over a mould, creating diagonal wedges would require inserts in the mould (read more about this in Chapter: Producible shape).

The maximum length of these wedges (the same as the length of all overlapping components of the two drum halves) has been calculated to be 60 mm, to achieve the desired compactness during nesting, see Appendix: Nesting dimension.

In this concept the positioning of the rings around the body has been improved, to fit the dimensions of handling devices which grab the drum around its belly.

Lid

A basic design of the lid has also been made. The lid has an additional function compared to the lid on the N55, it will give some outward support to the drum if the walls are pushed inward. This is achieved by making a "sunken lid" which goes into the drum about 5 cm. In this way walls of the drum can support on the lid. The lid is fastened to the drum in the same way as a conventional lid, using a lid fastener (a metal ring).

The lid can also be made using twin sheet thermoforming, in this way the lid can be given a smooth inside and on the outside a shape which maximizes the stiffness, as show in Figure 92.

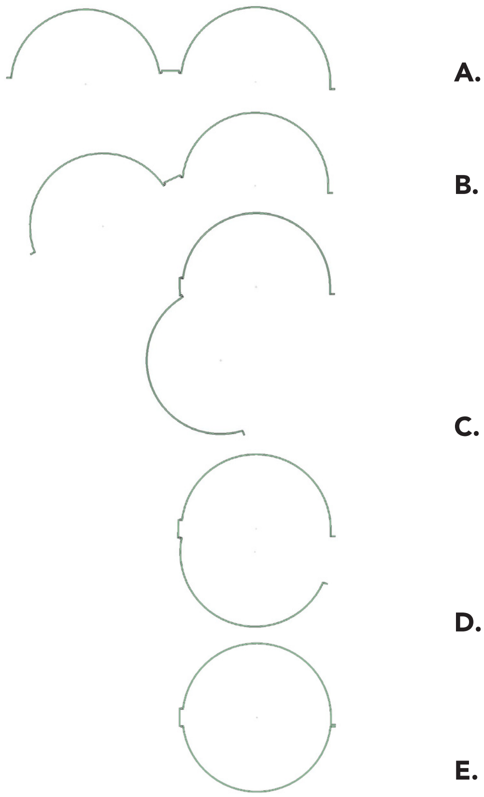


Figure 89. Top view of the movement of the external support. From open position (A) to closed position (E).

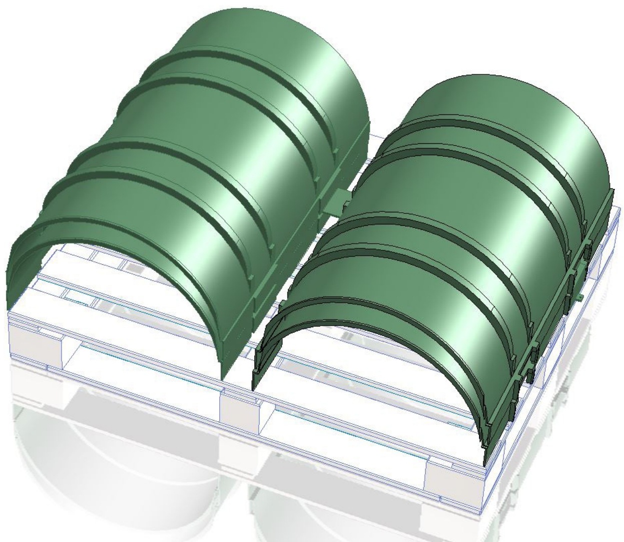


Figure 90. The drum halve ready for nesting. Still connected together with the external support.

WITH HINGE

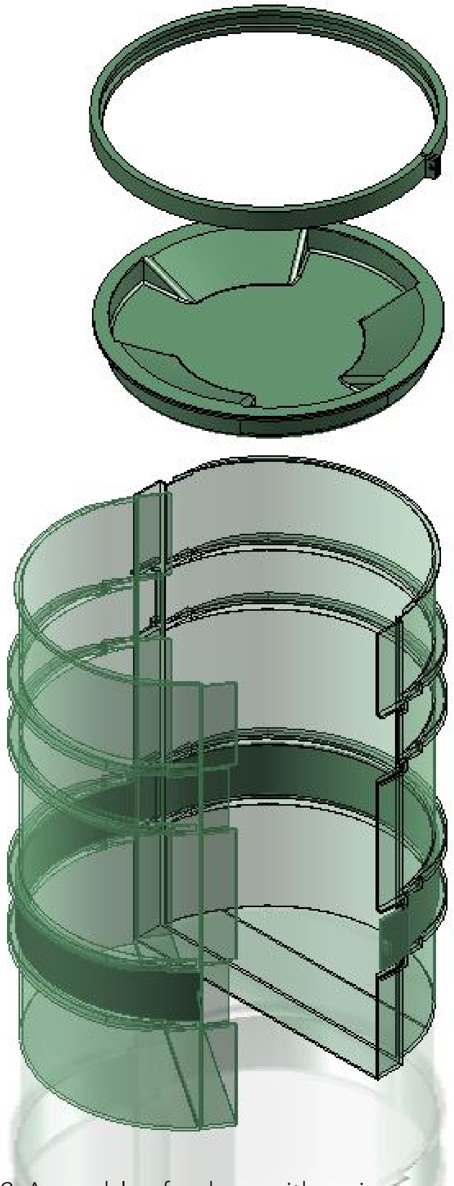


Figure 92. Assembly of a drum with an incorporated external support, which remains attached to the drum

Figure 91. The two arches of the external support, which hinge around the joint plate (in the middle of the image).

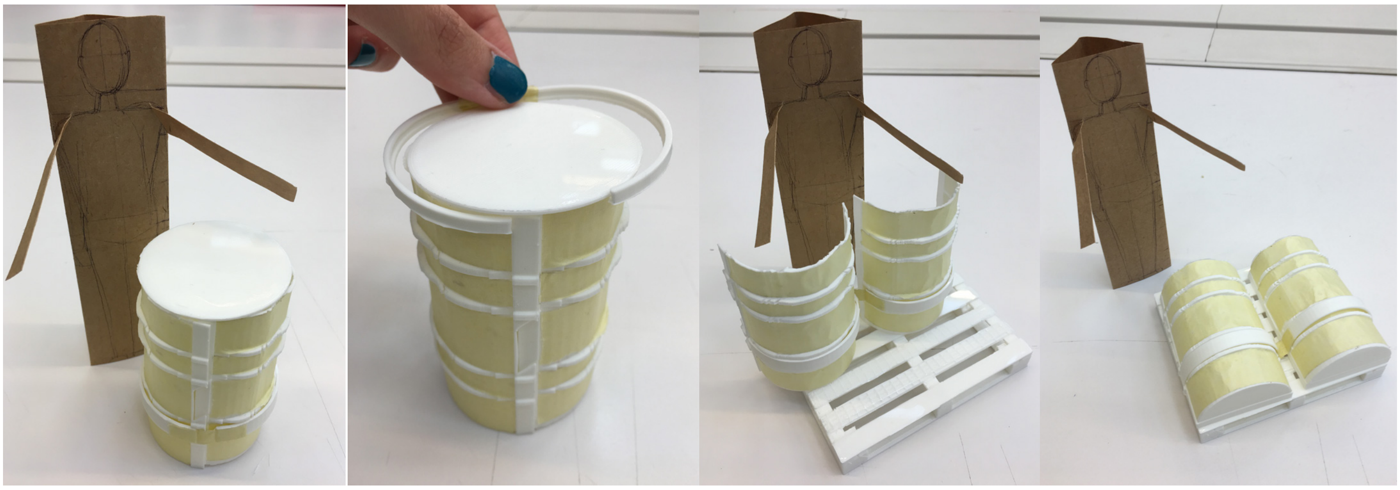


Figure 93. Scenario of a drum with attached external support being opened and layed on a pallet for nesting

Ergonomics

An issue however with having the two drum halves connected at all times, is that it folded open drum is quite large and weighs around 10 kilograms (based on the rough SolidWorks model of this concept), making it difficult to handle by one person. Especially when stacking the connect drum halves this might be an ergonomic issue. For an indication of the dimensions, a paper puppet, with P50 male dimensions (DINED, 2004) has been placed next the a 3D printer prototype of drum, in Figure 93.

Without hinge

For the reason mentioned about, I have chosen to create an external support ring which is not always attached to the drum. It is not around the drum when the drum is empty. It is only positioned when the drum needs to be filled and when it is full of juice.

Because the drum no longer needs to hinge open like a book, a different type of external support can be created. In this design (Figure 94) (illustrated in more detail in Appendix: Technical drawings), the external ring opens at another location than the drum halves. The closure and hinge of the external ring, which are its vulnerable points, are located at the middle of the drum half (its strongest point).

A force which threatens to split open the drum halves, will not work to open the external ring, the force required for this works in another location/ direction. This makes the construction more secure.

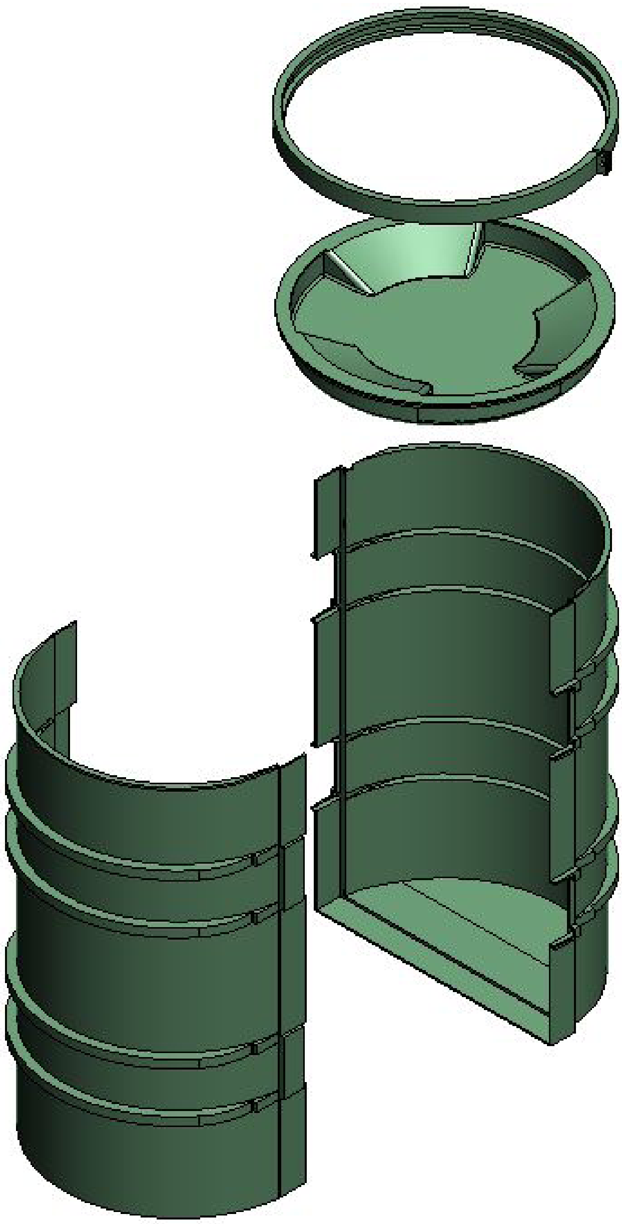


Figure 95. Exploded view of without hinge concept. The external ring is a separate component, which is only positioned when the drum is filled with juice.

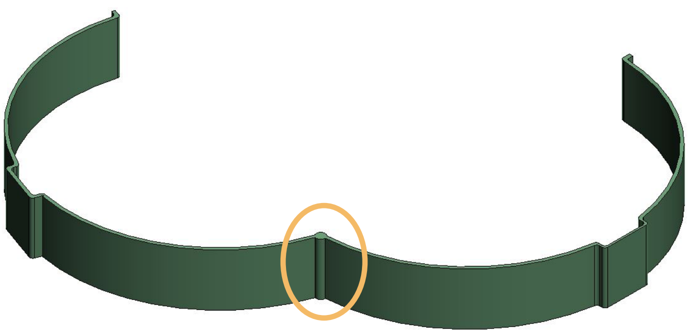


Figure 94. The external support hinges (hinge highlighted) open at a different location than the previous design, at the center of body half (not at the overlapping area).

Twin sheet

One final iteration of the design was made, as shown in Figure 98 (for detailed drawings see Appendix: Technical drawings). The focus of this design is to incorporate the benefits of twin sheet thermoforming (introduced in Chapter: Production technique). The previous designs were made primarily suited for conventional, single sheet thermoforming.

One of the benefits of twin sheet thermoforming is that outside shape of the drum does as directly influence the inner surface. Different levels in the wall of the drum have been created, as illustrated in Figure 96. This means that, for example the rings on the body do not create indents in the inner surface. In this way the inner surface can be kept very smooth, whilst incorporating strengthening patterns on the outside, where desired. The smooth inner surface prevents the plastic liner from riping and makes it easy to clean by hosing down with water (the inside is closer in contact with the juice, although it is never in direct contact due to the plastic liner).

The two layers of the drum wall need to weld together during the production process. This will happen in the flanges of the drum (overlapping areas) as well as in the designated area above and under each ring (read more about this in Chapter: Producible shape).

The indents in the rings of the drum, have been eliminated by adjusting the dimension. Previously this indent created a sharp, vulnerable corner in the design. This has been flattened.

One of the critical points of the drum is how it will react to inward pointing forces (this is explored further in Chapter: Mechanical calculations). If a force is exerted on the middle of the arc of one drum half, this will push the drum halves against each other (as shown in Figure 97). To prevent one half slipping into or over the other half, or piercing each other, the overlapping flanges should be sufficiently rigid and the contact surface as large as possible. The twin sheet design has wider flanges than a single walled design.

In addition to alterations made due to the production technique, the nesting of the drums was also improved by making the rings on the body wider. This increases the nesting surface of drums (read more about this in Chapter: Transport scenario).

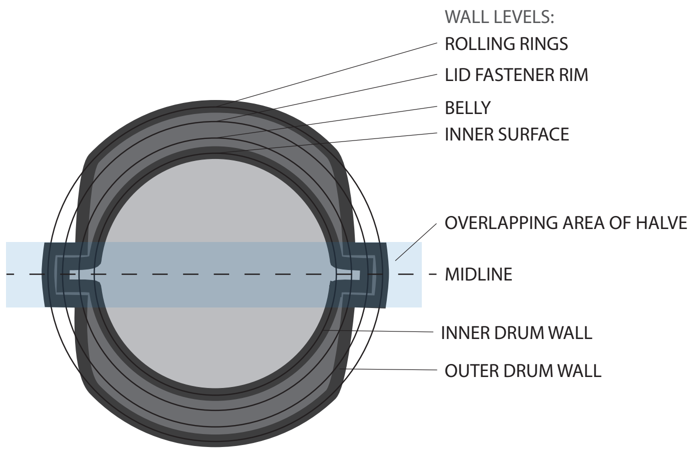


Figure 96. Twin sheet concept: Exaggerated top view of different levels in the wall of the drum.

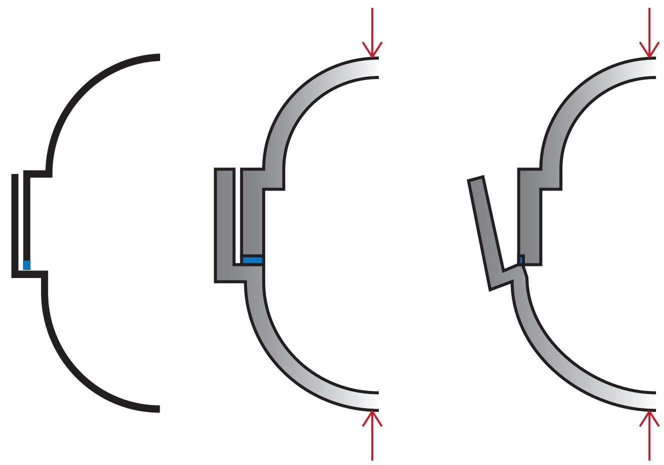


Figure 97. Top view of a section of the drum. Red arrow: inward forces. Blue: Contact surface of the two halves. (Left to right: single wall design, double wall design, double wall design extreme position)

Takeaway

Through multiple iterations a design has been created which addresses the following topics:

- Creating a compactly nestable design, taking into consideration the desired nesting method (without air-locking) and the limitations set by the required wall thickness.
- Increasing the strength/rigidity of the drum; by creating a double wall structure (with two twin sheets, instead of one thick one).
- Keeping the two drum halves together during use: By introducing a metal external support ring.
- Creating a smooth inner surface and minimizing seams by creating a design for twin sheet thermoforming.
- Location of body rings (mainly for structural support): At an optimal height for handling and function as "strapping channel" and channel for the external support ring.
- Providing additional outward support, by creating a sunken lid.

The previous concept has been altered to make advantage of the possibilities of twin sheet thermoforming.

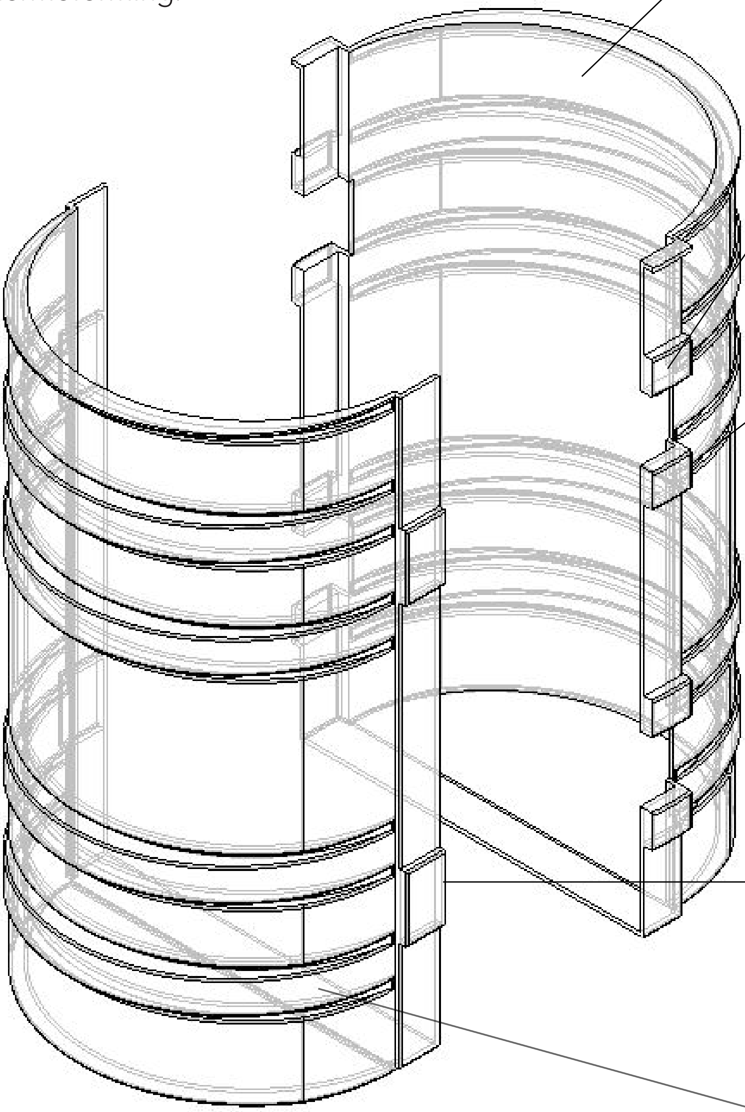


Figure 98. Twin sheet thermoforming concept: the two halves of the drum next to each other.

Smooth inner surface

The outside sheet of the drum contains details required for handling and rigidity/strength. The inner wall is smooth.

Wider rings

The width of the rings has been increased to create a larger surface area for drums to nest on.

Contact between wall layers

Above and under each ring on the body of the drum, an indent has been created, this a zone where the inner and outer thermoformed sheet weld together. These contact points are required to create a rigid drum.

Increased contact surface betweens halves

The area of the flanges where the two halves meet has been increased.

Eliminating nesting indents

By adjusting the dimensions of the rings around the body, the necessity for "nesting dents" has been eliminated (and thereby a vulnerable point of the design).

31. PRODUCIBLE SHAPE

In this chapter the feasibility of the design for production will be discussed.

Components

The drums consists of five components (Figure 100). The following parts will be produced by twin sheet thermoforming of HDPE:

- Inner drum half:
- Outer drum half
- Lid

The other components will be made of metal:

- External support ring
- Lid fastener

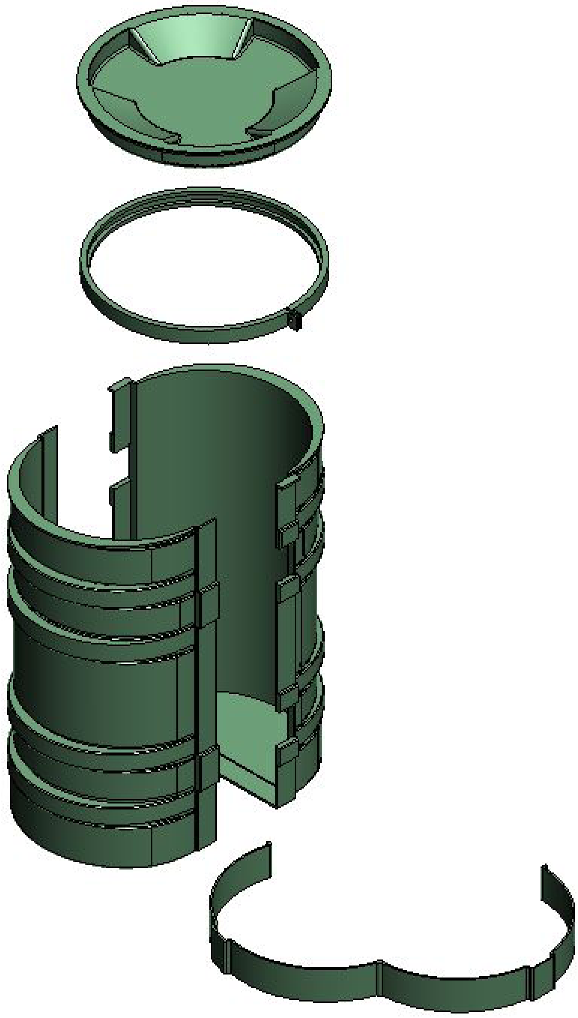


Figure 100. Exploded view of all the components of the final design

The body of the drum

To create the halves of the drum, two separate thermoforming moulds must be made, one for the inner drum half (Figure 102) and one for the outer (Figure 103).

The moulds will be created in the orientation in which the drums are depicted in the aforementioned figures. The lower mould half is used to create the inner surface of the drum. The upper mould is used to create the outer surface. Then the two moulded sheets are joined.

In the current edges have been rounded to a minimum radius of 5mm. During further development of the product topics such as the wall thickness distribution should be investigated.

In a prior iteration of the design, diagonal wedges were created (Figure 105). These would however be difficult to produced by thermoforming. Basically a sheet of plastic is draped over a mould, the material would not be able to reach the area indicated in orange. Maybe an insert in the mould could solve this issue, however this would also increase the production costs.

It may be interesting to investigate potential cost savings, by creating one mould with interchangeable inserts. Seeing as the two drums halves are identical, except for the area with overlapping flanges.

Lid

The lid will be produced by twin sheet thermoforming in the orientation illustrated in Figure 99. The upper part contains detailing for extra support against inwards forces on the side walls of the drum. The lower part creates a smooth inner surface. These two parts are joined together in the production mould.

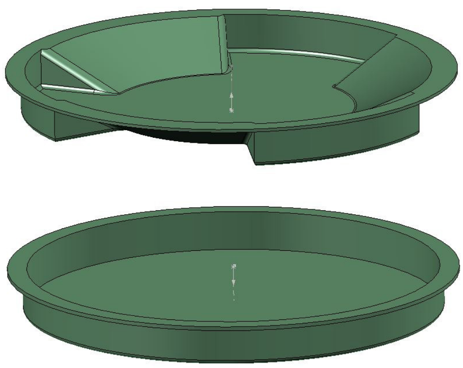


Figure 99. Exploded view of the lid. The upper half is formed by the upper mold. The lower half by the lower mould. The two are joined together.

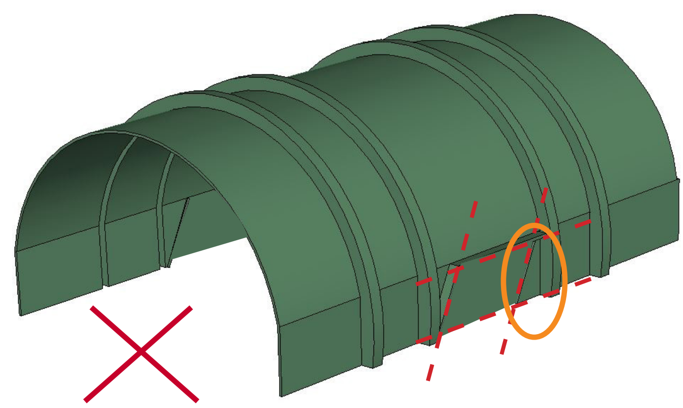


Figure 105. Diagonal wedges require inserts to produce. Problem indicated in orange.

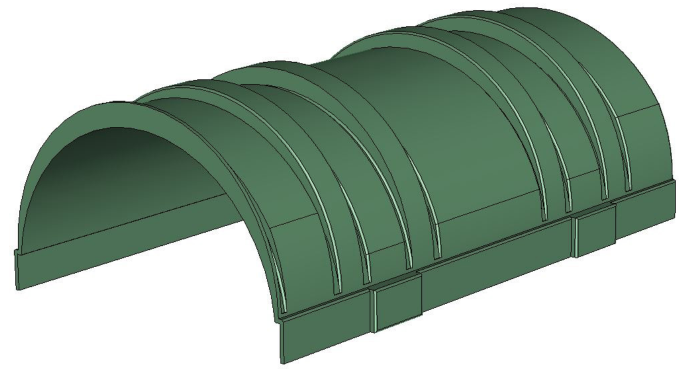


Figure 102. Inner drum half: twin sheet thermoformed shape

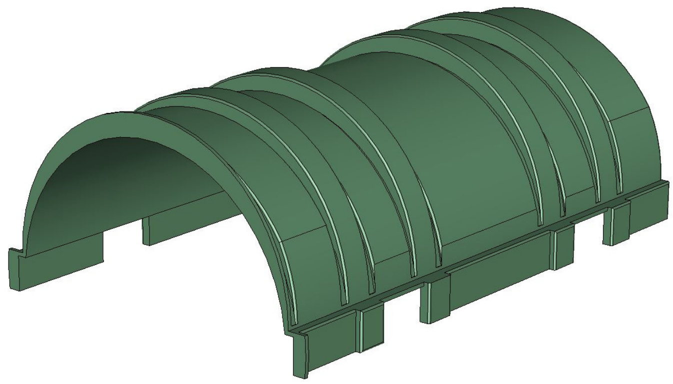


Figure 103. Inner drum half: twin sheet thermoformed shape

Figure 104. Bolt closure on a metal ring (Geoplastics, 2017)

Figure 101. Slim weld-on stainless steel hinge (Discountsteel, 2017)

External support ring

An initial design of the external support has been created, it consist of two metal arches with a bump (to accommodate the overlapping flanges), connected by a hinge. For an illustration see Appendix: Technical drawings. This part could be produced by rolling sheet metal. A hinge (Figure 101) would be welded on to connect the two arches.

Lid fastener

A metal lid fastener, with bolt closure, will be used (Figure 104). During the interviews with cold storage workers, it became clear that lid fasteners with a clamp closure instead of a bolt can be difficult to close (see Appendix: Interviews). This is a prefabricated component which is currently used for many plastic drums.

Takeaway

Further investigation is required to guide whether the design is truly producible. The current design has be created with the basic production principles in mind. All part except the lid fastener will be custom made.

32. COST PRICE ESTIMATION

An overview has been created for the company, as an introduction of the types of costs involved in product development. Requesting quotes at producers did not fit within the scope of this project.

Topics

At this point of the product development, and due to time constraints, a precise calculation of the costs involved is not feasible. However an overview of the cost categories has been created (Table 6). This can be filled in later in the design process. This chapter creates a guide of what the company can expect when developing the product further.

Development costs

At the moment the design is at the beginning of the embodiments phase. Before becoming an actual product, the embodiment must be continued. This requires engineering man-hours (see row: Engineering costs). During this process, prototypes will be made, as well as test runs at the chosen production facility (see row: Prototyping). Based on my own prior experience, each thermoforming mould (only for initial prototyping purposes) will cost around 100 euro. The costs of the actual thermoforming not included.

Cost price of the drum

Commercial vacuum forming involves the following costs (Lovejoy, 2010):
1) Tooling. The mold has to have cooling channels. Prototypes can be done on wood or epoxy molds but these will not last very long in production because they will deform and crack under repeated heating/cooling. Also, wood and epoxy hold heat and the cooling times can be very long. Production molds are commonly made from aluminum, but other metals can be used. The mold must have channels for the air, as well as channels for cooling water.
2) Material costs.
3) Molding costs, which include clamping the sheet of plastic, heating it up, drawing it down over the mold, allowing it to cool, and then removing it.
4) Post processing costs, such as cutting the mold away from the surrounding sheet of plastic.

For a (single sheet) thermoformed product of 40*50 inches, the total costs, for a batch size of 500 products, lies in the region of 100.000 euro (ProductivePlastics, 2017). The new drum however is quite a lot larger and consist of multiple components, which are twin sheet thermoformed. Currently Maia Global purchases N55 drums for 35,80 euro per drum (Maia Global, 2017). I expect the new drum will be more expensive (even when eliminating the margins of the drum supplier, the new design will come directly from the producer).

Cutting down costs

Some directions which could be explored to cut down the costs include:

- Using the same mould for both halves of the drum. The drum halves are identical, except for the overlapping flanges. These could be created with an interchangeable part in the main mould, to reduce mould investment costs. However, it is also possible that creating two mould is less expensive than developing and operating interchanging parts of the mould.
- Design a drum lid using single sheet thermoforming: By altering the design of the lid this could be achieved, however the maximum strength will always be lower than an optimized design achieved with twin-sheet thermoforming. This would cut down the production and tooling costs.
- Using inexpensive design engineering labour in the form of interns may cut down costs, however expectations should be managed with care (see Chapter: Reflection.

Saving costs in the supply chain of juice

Many companies have a very poor understanding of their full packaging costs, including the labour and fuel costs of packing and distribution, labour costs of unpacking, packaging waste disposal costs and costs of lost product due to inadequate packaging (lost revenue, labour costs etc). This can make it more difficult to promote the benefits of a new and more efficient packaging system if these costs are not calculated (Verghese & Lewis, 2007).

This means that a packaging which is more expensive to produce, provided by Maia Global with a higher purchase price or lease rate, can still be the inexpensive option for a customer. If the savings are calculated throughout the supply chain.

Within the scope of this project, the specific costs of each phase have not been collected. However, it is expected that the new design will have consequences for the following cost (other cost will remain the same):

- The transport costs of empty drums will decrease due to the improved return ratio. Assuming that customers wish to receive 814 drums in one go, per order, which is a significant increase compared to the current 544 drums per container (as calculated in Chapter: Transport scenario). The shipping of one container from

Table 6
Overview of costs involved in product development

Cost estimations		
Category	Component	Costs (euro)
Design/engineering costs		
Further professional development is required, including new design iterations and embodiment and production management. This time investment varies immensely on the assignment and information / direction provided to the designer.		
External, experienced, design engineer fee		
	Hours of work	#
	Fee per hour	Approx. 100 (Mechanicalengineeringpros, 2017)
	Total	#
Prototyping costs		
Before the final production, prototypes should be made for testing. Prototypes can be done on wood or epoxy molds but these will not last very long in production because they will deform and crack under repeated heating/cooling (Lovejoy, W., 2010).		
Tooling investment costs		
	Mould 1 (inner half)	#
	Mould 2 (outer half)	#
	Mould 3 (lid)	#
Costs per drum (incl. material, forming and post processing)		
	Drum halves	#
	Lid	#
	Lid fastener	#
	External support	#
	Total	#
Production costs		
Production molds are commonly made from aluminum, but other metals can be used. The mold must have channels for the air, as well as channels for cooling water (Lovejoy, W., 2010). These costs will vary per production batch size.		
Combined costs of parts, tooling & transport		
	Inner half	#
	Outer half	#
	Lid	#
	External support	#
	Lid fastener	#
	Total	#

Turnhout, Begium (the service center) to the harbour of Santos, Brazil costs approximately 1.500 euro, including all accompanying costs such as low sulphur surcharge (a mandatory fee charged for the use of more expensive, less polluting fuel), customs and insurance (Flexport, 2017). Depending on order quantities, a saving can be calculated. Lets assume a customer wants 1500 drums; the new design can achieve this in two containers, the N55 requires three.

- There may be a minor decrease in the storage costs of empty drums. 35 drums of the new design fit on an industrial pallet compared to 32 N55 drums (calculated in Chapter: Transport scenario).
- The Reefer loading scenario, for the transport of drums full of juice, has been improved (as described in Chapter: Transport scenario). More pallets are placed on floor level, reducing the amount of pallets required by 4 per Reefer. A saving is made per pallet, because these no longer need to be wrapped in plastic film, reducing labour cost and disposal fees.
- The handling costs of the drum will increase slightly, due to the additional (dis)assembly steps. The newly introduced steps are (dis)-assembling the halves of the drum and placing the external support ring.

Takeaway

At this point of the design process an estimation of the cost price has not yet been made. An overview of the costs involved has been created, to give the company an idea of the types of costs involved in product development. This can be filled in with future quotes from suppliers. It is important to keep in mind that a drum with higher production costs can still be an economical solution when looking at the entire supply chain of juice.

33. TRANSPORT SCENARIO

In this chapter, we will discuss the way in which the new drum will be transported. Two different scenarios which will be explored; when the drum is full of juice and when it is empty and nested.

Introduction

The transport scenarios of the new design will be compared to that of the N55 drum. Seeing as the N55 is the reusable drum with the highest return ratio (also referred to as reduced empty volume), currently on the market. The loading scenario of the N55 is based on the Loading Guidelines for Plastic Drums (Maia Global, 2017), provided by Maia Global to their customers. The transport of empty drums has been the main focus, however improvements have also been made in the transport of drums full of juice.

Drums full of juice

Once drums have been filled with juice, they are transported in cooled containers called Reefers. The payload (amount of weight with can be loaded inside a container) of such containers in relatively low, 29.340 kg (K-tainer, 2017). This results in Reefers with a lot of empty space left unused. The weight restriction only allows for 110 N55 drums, loaded as shown in Figure 109.

The bottom level of drums is loaded without pallets. The dimensions of the N55 drum are slightly too large to fit four in a row, so they are loaded in a messy pattern. The second level of drums is loaded on pallets as shown in Figure 107. The top diameter of the drum prevents 4 drums being loaded on a pallet, making inefficient use of space. The new design fits 4 on a pallet (see Figure 106), with a small overhang, which is permissible. The drums also have more support against each other due to the non-tapered shape.

The new design, which has a slightly smaller diameter, can be loaded on the floor level of a Reefer, in neat rows of 4 drums. Allowing for 80 (instead of 74) drums to be loaded without pallets, as shown in Figure 108.

In these calculations it is assumed that the same amount, 110 drums, of the new design will be transported. However, the new design requires 4 pallets less in transport. A pallet weighs 28 kg (CHEP, 2017), which results in a saving of 28*4= 112 kg. This saving can compensate for a weight increase of the tare (empty) weight of the new drum by +/-1 kg, if this is required. In further development, it may be interesting to adjust the content volume per drum, to prevent the last two drums from being loaded on one pallet.

Figure 107. Three N55 drums on a 1.000 * 1.200 mm pallet (four would stick out over the edge too much). Strapped together (yellow band) for extra support.

Figure 106. Four new drum on a 1.000 * 1.200 mm pallet. Strapped together (yellow band) for extra support.

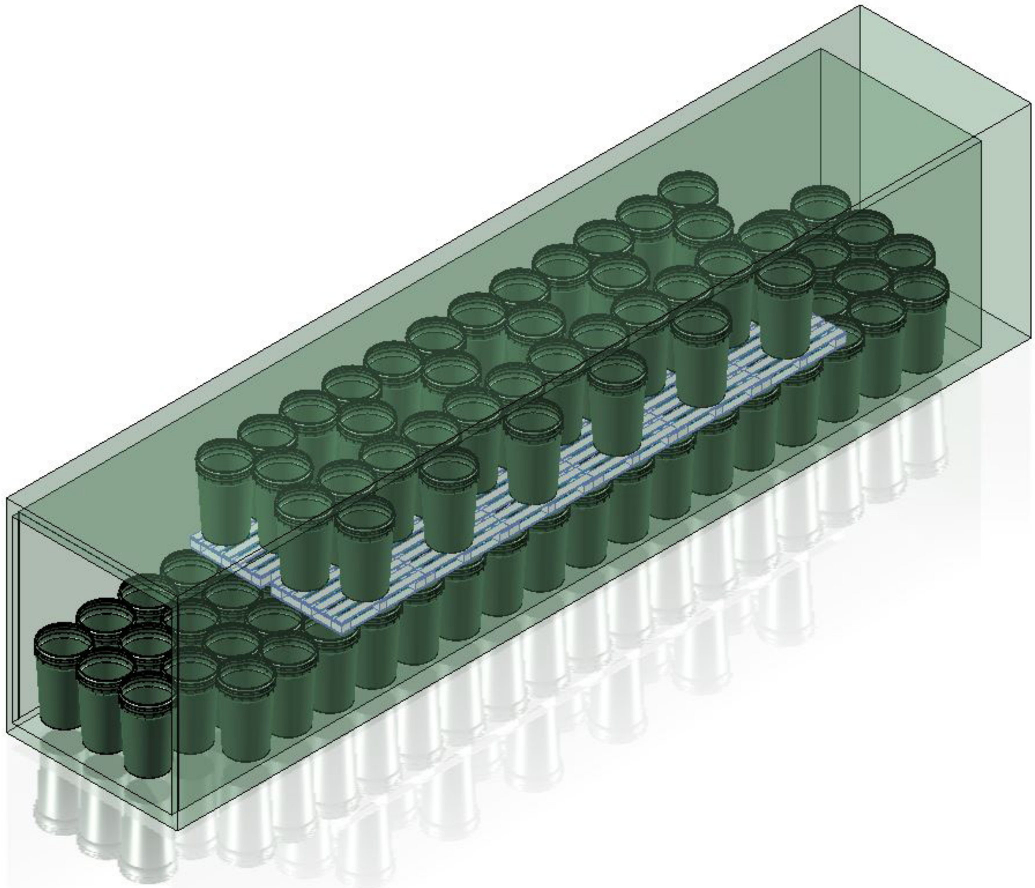


Figure 109. 40 foot Reefer loaded to maximum weight capacity, with 110 N55 drums full of juice. 74 drums on floor level and 36 on the second level on 12 pallets.

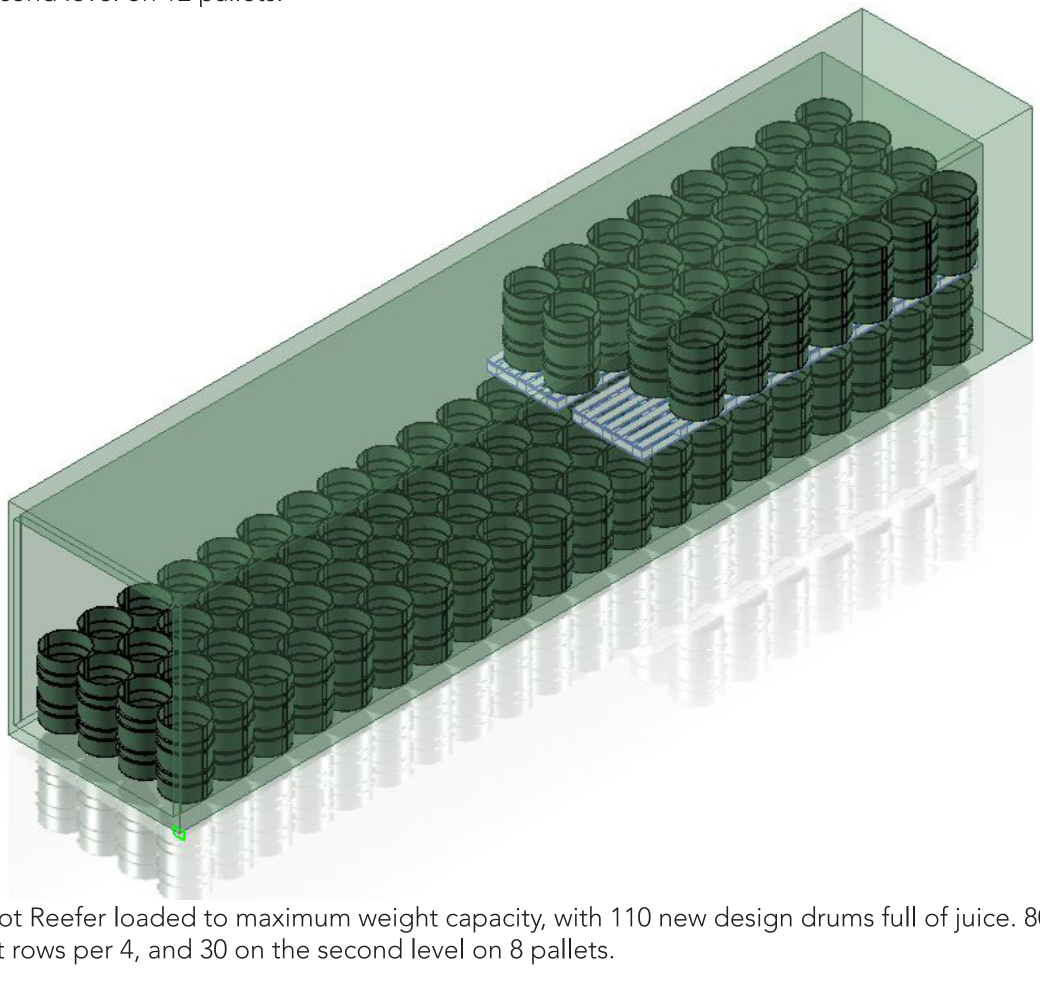


Figure 108. 40 foot Reefer loaded to maximum weight capacity, with 110 new design drums full of juice. 80 drums on floor level in neat rows per 4, and 30 on the second level on 8 pallets.

Being able to place more drums on the floor level is also beneficial because it means that fewer drums need to be secured in place with plastic wrap during transport (Figure 112). This minimizes the amount of waste. Only drums on the second level are wrapped in plastic, this is to keep them securely in place on the pallet.

Figure 112. Drums wrapped and strapped in a Reefer (Maia Global, 2017)

Empty drums

One of the main sustainability goals was to create a drum with an increased return ratio (also referred to as; a reduced empty volume). The way I chose to achieve this, is to split the drum in two halves which can be nested. The achieved benefit of this design will be explored in this chapter.

The basics of nesting

Nesting is the stacking of drums one inside another. The height of the created stack is determined by the height of a drum and the denesting height. The denesting height is the distance that the inner drum sticks out of the outer drum, when two drums are nested (Figure 114).

The total height of a stack is determined by the following formula (where x is the amount of drums in a stack):

Stack height = Drum height+(x-1)*denesting height

The new design will be nested in a different orientation. The two halves will be disassembled and be lied down next to each other (Figure 113).

Compared to the N55 drum:

The footprint of the drum increases (amount of floorspace taken up by one drum).

The drum height decreases (in nested position this is the diameter of the drum plus half the length of the overlapping flanges).

The denesting height decreases (the new value is calculated in Appendix: Nesting calculation).

These changes create the possibility of nesting more empty drums in a transport container. To create a neat and stable stack some requirements apply. The drums should have an edge to rest upon each other (Figure 110)without air-locking (this is the sticking together of drums if the contact surface of nested items is too large).

The height of both drum halves should be the same (Figure 111). In this way both stacks (if inner and outer drum halves are nested in separate stacks) reach the maximum height after the same amount of drums (preventing unused space in transport.

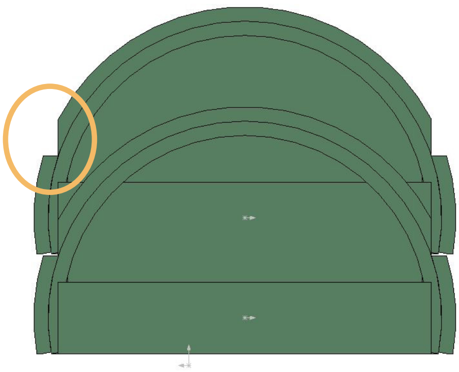


Figure 110. Nesting indents (one indicated in orange)

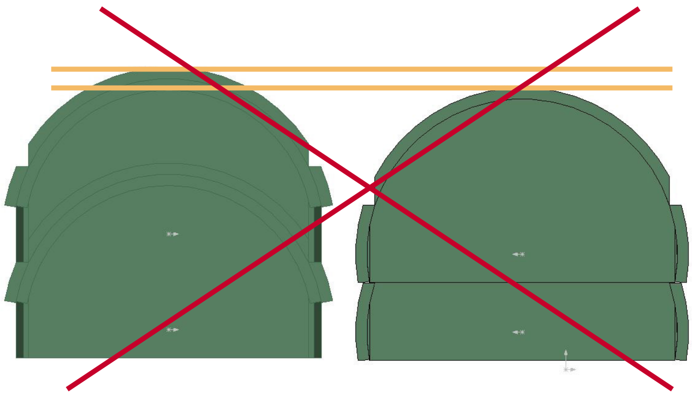


Figure 111. Unequal nesting heights

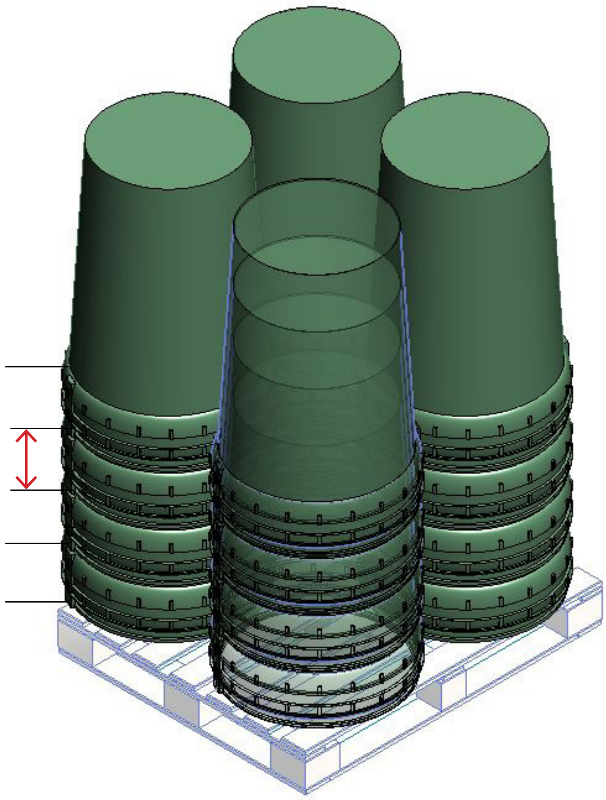


Figure 114. Nesting method of the N55 drum. 4 layers of drums. Red arrow indicates denesting height, 190 mm.

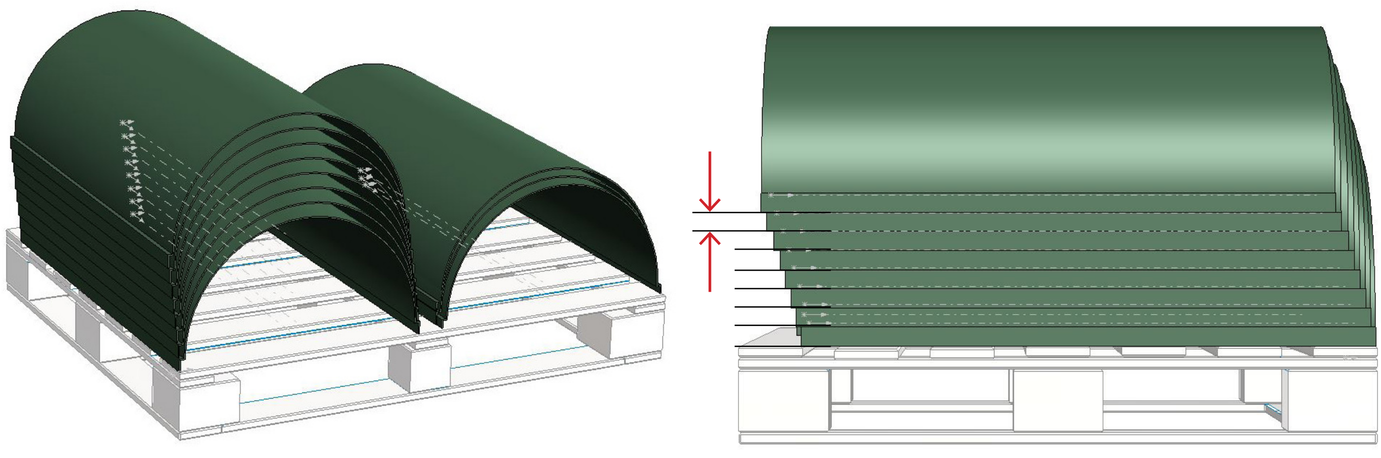
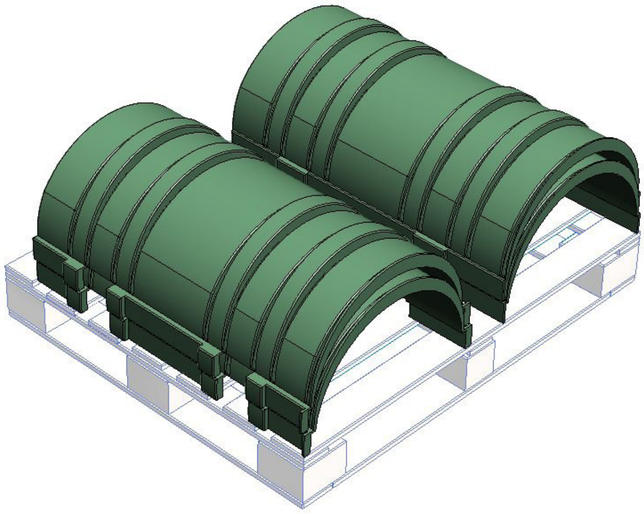


Figure 113. Nesting method of the new design. Left: Isometric view. Right: Side view. Red arrow indicates denesting height, to be determined on the next page



Nesting of the final design

The images on this spread show how the final design will be nested.

Figure 115. Twin sheet concept nesting: Isometric view

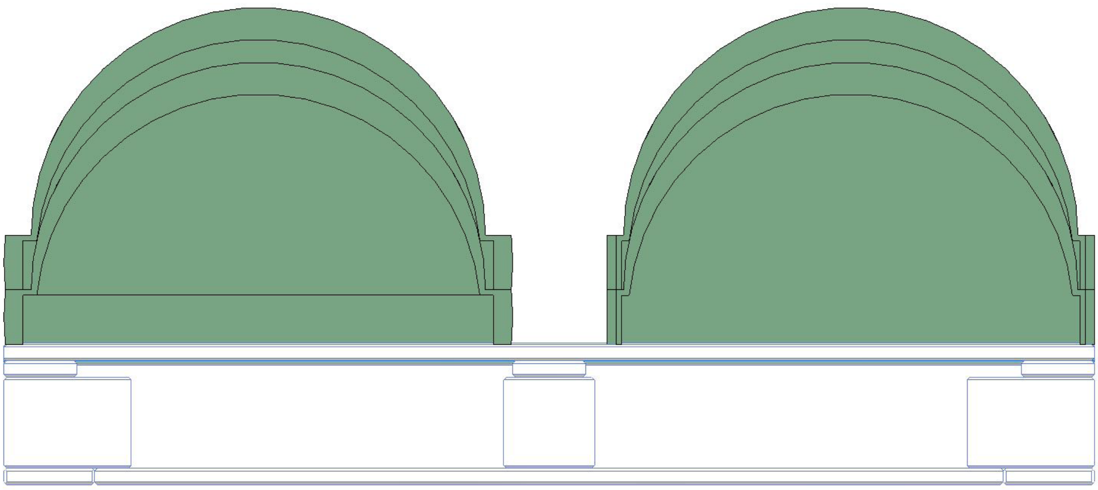


Figure 116. Twin sheet concept nesting: Front view. The outer halfs are stacked on the left. The inner halves are stacked on the right.

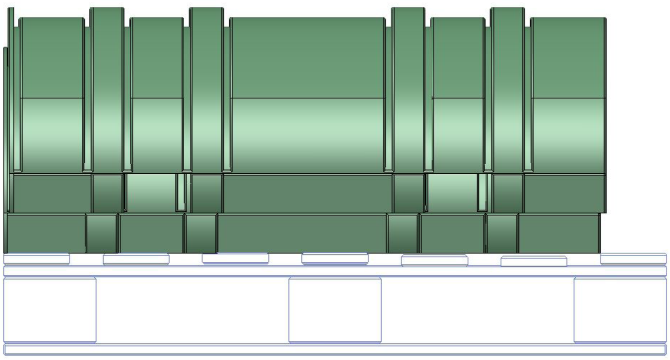


Figure 117. Twin sheet concept nesting: Outer half of drum

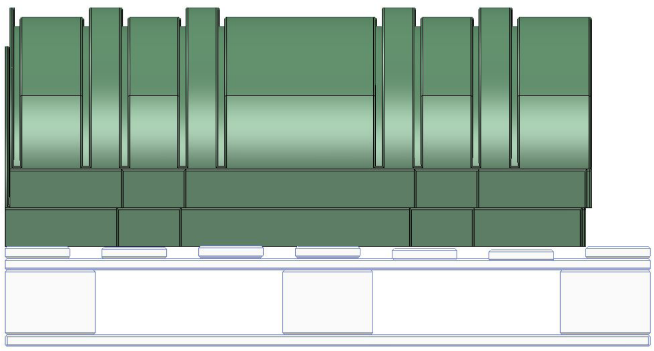


Figure 118. Twin sheet concept nesting: Inner half of drum

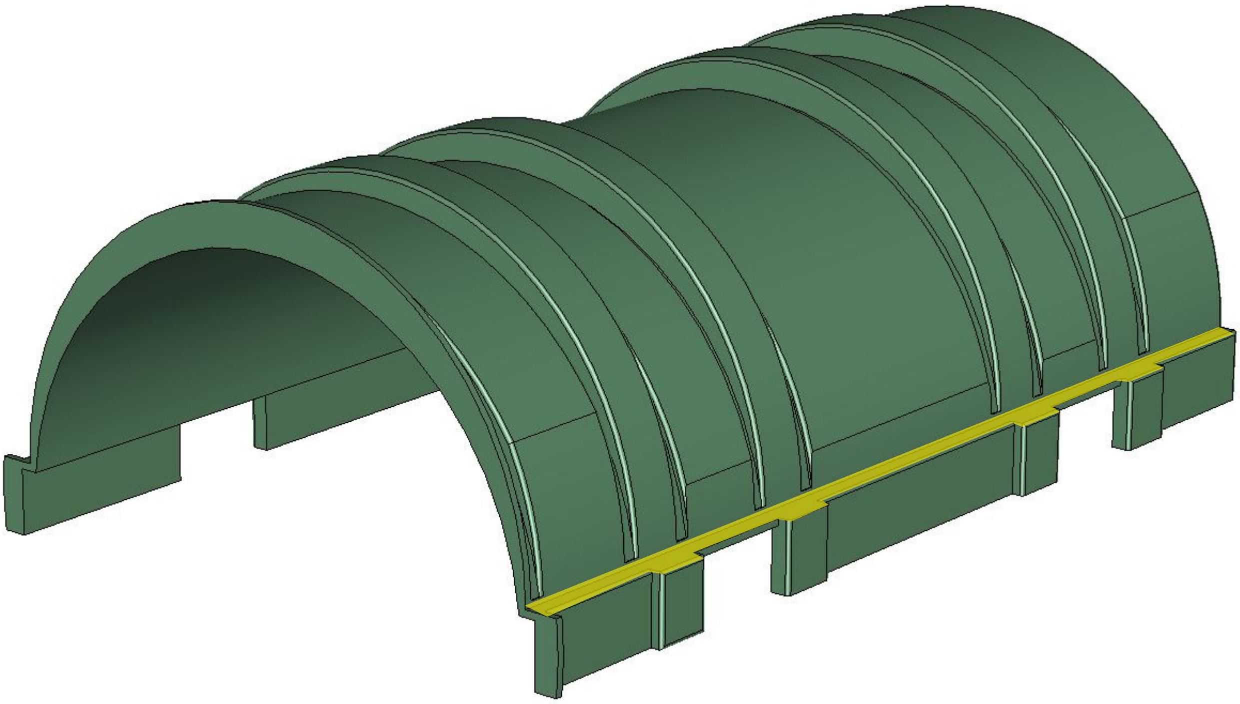


Figure 119. The nesting edge of the Outer Drum Half is highlighted in yellow.

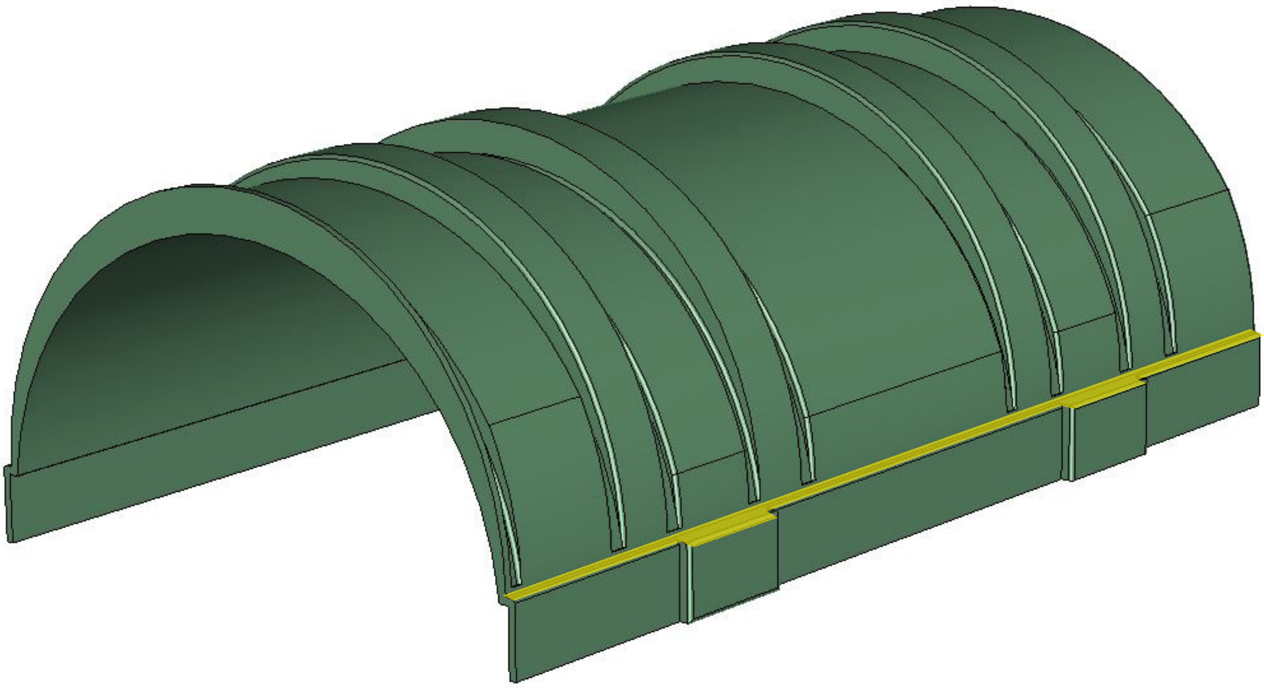


Figure 120. The nesting edge of the Inner Drum Half is highlighted in yellow.

Nesting in a container

Different layouts for nesting drums in a container have be calculated in Appendix: Nesting dimensions. By nesting the new design in a similar pattern as the N55 drum (Figure 123), an increase of 51 drums per container can be obtained (Figure 122). This is not very much, when considering the increased complexity of the design of the drum.

However, when the drums are loaded in the container in a different pattern, without the use of pallets, as shown in Figure 121, an increased of 270 drums is achieved. This is a substantial increase. Therefor this loading pattern is recommended.

Takeaway

When drums are full of juice, the limiting factor for the amount of juice which can be transported in a Reefer, is the weight. Due to this, the same amount of new design drums can be transported as the N55 (110). However, fewer drums need to be place on the second level. This reduces the use of packaging materials which are discarded after transport.

When empty drums are transported, 814 drums of the new design fit in a container (compared to 544 drums of type N55). This allows for more efficient transport.

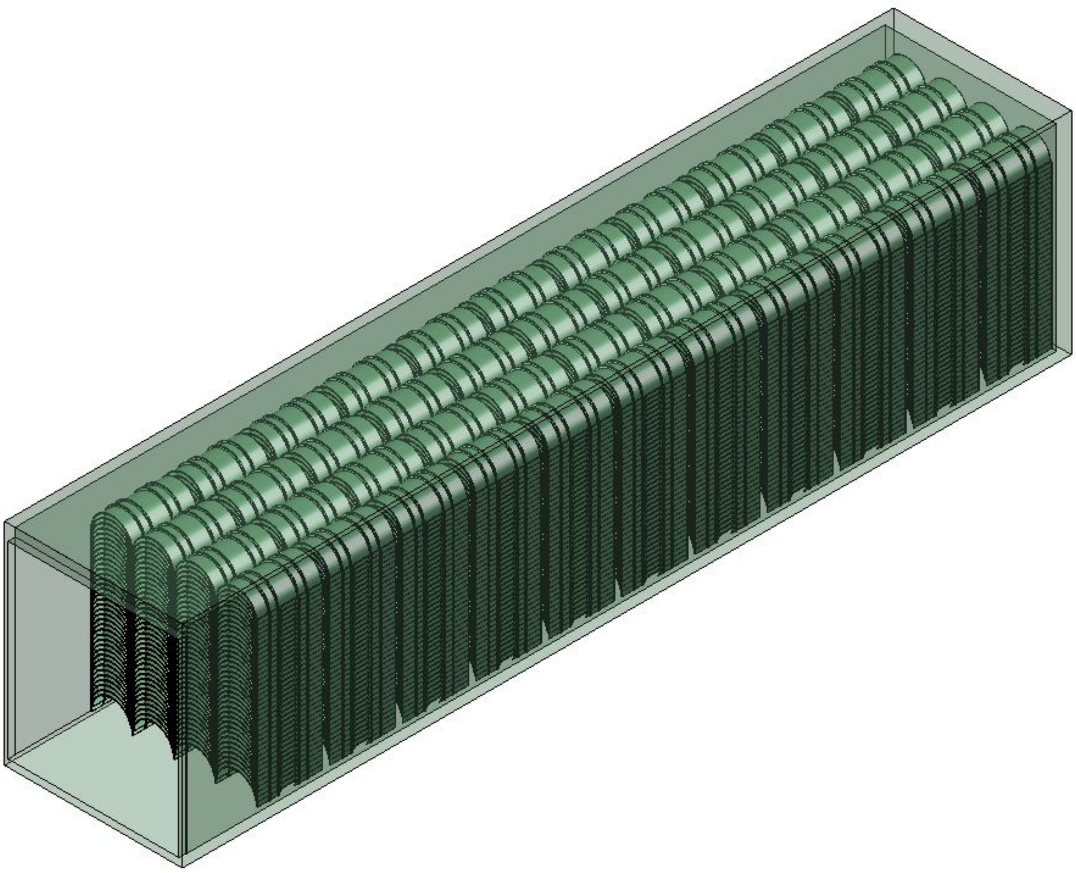


Figure 121. 40 foot high cube container, filled to maximum volume, leaving space for 2 pallets of lids and lidfasteners (weight limit allows for more), with empty nested drums of the new design. Without the use of pallet. 814 drums.

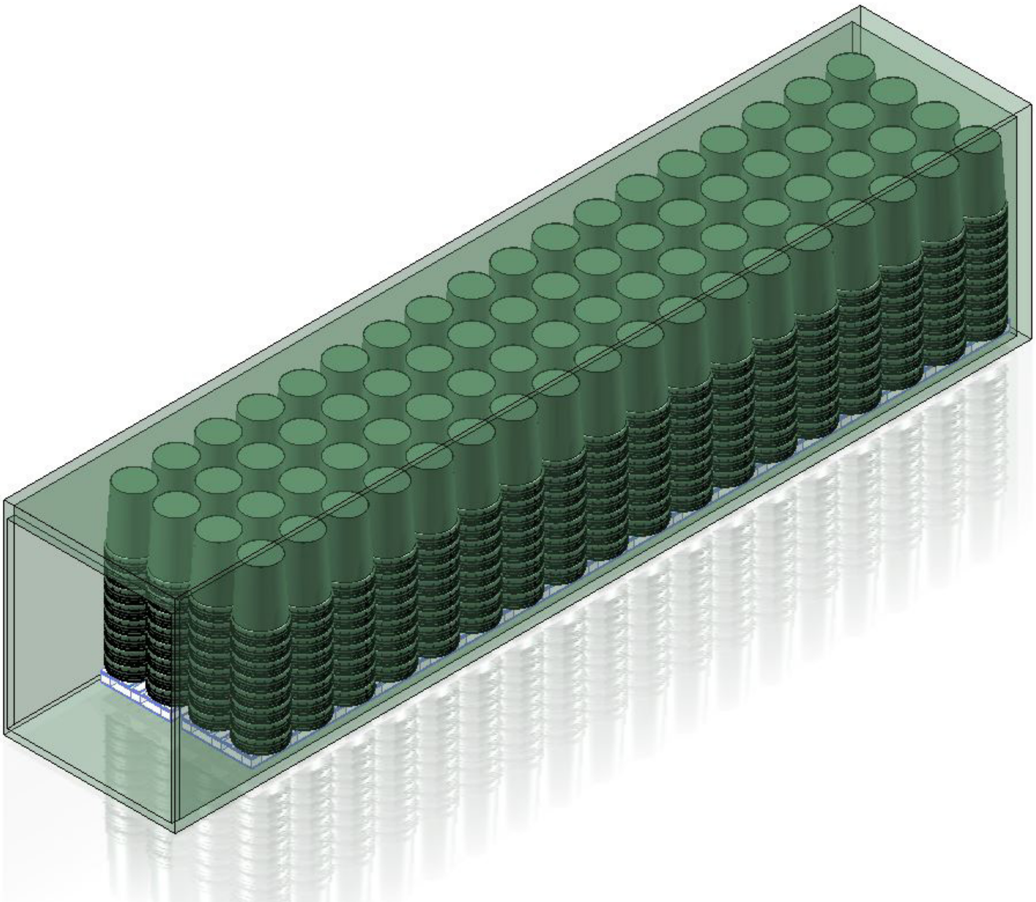


Figure 123. 40 foot high cube container, filled to maximum volume, leaving space for 2 pallets of lids and lidfasteners (weight limit allows for more), with empty nested N55 drums: 544 drums.

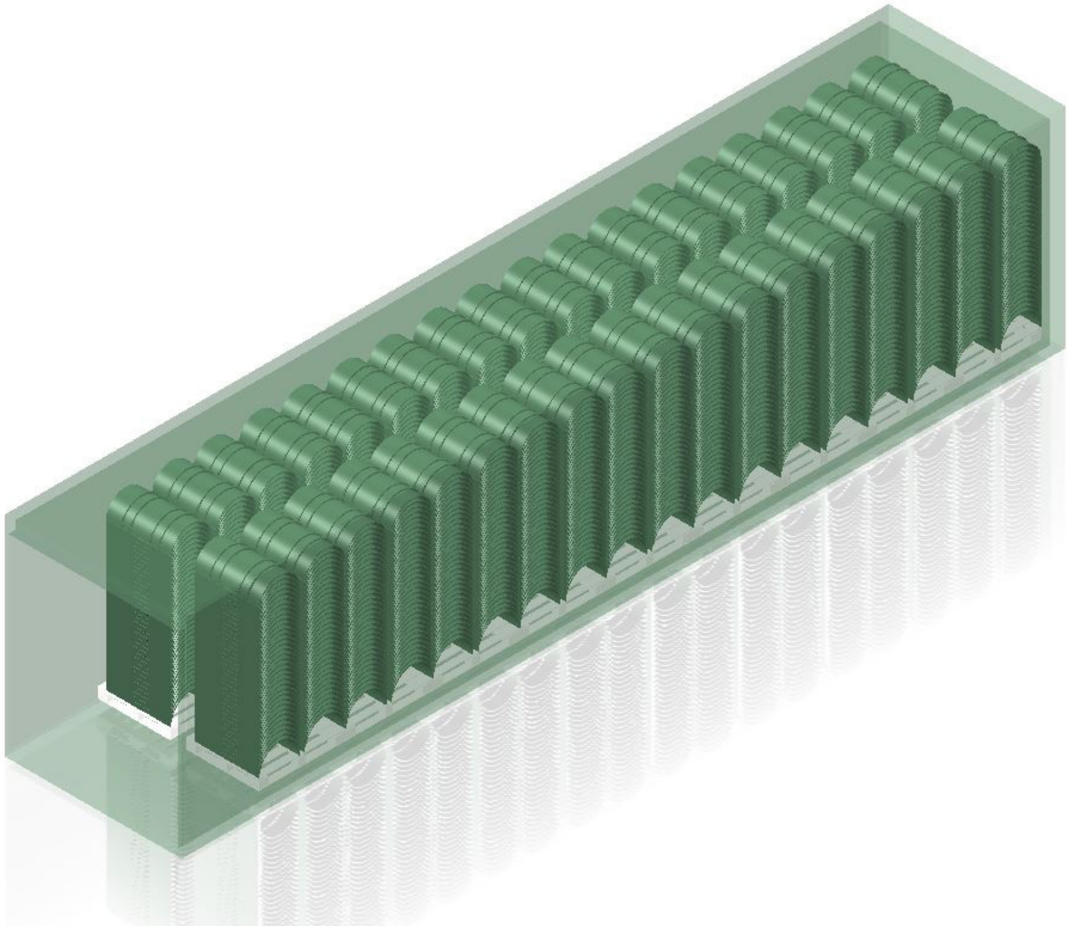


Figure 122. 40 foot high cube container, filled to maximum volume, leaving space for 2 pallets of lids and lidfasteners (weight limit allows for more), with empty nested drums of the new design. 595 drums.

34. MECHANICAL CALCULATIONS

In this chapter, primary mechanical calculations will be made to see how the new design will cope in different use scenarios. Until now, the design has been based on the dimensioning of existing, quite similar, designs of HDPE blowmoulded drums. It has been assumed this dimensioning should be sufficient, now this will be checked.

Scenarios

Multiple scenarios will be investigated. These are the main scenarios which determine the shape of the new design. Scenarios which remain the same as for existing plastic drums, will not be explored (such as handling with a pincher). Seeing as in these scenarios, the new drum will behave very similar. In these scenarios the drum is expected to perform slightly better, due to the benefits of twin-sheet thermoforming.
Each important scenario will be described, simulated in SolidWorks and conclusions will be drawn for the further development of the drum.

Assumptions

General information about the calculations and assumptions made for all the calculations are listed below.

Table 7
General information and assumptions used in the simulations

Simulation method	SolidWorks finite element static study
Model	Simplified model of the final design (see Appendix: Technical drawings). The drum has be simplified to a single wall (not twin sheet) drum with a wall thickness of 4mm, due to issues with meshing such a thin/intricate design. The consequences of this simplification are dicussed in the discussion at the end of this chapter.
Material of the drum & lid	High density polyethylene (HDPE) Density: 952 kg/m^3 (grades vary between 939-960 kg/m^3) (CES, 2016) Yield strength: 25 MPa (grades vary between 17,9-29 MPa) (CES, 2016) Tensile strength: 30 MPa (grades vary between 20,7-44,8 MPa) (CES, 2016)
Material of external support ring	Alloy steel (average) Yield strength: 620 MPa (SolidWorks, 2016) Tensile strength: 724 MPa (Solidworks, 2016)
Connections	All connected parts will be simulated as bonded together.
Mesh	For reliable results, it is recommended that the aspect ratio be under about 5 for structural analysis (Radostina, V., 2014). However this was not achieved in my calculations, due to the thin walls of the design and issues with meshing. The maximum aspect ratio will be indicated per scenario.
Temperature	All simulations are made at room temperature.

Nesting of empty drums

When drums are empty they will be laid down on their side and nested. The maximum height of a stack, used for efficient transport, is 35 drums (see Chapter: Transport scenario). The nesting edges (edge where two drums are in contact with each other) of the bottom drum, will need to resist the weight of all these drum (see Table: 8 and Figure 125). The stresses must not exceed the yield strength, to prevent plastic (permanent) deformation.

In the simulation the Inner Drum Half is used, because this has a smaller nesting edge. The force will be the weight of 34 Outer Drum Halves, as these have a larger volume than the Inner.

Results

The maximum stress is 3,80 MPa (present in the corners of the wedges) (Figure 124). This stress is far below the yield strength, and therefor acceptable. The maximum displacement is only 1,59mm in the top edge, this means the drums will remain nested on the nesting edge, without slipping off.

A second calculation was performed with an extreme force of 10.000 N (+/- 1.000kg). In this scenario the maximum stress was 20,2MPa, this is still below the yield strength. However the deformation is very large; 8,47mm. The deformation is the determining factor for the tolerable weight.

Conclusion

The drum can easily be nested 35 unit high, without plastic deformation. The maximum elastic deformation is below 2mm, meaning the drums will remain nested on the nesting edge as envisioned.

The stresses are so low (3,8 MPa << 25 MPa) that more could be stacked on top of the pile. For example some lidfasteners/external supports on a pallet.

Table 8
Forces in scenario: Nesting of empty drums

Study subject	A simplified model of the Inner Drum Half. This version has a single wall thickness of 4mm.
Fixture	Lying on the ground, in nesting position. The bottom edge is fixed in position, the side walls are simulated as a roller/slider.
Force	The weight of 34 drum halves. 34*5,639*9,81= 1.880N Calculated using: Volume of Outer Drum Half (the bigger drum half): 5924 cm^3 Weight per drum half: 5,639 kg
Location of force	The entire nesting edge of the drum
Permitted displacement (elastic deformation)	The nesting edge is 8mm wide, with additional protrusions (the wedges) of 10 mm. A maximum horizontal, outward displacement of approximately 3 mm is tolerable.
Aspect ratio	20

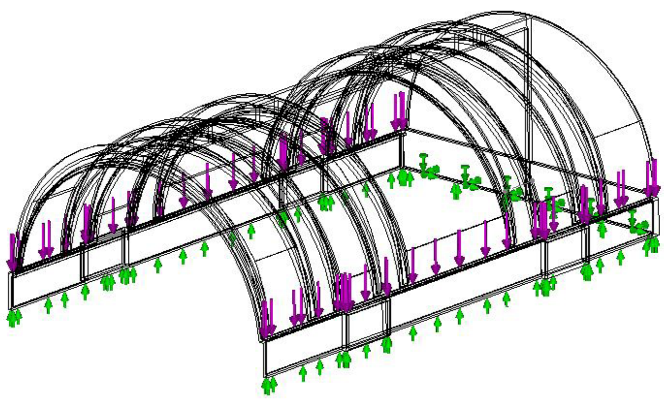


Figure 125. Scenario: Nesting of drums. Green arrows: fixed geometry of the bottom edge (to the right in the illustration) and roller/slider of side walls. Purple arrows: Weight of 34 drums

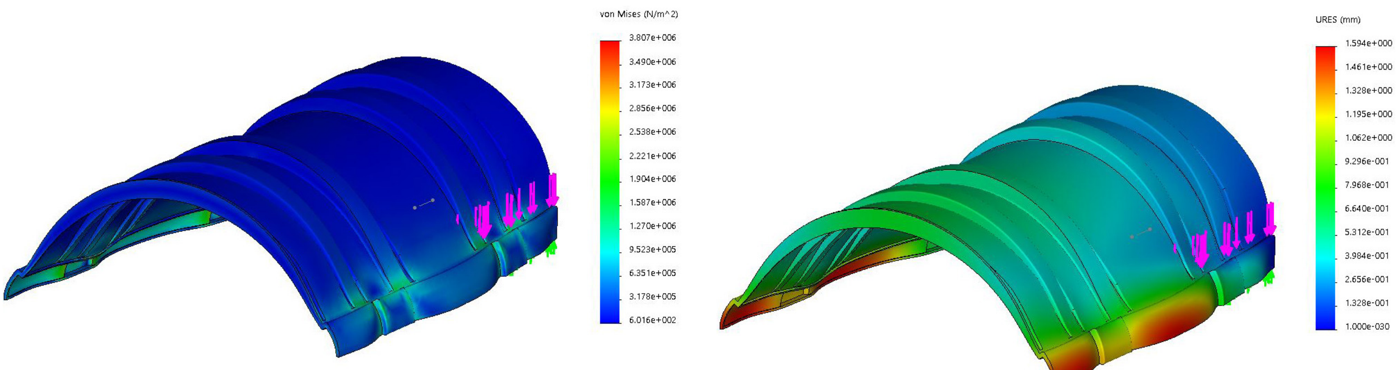


Figure 124. Results for nesting of drums. Left: Maximum stress (red) 3.80 MPa. Right: Maximum displacement (red) 1.59mm

Stacking of filled drums

Once drums have been filled with juice they are placed on pallets and stacked, preferably in stacks of 6 levels high.

Initially simulations were attempted using an entire drums assembly, to incorporate the effects of all components on the result. However the simulations failed, due to unknown reasons. Therefor the simulation was simplified; only the outer drum half was used, the other components (inner drum half, external support and lid) were excluded from the simulation (Figure 126). This simulation also failed before giving a result. The force was decreased to 4.000 N (Table 9), this simulation gave results. These will be discussed in this chapter.

Results

The maximum calculated stress is 13 MPa, located under the lid fastener rim. This is lower than the yield strength of 25 MPa.

The maximum displacement is 50mm at the top of the right flange. It is peculiar that the displacement of the drum is not equal in the left and right corner of the drum. Seeing as the drum is symmetrical and the force is evenly distributed over both halves. This indicates that an error has occurred in the simulation.

Conclusion

Due to the failing of simulations no results were obtained for the desired scenario. The results for a force equal to a stack of 4 layers high, was calculated. The drum will withstand this, which is a good sign. However the results for the displacement very illogically asymmetrical, suggesting an error in the simulation. A displacement of 50 mm is large (especially as the force it less than in the desired scenario). This might however be minimized by including the effect of the lid and lid fastener.

Table 9
Forces in scenario: Stacking of filled drums

Study subject	The outer drum half of a stack of drums.
Fixture	Fixed geometry of bottom of drum
Force	Half of the weight of 5 drums filled with juice and 4 pallets (weight of the drums is distributed over 4 drums). (((5*(250+10)+(4/4*28))*9,81)/2= 6.5014 N Due to failing simulations, finally a force of 4.000N was used (this is slightly more than 3 drums and 2 pallets, total stack height 4 layers).
Location of force	Top edge (lid fastening rim)
Permitted displacement	Not relevant, would partially be compensated by the lid fastener.
Aspect ratio	35

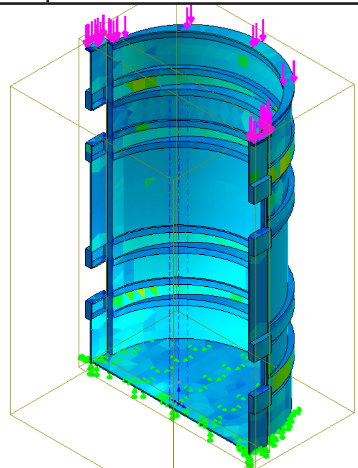


Figure 126. Scenario: Stacking of filled drums. Green arrows: Fixed geometry of the bottom to the floor. Purple arrows: Half of the weight of 4 layers of drums including pallets.

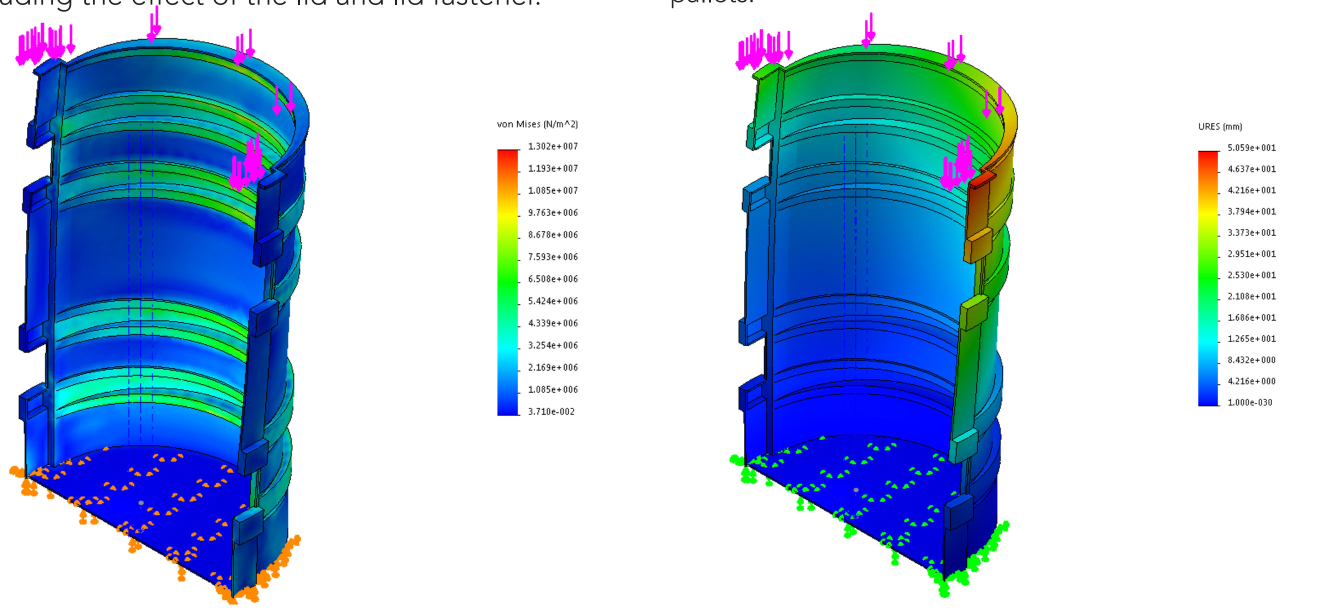


Figure 127. Results for stacking filled drums. Left: Maximum stress (red) 13 MPa. Right: Maximum displacement (red) 50 mm

Sea transport

An important scenario to calculate is that of drums during transport (as illustrated in Figure:128). The most extreme forces occur during sea transport, extreme forces can take place, if the ship is caught in a storm on a rough sea. The drums should survive this.

BOC was not able to provide information about the forces during sea transport (this has apparently not been used during the development of the Orca packaging), therefor I have collected information from literature.

In maritime transport, calculations should always be based on the least favorable assumptions. Acceleration values of 1.0 G should therefore be assumed (Transport Information Service, 2017).

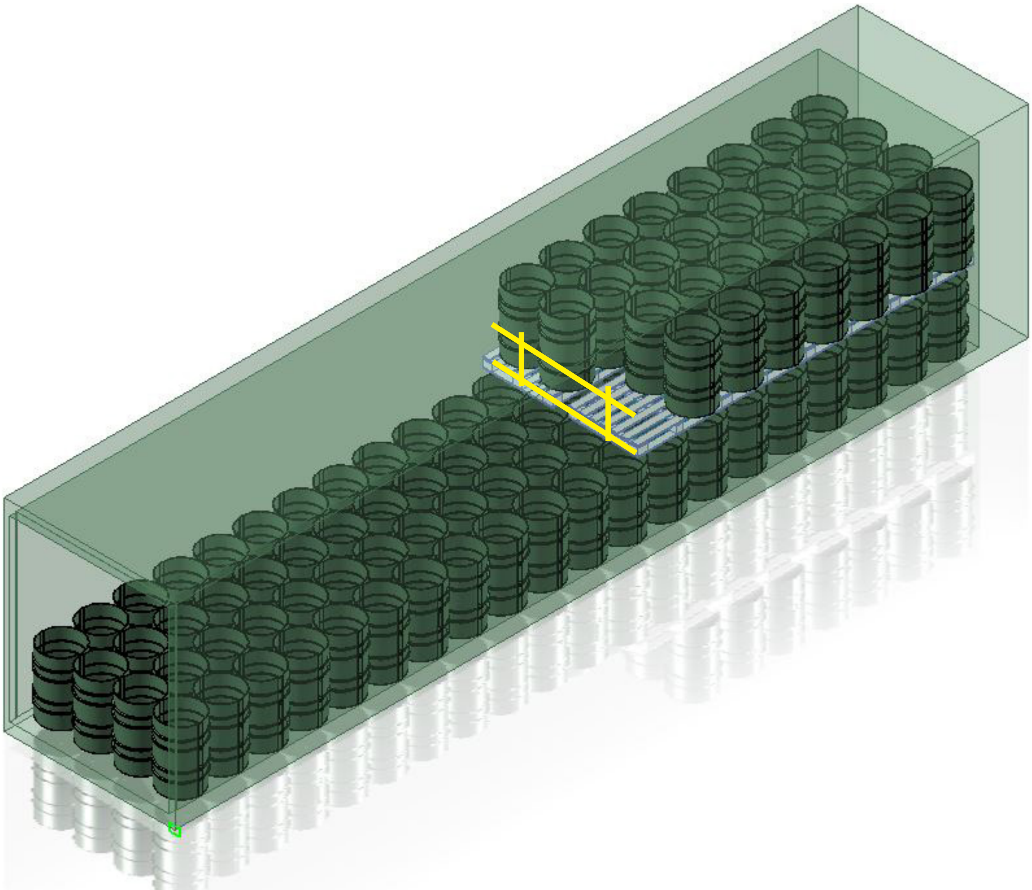


Figure 128. Sea transport of filled drums. The second level is kept in place using wooden supports, indicated in yellow, in the same way as is done with the N55 drum.

N55 drum

To get a global idea of whether the scenario I have created (Table 10) is realistic, the existing N55 was modeled in SolidWorks and simulated in the same scenario.

In this scenario, a collisions takes place of 4 drums against the wall of the container. The weight of 4 drums collides against the neck of the drum closest to the wall.

Results

The maximum stress of 29,8 MPa, is calculated in the fine details of the neck (Figure 129). This value is equal to the tensile strength, they will break.
In the main shape (not the minor details) the maximum stress is in the region of 12 MPa, this is below the yield strength of 25 MPa. The maximum deformation is 48mm.

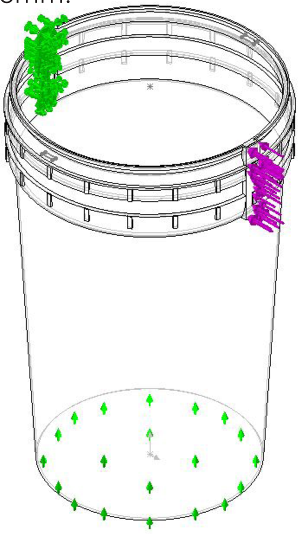


Figure 130. Scenario: N55 drum. Green arrows: fixed geometry of the left zone on the neck and roller/slider of the bottom. Purple arrows: Force of colliding drums

Table 10
Forces in scenario: Sea transport, N55 drum

Study subject	N55 drum body (4mm wall thickness HDPE)
Connection	No connections
Fixture	Fixed at a section of the neck which is the zone of the drum with the largest diameter (pushed against wall of container) Roller/ slider on the floor.
Force	Four drums colliding against the wall of a container. m= 4*(10 (drum tare weight) + 250 (juice)) kg = 1.040 a= 1 G = 9,81 m/s^2 F = m × a = 1.040*9,81= 10.202 N
Location of force	Opposite section on the diameter of the neck of the drum
Aspect ratio	36

Conclusion

The details which have been modeled in the neck of the drum will break during collision. This may be caused by the way in which I modeled the details in SolidWorks, read more about this in the discussion. However the main shape of the drum does not break or even deform permanently. The main shape easily survives this scenario, therefor so should the new design as well. This same scenario will be used and the results compared for the new design.

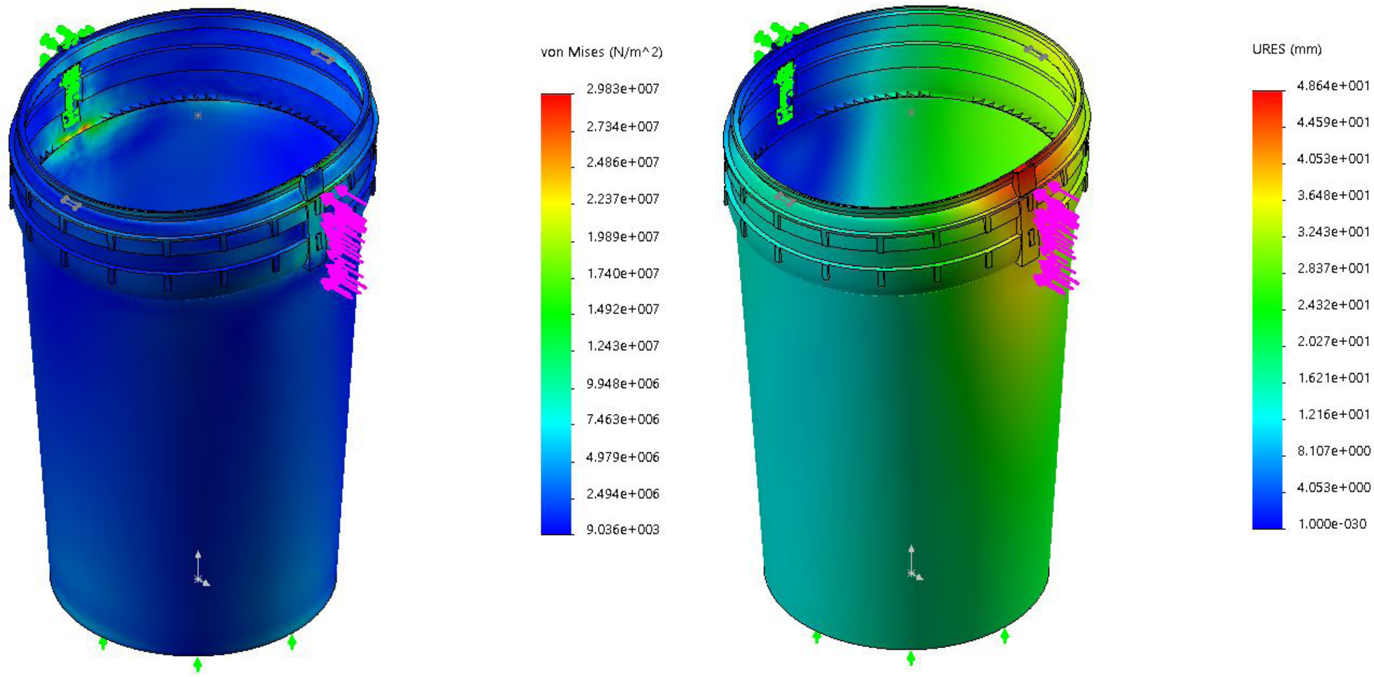


Figure 129. Results for N55 drum. Left: Maximum stress (red) 29,80 MPa. Right: Maximum displacement (red) 40 mm

Inner drum half and lid

The same scenario as used for the N55 drum will now be used for the new design (Table 11).

Only the Inner Drum Half is used during this simulation, seeing as it can not support on the Outer drum half when hit by an inward point force. The sunken lid has been simulated as a bonded component, because it (used in combination with the lid fastener) provides outward support to the drum wall.

The location of the force which is most critical, is the area directly next to the overlapping flanges (Figure 132). Here the inner drum half is not protected by the outer drum half and it has the least support from its own geometry.

If the Inner Drum Half is pushed inward, too far (the specific value has not yet been determined) this might cause the plastic liner to tear.

Results

A maximum stress of 297 MPa has been calculated (Figure 131). This far exceed the tensile strength of 30 MPa. Even in the less critical areas of the drum (light blue), the calculated stress reaches 50 MPa. This means the drum will fail in multiple locations. Due to this the deformation value is not relevant.

Conclusion

Extensive design alterations must be made, to be able withstand this force. The drum does not suvive the current scenario.

In the next calculation, the effect of the external support ring will be investigated. To see it this can help solve this issue. The external support ring will absorbs some of the impact.

Table 11
Forces in scenario: Sea transport, inner drum half & lid

Study subject	Inner Drum Half with Lid
Connection	The Inner Drum Half and Lid are bonded together
Fixture	Fixed at left flange (pushed against wall of container). Roller/ slider on the ground (bottom of drum)
Force	Same as Sea transport, N55 drum: F = m × a = 1.040*9,81= 10.202 N
Location of force	Side wall of drum, directly next to the overlap flange
Aspect ratio	35

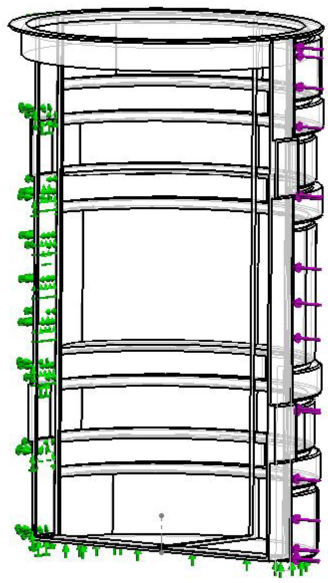


Figure 132. Scenario: Sea transport inner half with lid. Green arrows: fixed geometry of the left flange and roller/slider of the bottom. Purple arrows: Force of colliding drums

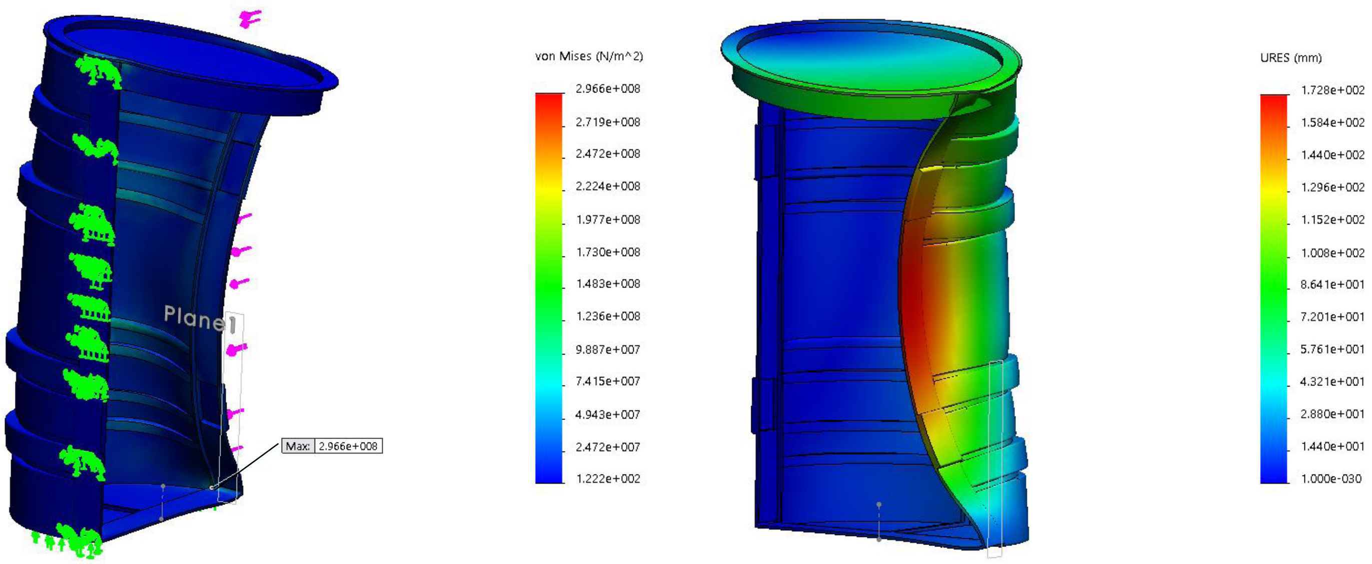


Figure 131. Results for sea transport: Inner half with lid. Left: Maximum stress (red) 297 MPa. Right: Maximum displacement (red) 172mm

Drum assembly

The same scenario will be applied as in the previous simulation. However this time all components of the drum will be included (Table 12). Specifically the external support ring is expected to improve the result.

The function of the external support ring, is originally to keep the two drum halves together. However is also functions as a "bumper" when drums collide.

Results

The largest stress in the steel external ring is 1.879 MPa, this far exceeds the tensile strength of 724 MPa. This maximum stress is present in the bottom edge of the "bump". The main surface of the bump has values in the region of 1.400 MPa.

In the HDPE components, the largest stress has been calculated in the outer drum half, in the zone where the drum meets the bump of the metal ring. This value is far too high 1.086 MPa (the tensile strength is only 30 MPa).

A second simulation was done with the wall thickness of the external support ring increased to 10 mm, the maximum stress is only 431 MPa.

Conclusion

The external support ring introduces a new issue; the metal ring will damage the body of the drum. This is cause by the very differing mechanical properties of the components.

The stresses when using the 5mm external ring are far too high, the over-dimensioned 10mm (massive) ring has much lower, acceptable stresses. Using a profile ring will save a lot of weight.

Table 12
Forces in scenario: Sea transport, assembly

Study subject	Drum assembly (including external support ring, 5mm thick)
Connection	The lid is bonded to the two drum halves. All other parts have surface contact but can more seperate of each other.
Fixture	Fixed at left flange (pushed against wall of container). Roller/ slider on the ground (bottom of drum)
Force	Same as Sea transport, N55 drum: F = m × a = 1.040*9,81= 10.202 N On the rings of the body and external support.
Location of force	Side wall of drum, directly next to the overlap flange
Aspect ratio	308

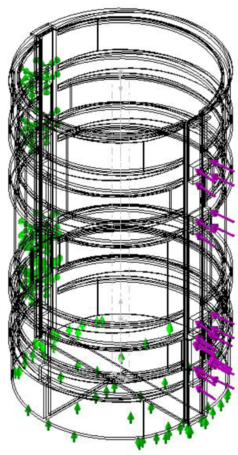


Figure 134. Scenario: Sea transport, assembly. Green arrows: fixed geometry of the left flange and roller/slider of the bottom. Purple arrows: Force of colliding drums

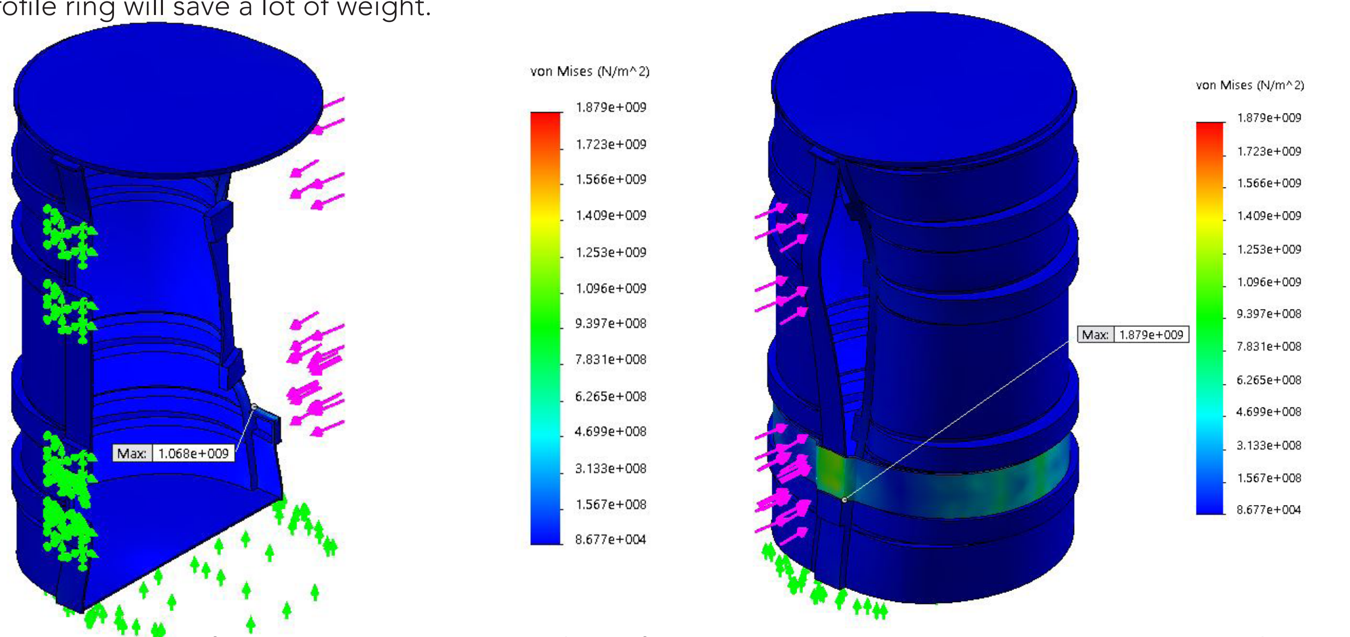


Figure 133. Results for sea transport: Drum assembly. Left: Maximum stress in HDPE component 1.068 MPa (the Inner drum half is hidden in the visualisation). Right: Maximum stress in steel component (red) 1.879 MPa

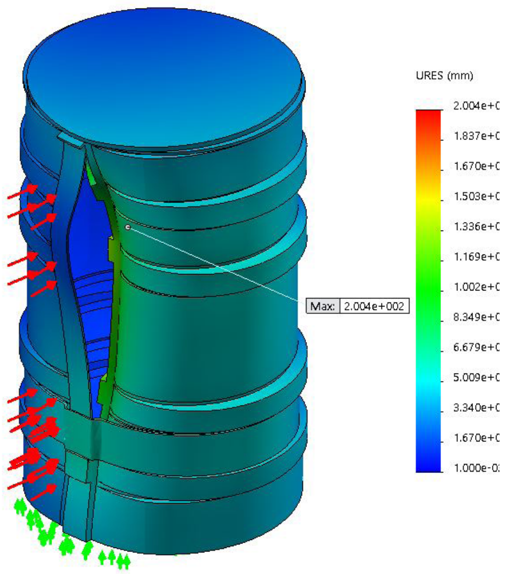


Figure 135. Results for sea transport: Drum assembly. Maximum displacement 200 mm

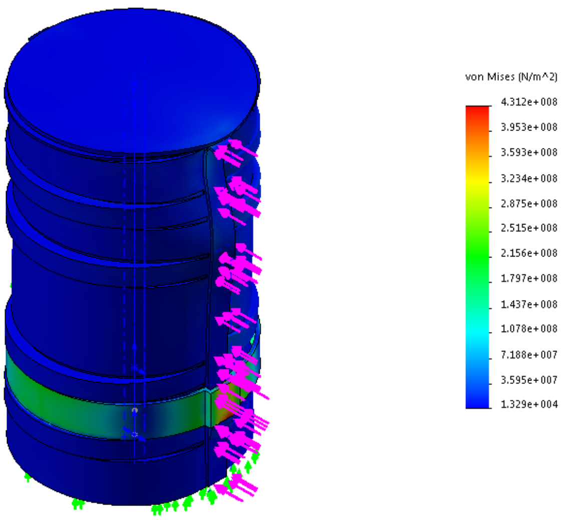


Figure 136. Results for 10mm thick external ring. Maximum stress 431MPa

Discussion

The results of the simulations made in this chapter should only be used as "educated guess" of how the drum will perform. This is due to multiple factors:

- Simplification of the product: Due to meshing issues, the twin wall design of the drum could not be simulated. A simplified version with a single wall of 4mm was used. This of course influence the results.
- Aspect ratio: Although the model was simplified and the mesh settings were set to maximum fidelity (where possible, without the simulations failing), the achieved aspect ratios are too high. Making the results fairly unreliable.
- Room temperature: Given more time it would have been valuable to calculate the effect of the temperature (cold) on the drum. When the drum is filled with frozen content the material properties are different.
- Effect of the lid: In these simulations the lid has been simulated as a bonded component to the drum halves. In reality the parts are not bonded, only fastener with the lid fastener. This was done to simplify the simulations, to cut back the simulation time.
- The sea transport scenario has been created based on information from a website about sea transport, it would be valuable to contact an expert to ensure my assumptions were corrected.

Further development

A limited amount of simulations was made, due to time constraints. However these give an initial indication of the points which require further attention. In particular the inward forces on the drum wall should be taken into account. Also the maximum tolerable inward displacement, which could cause the liner to tear should be determined.

I also suggest that the following alterations and simulations are done at this early phase of the embodiment design:

- Solve the issue of the external support ring damaging the plastic parts.
- Unwanted opening of the external support ring: The external support ring has two main weak points, the hinge and the bolt closure area, these should be explored further.
- Contact between the two drums halves: When the two drum halves are pushes towards each other, this may even cause the inner drum half to slip out of its position, further into the outer drum half, it should be investigated whether this is the case.
- Durability: All parts of the design should be tested for their durability with fatigue studies.

Takeaway

In this chapter "educated guesses" have been made of the behavior of the drum (with a 4mm single wall) in different scenarios. The nesting of empty drums is not an issue. The stacking of drums has been validated until 4 layers high. Simulations for 6 layers high did not succeed, due to yet unknown reasons.

The much higher, inward facing forces during transport, are an issue in the current design. The external support ring helps to absorb some of the force, however in its current design it pierces the body of the drum.

These significant issues and the effects of twin sheet thermoforming should be addressed soon in the further development of the drum.

35. CARBON FOOTPRINT

In this chapter an initial calculation will be made of the carbon footprint of the new design.

Goal

In Chapter: Sustainability, multiple strategies were introduced to create a drum with a low carbon footprint. The decision was also made to focus primarily on design a drum which:

- is suitable for reuse
- has an improved return ratio of empty drums
- is produced using low impact materials/ production techniques

In this chapter an initial check will be done to see how these goals have been fulfilled. The suitability for reuse has currently only been addressed by the material choice (see Chapter: Production technique). The other two topics will be explored here. For this, a comparison of the carbon footprint of the new design and that of the N55 drum (amongst other drums), will be made in the form of a simple, initial Life Cycle Analysis.

System boundary

The system boundary determines the processes which are included within the life cycle analysis. The flow diagram (Figure 137) illustrates the processes in this system. The grey boxes have been included in the analysis.

Production

The carbon footprint of production has been calculated using data gathered from the Idemat database (Idemat, 2016). The carbon footprint of the materials and main production technique have been calculated (Table 13). Post processing steps, such as cutting away brims and the weight of these brims (residual material) have been excluded from the calculation, due to lack of detailed information about the production at this phase of the embodiment.

For the new design a carbon footprint has been calculated of approximately 48 kg CO2 equivalent. This is more than double the carbon footprint of the N55 drum (22,3 kg CO2). This is not a good score, however it was to be expected, seeing as the flaws of the N55 drums are mainly caused by the flimsiness of the design, creating a more rigid/ strong design with improved performance easily increases the amount of material used and thereby the carbon footprint. To create a design with a lower carbon footprint in production and an increased performance a drastic redesign is required.
Based on conclusions from Chapter: Mechanical calculations, I made an estimation of the amount of material which can be reduced from the drum by creating a optimized design (less over-dimensioning of the metal ring, simpler lid, slightly thinner walls). The result of this design (New design V2) gave a score of 32,8 kg CO2. This is still higher than the N55, however it is significantly improved compared to the initial 48 kg CO2.

Both of these scores are still below the carbon footprint of the metal drum (67,9 kg CO2).

Transport

The efficiency of the transport scenario of drums filled with juice remains unaltered (as described in Chapter: Transport scenario).

However the transport scenario of empty drums has changed, as illustrated in Figure 138. Due to more efficient nesting, 814 empty drums fit in a container instead of 544. In certain situations this can have large consequences for the carbon footprint of supply chain.

Let's assume an order is placed for 1.500 drums. With the use of the new drum two containers of empty drums must be transported. Whilst the N55 required three containers. One less container needs to be transported in the new situation. The transport of a container from the service center in Turnhout (Belgium) to Brazil, has a carbon footprint of 3,26 tonnes of CO2 (Flexport, 2017). The means a total carbon footprint reduction of 326.000 kg CO2. Per drum this is reduction of (326.000/1.500) 217 kg CO2.

If a customer only orders a small quantity of drums, below 500, the benefits of compact nesting are diminished, unless smaller containers are used (20 foot container instead of 40 foot) or the empty space in the container is used for another product.

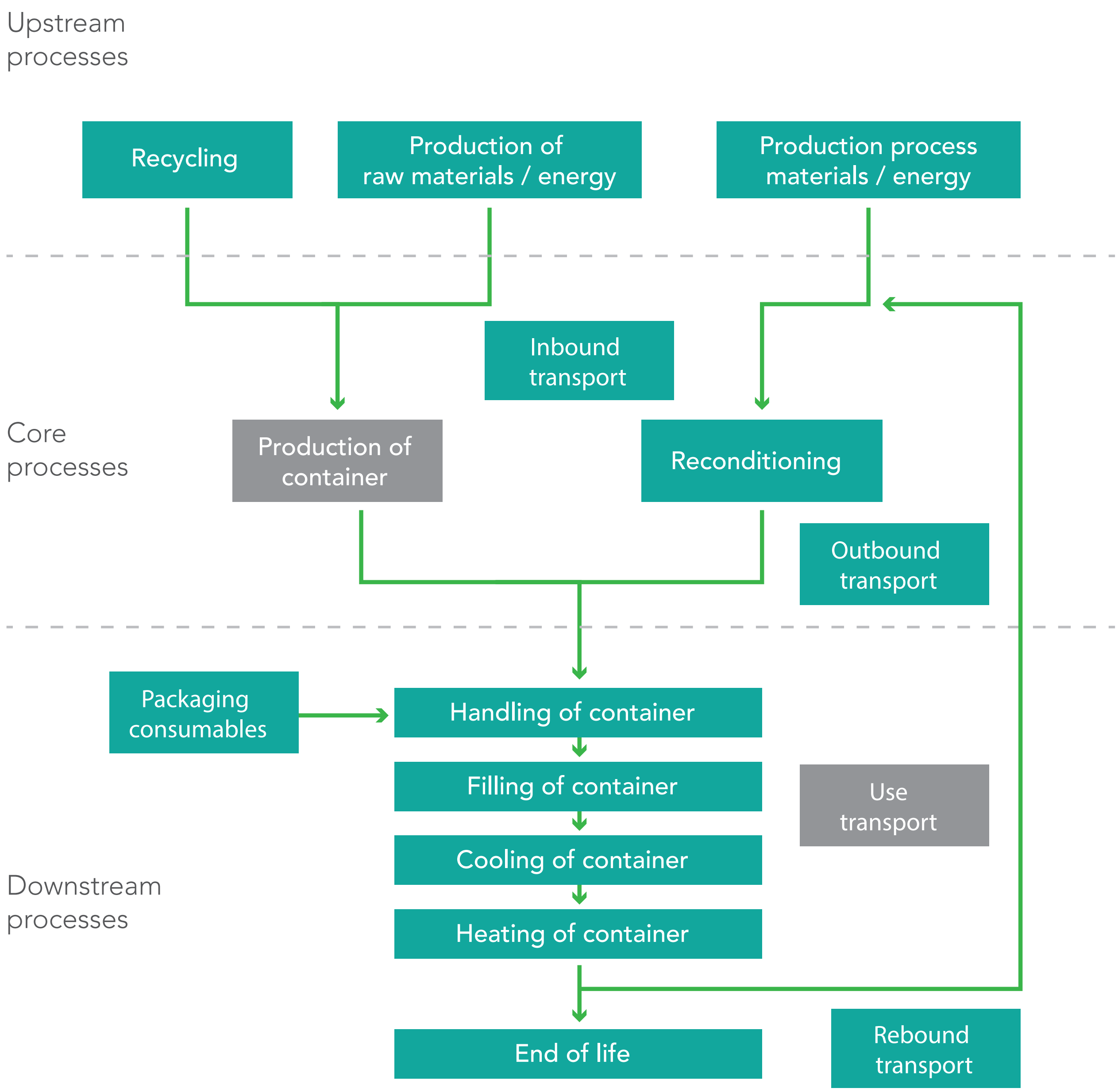


Figure 137. System boundary, the grey boxes are included in this life cycle analysis

Comparison of production and transport

The carbon footprint reduction, in the scenario of a order quantity of 1.500 drums, is 217kg CO2 per drum.

The increased carbon footprint of production per drums is (48-22,3) 25,7 kg CO2. Assuming a lifetime of 5 lifecycles. This is an increased carbon footprint of (25,7/5) 5,1 kg CO2, per lifecycle.

The total reduction of the carbon footprint, per drum, in this specific (ideal) scenario, is (217-5,1) 211,9 kg CO2. This is a substantial result.

Other phases of the lifecycle

In further analysis of the carbon footprint, more phases of the lifecycle should be included. It is also important to keep in mind that the carbon footprint is not the form of pollution.
It is also interesting to note that the amount of packaging consumables which will be used during the transport of filled drums is reduced (as shown in Chapter: Transport scenario). Per lifecycle, 4 pallets less need to be wrapped in plastic film.

An important investigation, which can not yet be made at this stage of the embodiment design, is how durable the new design is, and whether an extended lifetime (increased amount of lifecycles) can be achieved (read more about this in Chapter: 39).

Table 13
LCA of production for the different types of drums

Production							
Product	*Part*	*Material*	*Weight (kg)*	*Process step*	*Carbon footprint data*	*Carbon footprint per kg of product (kg CO2 equivalent)*	*Carbon footprint*
New design							
	Body halves	HPDE	11,2	Material	Idematapp2016 PE (HDPE, High density Polyethylene)	1,97	22,1
			11,2	Thermoforming	Idematapp2016 thermo forming, machine only	0,200	2,2
	Lid	HDPE	3,2	Material	Idematapp2016 PE (HDPE, High density Polyethylene)	1,97	6,3
			3,2	Thermoforming	Idematapp2016 thermo forming, machine only	0,200	0,6
	Lid fastener	Steel	0,3	Material	Idematapp2016 Steel beams, pipes, sheet (from market mix 44% recycled)	2,15	0,6
			0,3	Rolling	Idematapp2016 Rolling steel	0,550	0,2
	External support	Steel	5,9	Material	Idematapp2016 Steel beams, pipes, sheet (from market mix 44% recycled)	2,15	12,7
			5,9	Rolling	Idematapp2016 Rolling steel	0,55	3,2
						Total per new design:	48,0
N55 drum							
	Body	HDPE	7,7	Material	Idematapp2016 PE (HDPE, High density Polyethylene)	1,97	15,2
			7,7	Blowmoulding	Idematapp2016 blow moulding, machine only	0,195	1,5
	Lid	HDPE	2	Material	Idematapp2016 PE (HDPE, High density Polyethylene)	1,97	3,9
			2	Injection moulding	Idematapp2016 injection moulding, machine only	0,423	0,8
	Lid fastener	Steel	0,3	Material	Idematapp2016 Steel beams, pipes, sheet (from market mix 44% recycled)	2,15	0,6
			0,3	Rolling	Idematapp2016 Rolling steel	0,55	0,2
						Total per N55:	22,3
Metal drum							
	Body	Steel	20	Material	Idematapp2016 Steel beams, pipes, sheet (from market mix 44% recycled)	2,15	43,0
			20	Rolling	Idematapp2016 Rolling steel	0,55	11,0
	Lid	Steel	5	Material	Idematapp2016 Steel beams, pipes, sheet (from market mix 44% recycled)	2,15	10,8
			5	Forming	Idematapp2016 Deep drawing steel	0,46	2,3
	Lid fastener	Steel	0,3	Material	Idematapp2016 Steel beams, pipes, sheet (from market mix 44% recycled)	2,15	0,6
			0,3	Rolling	Idematapp2016 Rolling steel	0,550	0,2
						Total per metal drum:	67,9
New design V2 (4mm single wall) (metal profile external support)							
	Body halves	HPDE	8,5	Material	Idematapp2016 PE (HDPE, High density Polyethylene)	1,97	16,7
			8,5	Thermoforming	Idematapp2016 thermo forming, machine only	0,200	1,7
	Lid	HDPE	2,5	Material	Idematapp2016 PE (HDPE, High density Polyethylene)	1,97	4,9
			2,5	Thermoforming	Idematapp2016 thermo forming, machine only	0,200	0,5
	Lid fastener	Steel	0,3	Material	Idematapp2016 Steel beams, pipes, sheet (from market mix 44% recycled)	2,15	0,6
			0,3	Rolling	Idematapp2016 Rolling steel	0,550	0,2
	External support	Steel	3	Material	Idematapp2016 Steel beams, pipes, sheet (from market mix 44% recycled)	2,15	6,5
			3	Rolling	Idematapp2016 Rolling steel	0,550	1,7
						Total per new design (V2):	32,8

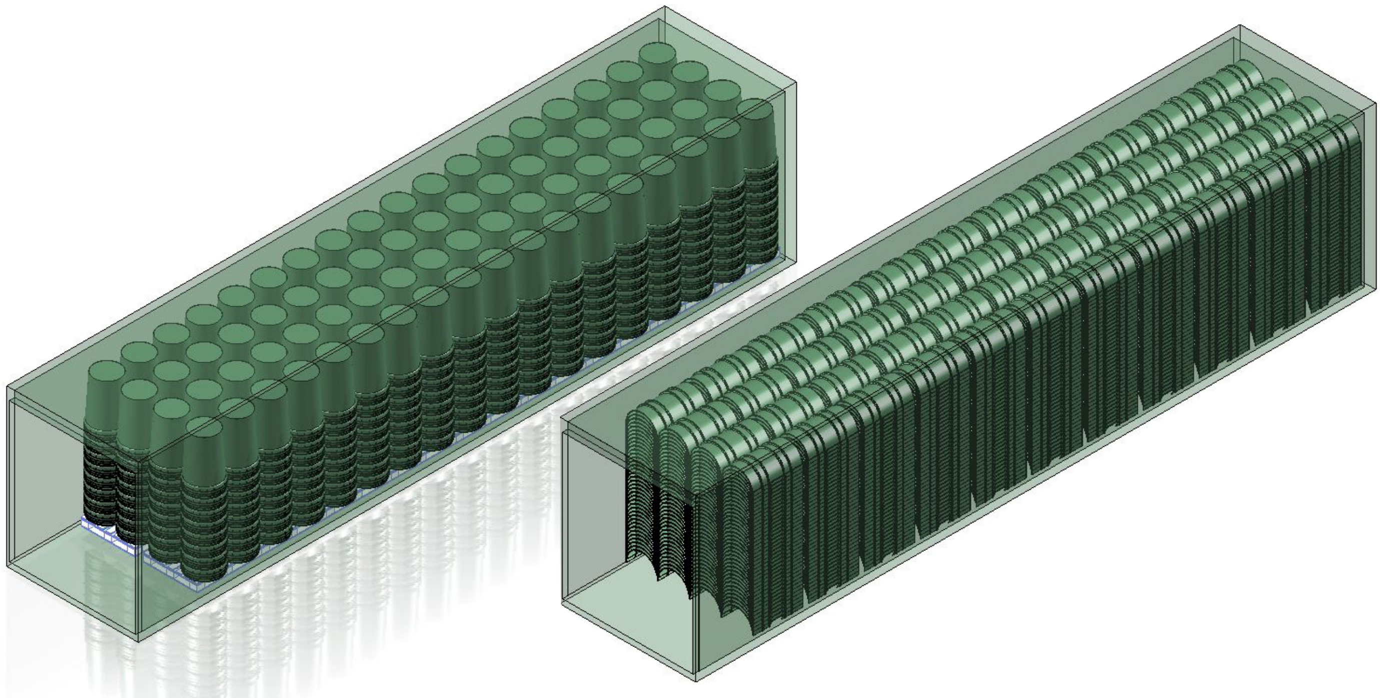


Figure 138. Left: 544 empty N55 drums in a container. Right: 814 empty drums of the new design

Takeaway

The carbon footprint of production of the new design is more than double that of the N55 drum. However the carbon footprint of a metal drum is still twice as large. The increased carbon footprint of production per drums is (48-22,3) 25,7 kg CO2. Assuming a lifetime of 5 lifecycles. This is an increased carbon footprint of (25,7/5) 5,1 kg CO2, per lifecycle. The carbon footprint reduction during transport, in the scenario of a order quantity of 1.500 drums, is 217kg CO2 per drum. The total reduction of the carbon footprint, per drum, in this specific (ideal) scenario, is (217-5,1) 211,9 kg CO2. This is a substantial result.

36. THE FINAL DESIGN

In this chapter the final design and its main benefits are presented.

Design specifications

Product type:	Packaging for liquids
Dimensions:	Height: 900mm
	Diameter: 580mm
Content volume:	55 gallons (205 liters)
Material:	Drum body: HDPE
	External ring: steel
Production technique:	Twin sheet thermoforming
Use type:	Reusable
Filled drums per container:	110
Empty drums per container:	814

Figure 139. The drum (assembled)

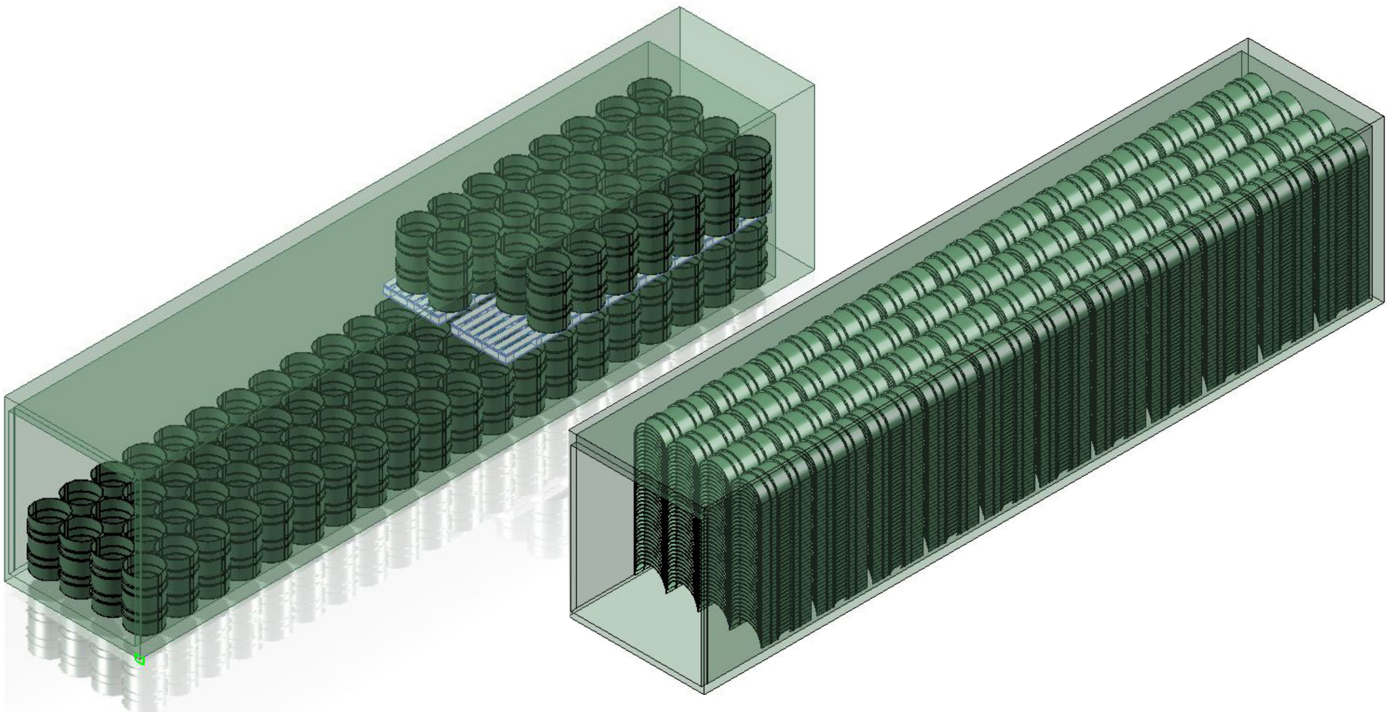


Figure 140. Left: 110 drums loaded in a 40 foot Reefer. Right: 814 nested drums in a 40 foot high cube container.

Figure 141. Exploded view of all the components of the drum (external support ring, lid, lidfastener, drum halves).

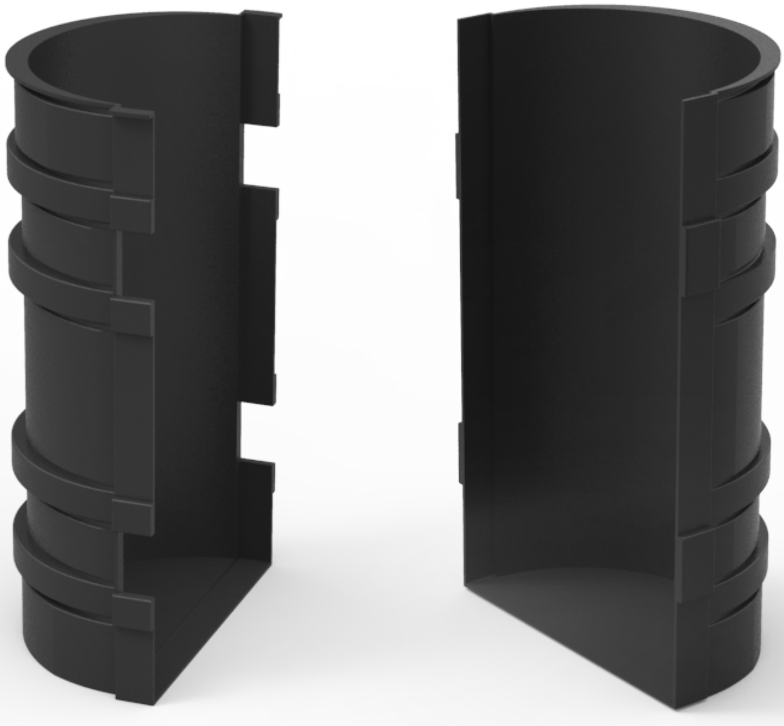


Figure 142. Left: The outer drum half. Right: The inner drum half.

Figure 143. 4 drums on a 1.000*1.200mm pallet.

Figure 144. Nested drums next to a human figure for scale. The front pallet contains 4 drums, the one behind has 35.

37. USE SCENARIO

The life cycle of a drum has previously been discussed in the Chapter: Product life cycle. In this chapter an overview will be given of how the life cycle of the new design differs from that of the N55 drum. This can be a valuable tool when acquiring feedback from stakeholders, in the further development of the drum.

Table 14
Life cycle phases of the new design

Phase	**Implications of the new design**
Production	Making use of a new production technique, in the field of drums, the twin sheet thermoformed design has potential to be more rigid and stronge than any other plastic drum on the market.
Nesting (shown in Figure 146)	When nested, 814 drums fit in a 40 foot high cube container. Compared to the 544 drums achieved by the U.S. Coexcell, N55 drum.
Assembly	Before use, the Inner Drum Half must be placed inside the Outer Drum Half. Then the external support ring is positioned and closed.
Filling	Due to the non-tapered shape of the drum, and the center of weight being positioned low in the drum (due to the external support), the drum is more stable than other plastic drums.
Moving with pincher (shown in Figure 145)	The same type of lid fastener is used as on existing drums, however the rim of the drum has a higher wall thickness making it more rigid, preventing deformation during handling with a pincher.
Moving with hugger	The drum is grabbed around the center of the body.
Moving manually	The rolling rings around the body of the drum are a perfect circle and the body is not tapered, this allows for controlled rolling.
Dumping juice	This remains unaltered.
Stacking	A single walled version of this design with a wall thickness of 4 mm can withstand stacking of at least 4 layers high. A double walled design is expected to withstand higher stacking.
Reefer loading/ transport	In a 40 foot Reefer container, drums fit next to each other in rows of 4. This allows for more drums on the floor level of the Reefer. 4 pallets less of drums need to be placed on the second level, this is 4 pallets less to strap together and wrap in plastic.
End of cycle	If damage occurs in one half of the drum, it can be replaced, without discarding the entire drum. External support rings may need to be replaced after some cycles.

Takeaway

The most drastic change is that the drum must be (dis)assembled, first positioning the drum halves and then fastening them with the external support, to achieve a substantial increase in the return ratio. 270 more empty drums fit in a container than is currently achieved with the N55 drum.

Figure 145. Pincher moving drums

Figure 146. Empty drums stored outside the warehouse

38. CONCLUSION

In this chapter the final result of this project is evaluated on the main criteria.

General conclusion

The product is currently in an early phase of the embodiment process. The design, in its current state (as presented in Chapter: The final design), is evaluated on the main criteria in Table 15. The results column shows the obtained results, based on the initial calculations and estimations made throughout the embodiment chapter. Read more about how to validate the design in more detail, in Chapter: Recommendations.

Table 15
Design goals and results

Topic	Goal	Result
Carbon footprint reduction	Lower kg CO2 equivalent than the N55 drum, throughout the lifecycle.	By creating a rough LCA of the production phase of the drums, it became clear that the carbon footprint of producing the new design is higher (Chapter: Carbon footprint). According to my calculations, the new design has a carbon footprint of approximately 48 kg CO2 equivalent. The N55 only 22,3. The metal drum 67,9. This is to be expected; the flaws of the N55 drums are mainly caused by the flimsiness of the design, creating a more rigid/strong design with improved performance easily increases the amount of material used. The increased carbon footprint of production per drums is (48-22,3) 25,7 kg CO2. Assuming a lifetime of 5 lifecycles. This is an increased carbon footprint of (25,7/5) 5,1 kg CO2 per lifecycle. In a scenario where 1.500 drums are ordered, the reduction of the carbon footprint during transport is 217 kg CO2, per drum. The total reduction, taking into account the increased footprint of production is (217-5,1) 211,9 kg CO2. This is a substantial result.
Return ratio	More empty drums an a container than the N55.	814 empty drums of the new design fit in a container, compared to 544 drums of type N55 (as calculated in Chapter: Transport scenario). This is an increase of approximately 50%. In terms of transported containers, this would mean that; if an order in the region of 1500 drums (300.000 liters of juice), is placed, two containers must be transported instead of three.
Reuse	Addresses topic introduced in Chapter: Ideal reusable drum.	The suitability for reuse has mainly been approached through increasing the efficiency of reverse logistics and focusing on the durability of the design. Calculations of the durability have not yet been made, in its current state, the durability has been addressed mainly by the material choice. A plastic drum (black HDPE) has been created, this is suited for outdoor storage and the temperature fluctuations during use.
Handling	The pain-points discovered in Chapter: Product life cycle, should be addressed.	In many aspects of handling the new design is similar to the N55 drum. The main improvements of the new design are the increased wall thickness at critical locations and non-tapered shape which increases stability. The specific effects on the performance (strength/rigidity) of the double walled design, achieved by twin-sheet thermoforming have not yet been explored (see Chapter: Mechanical calculations).
Costs	The production costs should remain in the region of 38 euro (the price Maia Global pays for N55 drums).	The production cost of the drum have not yet been calculated. It is to be expected that they will be higher than that of a blowmoulded drum. This drum is made of more material (to increase the performance) and it is made up of more components. However, cost saving have been identified throughout the lifecycle (Chapter: Cost price estimation).

Figure 147. Impression of the final design

39. RECOMMENDATIONS

In this chapter recommendations are listed for the further development of the design.

Transport scenario

- A trial should be done of how a worker can create a pile of 35 drums halves. Currently the idea is to nest the drums per 4 and then stack them on the large pile in an alternating pattern (4 facing forward, then 4 facing backward, to create an even stack which does not stick out backwards).
- The feasibility of loading the drums in a container using a forklift, without a pallet should be explored.
- It may be interesting to increase the volume of the drum, to slightly more than 55 gallons (Figure 148). Currently the diameter of max. 580 mm is ideal, as it allows for loading in rows of four. The height however is still variable (based on the space in the Reefer). By increasing the content volume of each drum, by making a taller drum, the maximum weight limit of a Reefer can be reached by only filling the floor level with drums. Removing the necessity of using pallets (which weigh +/- 230 kg). Also the use of disposable materials for transport; wooden support bars and plastic wrap (only used when creating a second floor of drums), are no longer required.

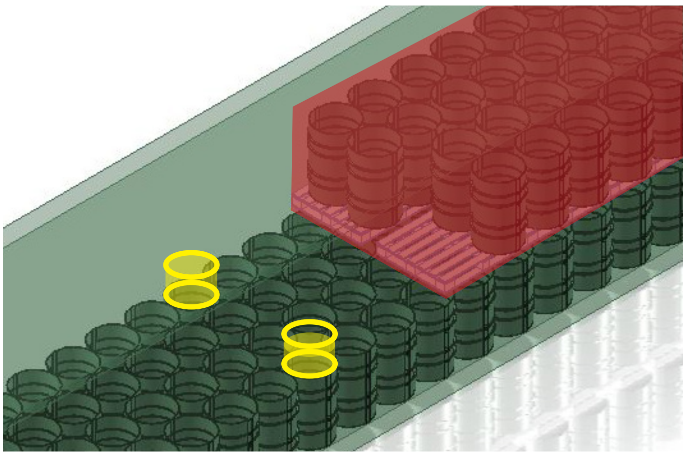


Figure 148. Drums in a Reefer. Red: Eliminate the second floor of drums & pallets. Yellow: This can be achieved by creating taller drums with a larger content volume.

Durability

- The durability of the drum still needs to be investigated. This can be done using fatigue simulations in SolidWorks (the endured forces are repeated multiple times).
- The design should be evaluated together with the service to determine how it will be inspected, cleansed and repaired if necessary.

Carbon footprint

- The over-dimensioning of the design should be minimized, to reduce the amount of materials used, as well as the carbon footprint of production.
- A more detailed LCA, also of production, should be made. In the LCA I made the scrap material/ brims were neglected, whilst in extrusion blowmoulding technology the amount of scrap during production can reach 40 % (Board, 2006).
- Different scenarios should be explored (different order quantities) should be explored, rather than only the most beneficial situation (of 1.500 drums) which has now been calculated.

Cost price

- The cost of producing the drum has not yet been calculated. Quotes should be request from producers.

Twin sheet thermoforming

- An expert should be contacted to check whether the drum is suited for the production technique in its current form.
- The effects of a twin sheet thermoformed design on the mechanical properties of the drum still need to be investigated, using a suited computer simulation program.
- The advantages of twin sheet thermoforming as a production technique might be interesting in the design of a more traditional drum (tapered) as well, which does not open up.

External support ring

- An exploration of how to prevent the external support ring from piercing the body should be made.
- The required thickness should be explored further. Maybe using an extruded profile bent into shape(Figure 150), to limit the weight of the ring.
- The transition between the "bump"on the ring and the rest should be smoothened, to distribute forces better during collision.
- The material which the external support ring is made of should be explored. Currently an initial design has been made of steel (based on the fact that the lid fastener ring is also made of steel).

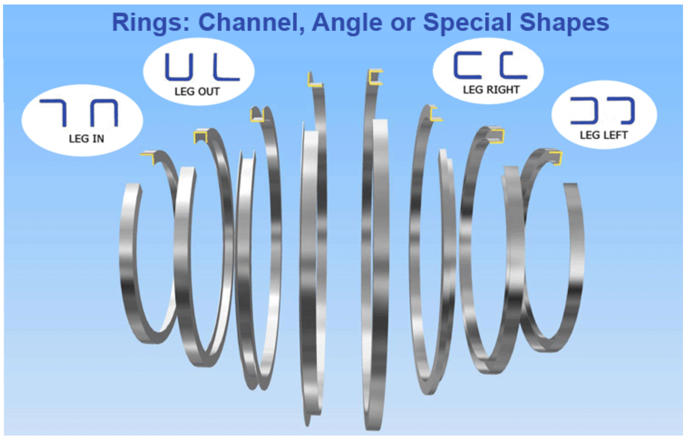


Figure 150. Aluminum profile rings (JohnsonRollforming, 2017)

Contact surface between drums

- The lid fastener rim should stick out less (Figure 149), to prevent lid fasteners from touching , which could cause them to open during collision in sea transport.
- The top and bottom "rolling ring" should be extended, to increase the contact surface between drums (Figure 149). In this way the forces during collision are spread out over a larger surface.

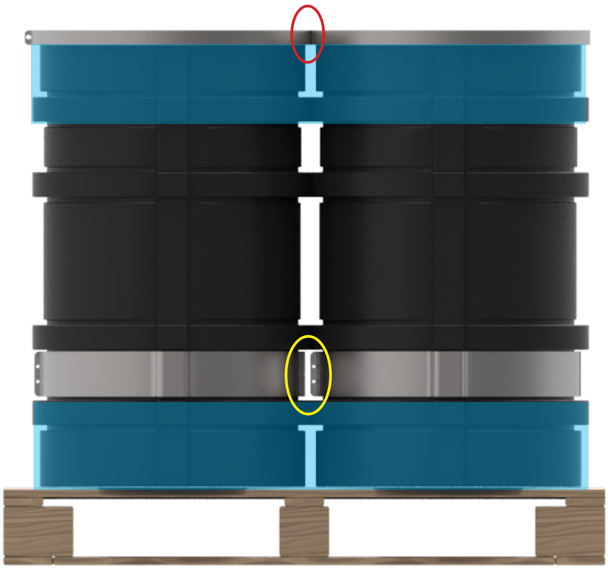


Figure 149. Front view of drums on a pallet, showing the contact areas between drums. Blue: The extended rings around the body. Red: The lid fasteners should not make contact. Yellow: Vulnerable closure on support ring.

Lid design

- The design of the current lid is the first iteration and is fairly over-dimensioned, this should be tweaked.

Takeaway

The main issues which must be resolved in the continuation of the project are;

- The design of the external support ring. To improve its design so it protects the plastics parts more than damaging them and its weight must be drastically reduced (by creating a extrude profile).
- Calculations/estimations of the durability of the drum need to be made.
- The effects on the mechanical properties of the drum of creating a double walled design (by twin sheet thermoforming) require investigation. The drum has currently only be mechanically evaluated based on a single wall (4mm) design.

40. REFLECTION

In this chapter I will reflect on the design process.

At a first glance, this design assignment seems quite straight forward; to design a drum container with a low carbon footprint. This could be interpreted as a relatively simple redesign of a drum, for example switching to a more eco-friendly material. However I wanted to explore a wider range of possibilities, to see if a large impact can be made. The main difficulty with this, was finding the freedom within the constraints of the context. To find which requirements are set in stone, and which are more optional. At times, the process felt like trying to find a magical solution which would be much better than current designs, without being given the required freedom to actually alter the design.

During the project the focus was not only on reducing the carbon footprint. Issues with handling existing drums and many other aspects where integrated in the design. This made the assignment more complex. For example, during the project it became clear that plastic drums (which have a lower carbon footprint in production and are more suited for reuse) have many issues. For this reason I felt I could not design a plastic drum without tackling these issues as well. Designing a new drum, which has the same issues as existing plastic drums, does not make customers want to switch away from the metal drum. Due to this, a large part of the time, lowering the carbon footprint was not at the front of my mind. This goal was interwoven in requirements to improve the existing plastic drum.

From my experience with the company I have come to understand that the industry is a very conservative one. New designs and minor changes in the system are received with great skepticism. The benefits of alterations in the system must be very big before even being considered. In retrospect this may have been an interesting way to approach the project; setting a well defined, justified, threshold goal for improvements. For example to state; the return ratio of the new drum must be a certain value. And work backwards from this. Now the goals were kept vague, focusing on what could be achieved (from design perspective) instead of focusing on what the desired result is.

In the current process the achieved return ratio was only calculated towards the end of the process. I first created a design which could be nested, with a gut feeling, shared by the company, that the achieved return ratio would be high. I then gave this shape and later calculated what this design could achieve. In this way, a design which seemed promising for the company, turned out to disappoint to them in the end. As it did not reach the goals the company had in mind, which had not been clearly formulated or communicated. The mechanical calculations could also have been done in an earlier phase.

The expectations for this project from the company were very high and not aligned with what I could deliver. Within the five months set for the assignment the company would have wished to have a finished product. Throughout the process, I tried to emphasize the fact that this is a tall order, especially as a graduation project and not an assignment done by an experienced design agency. I formulated the assignment as exploring possibilities and believe that this is of value for the company. The time I spent discovering what works and does not work, is time which does not need to be invested in an employee working for a salary much higher than that of an intern. In an ideal world I would have found the perfect solution and embodied this further, however this was not achieved, yet this project still has value which I hope the company acknowledges as well.

I would like to thank the company for letting me work on this project and their assistance. Working with the company was a valuable learning process. Not only about the world of juice logistics, but also about communication and my wishes for my career as an industrial designer. I believe it may have been useful for me to spend some more time introducing the company to the design process, and the amount of time and effort which goes into something so seemingly simple. As well as pro-actively keeping them updated about my progress, when I felt there was a lack of interest in my design process. My ideas sketches may have been too abstract for interpretation by non-designers, and created a lot of doubt in the company. Later the companies trust in my efforts returned as I embodied the ideas further, however towards the end I experienced their disappointment in my result.
I would like to thank Ruud and Lise for their guidance and constructive feedback during the project. They kept me on track to deliver a project with sufficient academic level, when I was often focused on the practical design. Whenever I had difficulties, within the design process or my period of illness, they were very quick to reply and kept me motivated.

Further design/implementation process

I would like to end off with some pointers, based on prior projects, for the continuation of a successful development project of a new packaging type at Maia Global. The approach illustrated in Figure 151, to minimizing packaging waste have been discussed extensively at an industry 'Round Table' in October 2004 at the Sustainable Packaging Alliance. Participants including brand owners, packaging manufacturers and raw material suppliers discussed the keys to a successful project, which they identified as (James, 2005):

- The need to have an effective project 'champion'.
- The need for senior management/CEO support for the project.
- The alignment of environmental objectives with business strategies.
- The involvement of important stakeholders at the beginning of the process (possibly including consumers through market research).
- Communication and engagement with partners throughout the process.
- Clear and shared objectives, both for the functional requirements of the packaging and re-design objectives.
- The collection of relevant data up front, including environmental information
- (e.g. LCA) and market feedback already received (e.g. warranty claims).
- An open mind—the need to look at completely new solutions as well as opportunities for incremental improvement.
- Sometimes an initial financial investment is required to make them happen, for example from government grants, co-investment by brand owners or by raising a levy of products sold.
- Identification of multiple benefits—to the business, to supply chain partners and to other stakeholders.

On a final note, the group concluded that reaching a successful outcome often requires patience and persistence!

Many of these points have been addressed during my project, however some require extra attention.

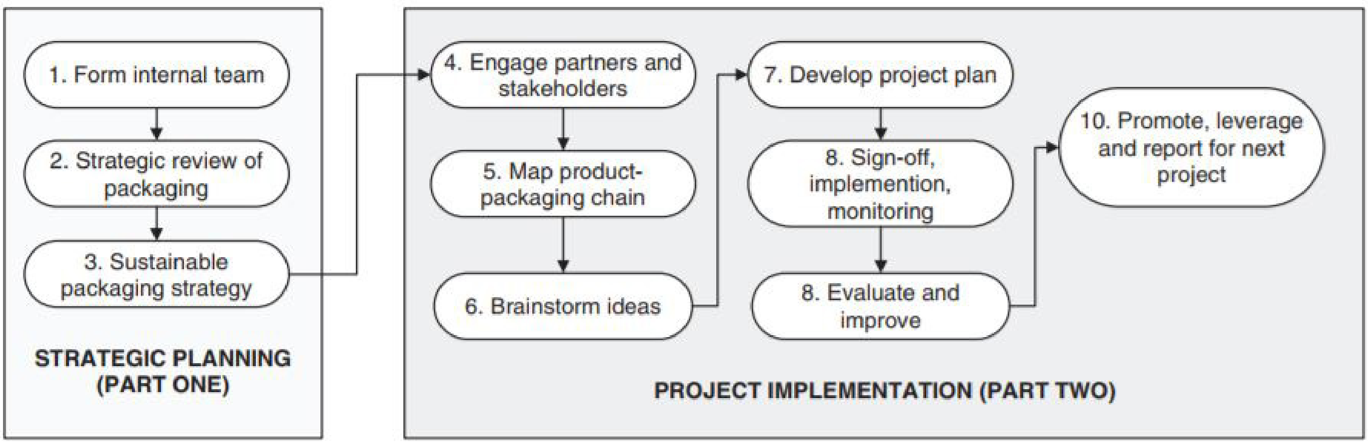


Figure 151. Creating links and achieving change methodology (James, 2005)

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