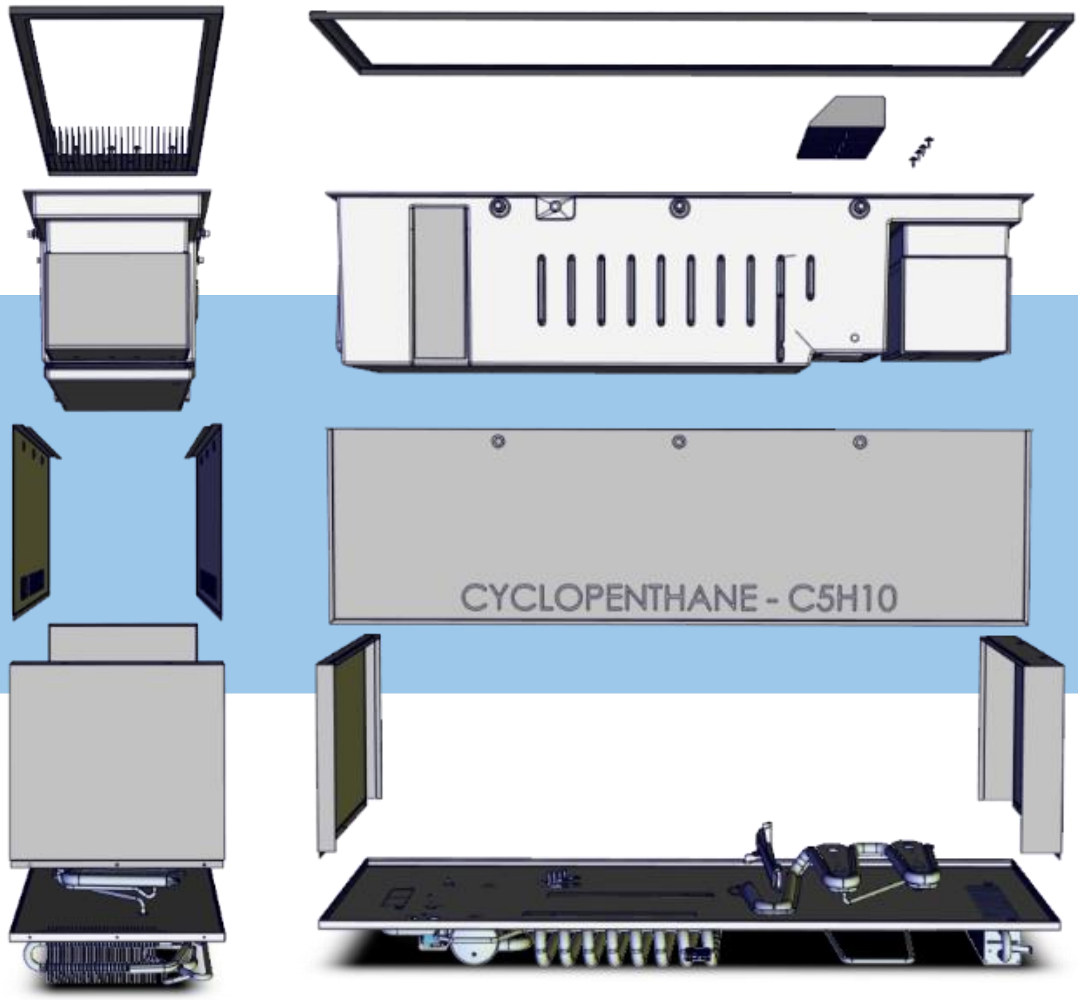
Improved production value through organised DFMA

allowing for one big manufacturing step less
through redesigning a recreational vehicle fridge



THETFORD TU Delft

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Executive summary

Thetford needs to improve their efficiency to generate more output, make space on their full factory floor for new products and decrease their human dependency at their absorption refrigerator plant in Etten-Leur. The market becomes more competitive and that is why Thetford choose to change its strategy from customer intimacy towards product leadership. This strategy is focused on generating new revolutionary products like iNDUS. The existing product portfolio does not alter much though while the output increased the past year and is not going to decline the coming years while new products are introduced. So how is Thetford going to generate more output with less people on reduced floor space?

In 2018 a feasibility study was done to explore the possibility of eliminating one big manufacturing step. The project was called 'one-step foaming' because the manufacturing route was designed to contain two foaming steps for isolating the fridge and could be shortened to just one foaming step. One-step foaming could fulfill the strategic needs of Thetford because of the necessary changes in the manufacturing route and design: one big foaming machine less and less assembly steps. The study was successful, but the design was not feasible for mass-production yet. A next step should be taken to further improve the manufacturing route and design.

This project tended to improve one-step foaming up to a level that would increase the output by at least 20% while reducing the necessary floor space by at least 20%. The method chosen to achieve this was by applying a DFMA study on both the present product and a product of a competitor. The lessons learnt would generate a design where the value of the work of production workers would be highest. Meaning: no use of materials or handling that would not add any value to the external customer. The customer is not going to pay more for this internal manufacturing change and that is why the project should result in a least a cost neutral business case while also generating the same customer experience.

The result is one concept, chosen from 3, that has an output increase of probably 57% with the same amount of workers, floor space reduction of 42% and cost price reduction compared to the new expected encasement of €21,83 with an investment of €250.000. These numbers are calculated only for the implementation of one-step foaming on the 140L fridge line (the beaker or N4140) and not the tabletop or the larger fridges. The assumption made is that new encasement regulation will be introduced resulting in a big change Thetford. The encasement regulation means that Thetford needs to change their cheap and light-weight cardboard encasement with heavy sheet metal encasement. When one-step foaming will be introduced on the 140L fridge line it will allow for usage of the automatic line 2nd step machine to foam other fridges as well.

The next step after this project is to validate the concepts by making a prototype. The project shows a high potential for Thetford to remain competitive on both the present and new product portfolio while not needing to move to another plant. Validation makes the promises of one-step foaming more realistic. Another important lesson for Thetford from this project is to rethink their level op operational excellence. In the past efficient production and high output were not important but they are now. Thetford is already started improving by implementing automation but it could do more in the sense of DFA and active automation. There is still high potential improvement to increase the level of operational excellence for Thetford and one-step foaming shows this.

Table of contents

List of abbreviations and specific words

A lot of words are shortened to abbreviation within this document or specific terms are used. The list of abbreviation and specific words can help with easier reading. Each word is defined in the report as well.

Table 1: list of abbreviations used in this document

Abbreviation/ word	**Meaning**	**Explanation**
ACU	Absorption Cooling Unit	A cooling unit with absorption technique
BOM	Bill of Materials	A list of parts and sub-assemblies. Mostly of the whole product.
CU	Cooling unit	Can also mean absorption cooling unit specifically
CAPEX	Capital Expenses	fixed assets like machinery
Beaker	140L Thetford absorption fridge, internal naming	For Thetford a big and slender/long fridge
Bounty	208L Thetford absorption fridge, internal naming	The biggest fridge produced in the plant in Etten-Leur
DF(M)A	Design For (Manufacturing and) Assembly	Methodology used in product design to decrease assembly and manufacturing time and product costs
DKM	The Dyson-Kissner-Moran corporation	Investor of Thetford, former main shareholder
EAG	European Appliances Group	The appliance division of Thetford in Europe. This presently consists of the Dutch cassette toilet, fresh up sets, spares and additives factory.
ERG	European Refrigeration Group	The refrigeration division of Thetford in Europe. This presently only consists of the Dutch fridge factory.
iNDUS	Smart sanitation system for campers	Newly developed product within the spirit of product leadership
KPI	Key Perfomance Indicator	Number that indicates the succes
LF	Large fridge	The fridges produced by Thetford in the Netherlands that are above 120L. Specific types are the Beaker and Bounty fridge.
MAA	Meewerkend Afdelings Assistant	Assistant supervisor
MT	Management Team	board of directors Thetford
MMT	Middle management team	layer of management below MT
NPD (engineering)	New product development (engineering)	Term used within Thetford to initially describe each new product development. Now the term is mostly used for Jump-the-curve projects.
OEE	Overall Equipment Effectiveness	Method and KPI to determine if equipment (a machine) is used to it's full potential
OEM	Original Equipment Manufacturer	For Thetford mainly RV manufacturers

PE	Process engineering	Department responsible for designing and improving production lines
PLC engineering	Product lifecycle engineering	Maintaining and improving the present (absorption fridge) portfolio. Also new product developments can be part of this
PUR	Polyurethane	Isolating foam used in the fridge cabinet and doors
RV	Recreational vehicle	This refers to campers, campervans and caravans
SF	Small absorption fridge	The fridges produced by Thetford in the Netherlands that are below 120L.
TBV	Thetford BV	The business unit of Thetford in the Netherlands. These are the headquarters and also have the fridge factory.
TCCA	Thetford Chenshuan Coolunit Appliance	Thetford factory of CUs in China
TEDC	Thetford European Distribution Centre	Thetford distribution centre located in Etten-Leur, The Netherlands

Introduction

Can one step foaming be a leap forward? That is the question this report tries to answer. In 2018 Thetford did a feasibility study to discover if it was possible to change the design to allow for a big manufacturing step less. It was possible, but it wasn't yet perfect to allow for mass production of the design.

There are two levels that are explored in this report: the regular design process and the addition of stakeholder engagement with incorporated Design For Manufacturing and Assembly (DFMA). The leap forward for Thetford will be generated by because the context of this report is not to do a regular design process but look a bit further. The basis is the graduation of the writer and this document serves as graduation report.

The assignment chapter describes what problems and goals are set for this project. One of the outcomes should be to allow the design to be mass produced but how can this be achieved? The analysis chapter looks at what methods can be used and what the main drivers are to best solve the stated problems. The basis for project is stated in the context chapter. This is placed before the analysis chapter.

The design outcome made within the context of the main drivers is stated in the combination of the concepts, concept choice and final concept chapters. They go through the details each design and validate them. The outcome is one design that best fits the main drivers. The closure of this report will be by the discussion and conclusion chapter.

Assignment

This chapter serves as fundament for this project: "Optimize recreational vehicle fridge design to highly improve manufacturability by removing just one process step". It will describe the assignment in four paragraphs that will answer the following questions: What will be solved? Why does this need to be solved and how is this going to be solved? More depth will be given in the later context chapter. The initial project brief and changes can be found in Appendix 1.

Problem

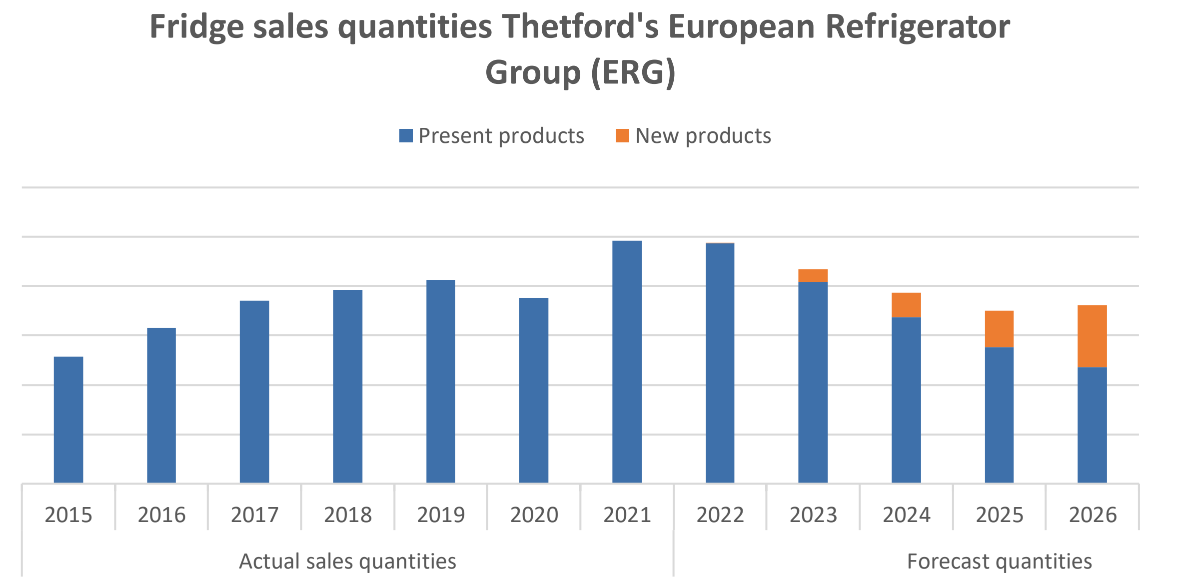


Figure 1: rise in total fridge production quantities will probably continue with the positive market and introduction of new products – data from Thetford internal

Thetford recently found the possibility to leave out a big manufacturing step at their Dutch fridge factory. This will most likely have a big impact on solving capacity problems that exist now and are expected to increase in the future.

Presently there is a high rise in demand in the RV market due to corona that will last for at least the two coming years. In the future new and different products will be introduced that require floor space while there is still uncertainty on the future production quantities of the present product portfolio (see Figure 1 for rising production quantities). Actions already taken are to hire more production personnel (see Figure 3 for campaign on hiring people), work in expensive and inefficient double shifts and expand the production shop floor by cannibalizing from distribution (see Figure 2). On the long run these actions cannot be sustained and other actions like one-step foaming need to be taken.

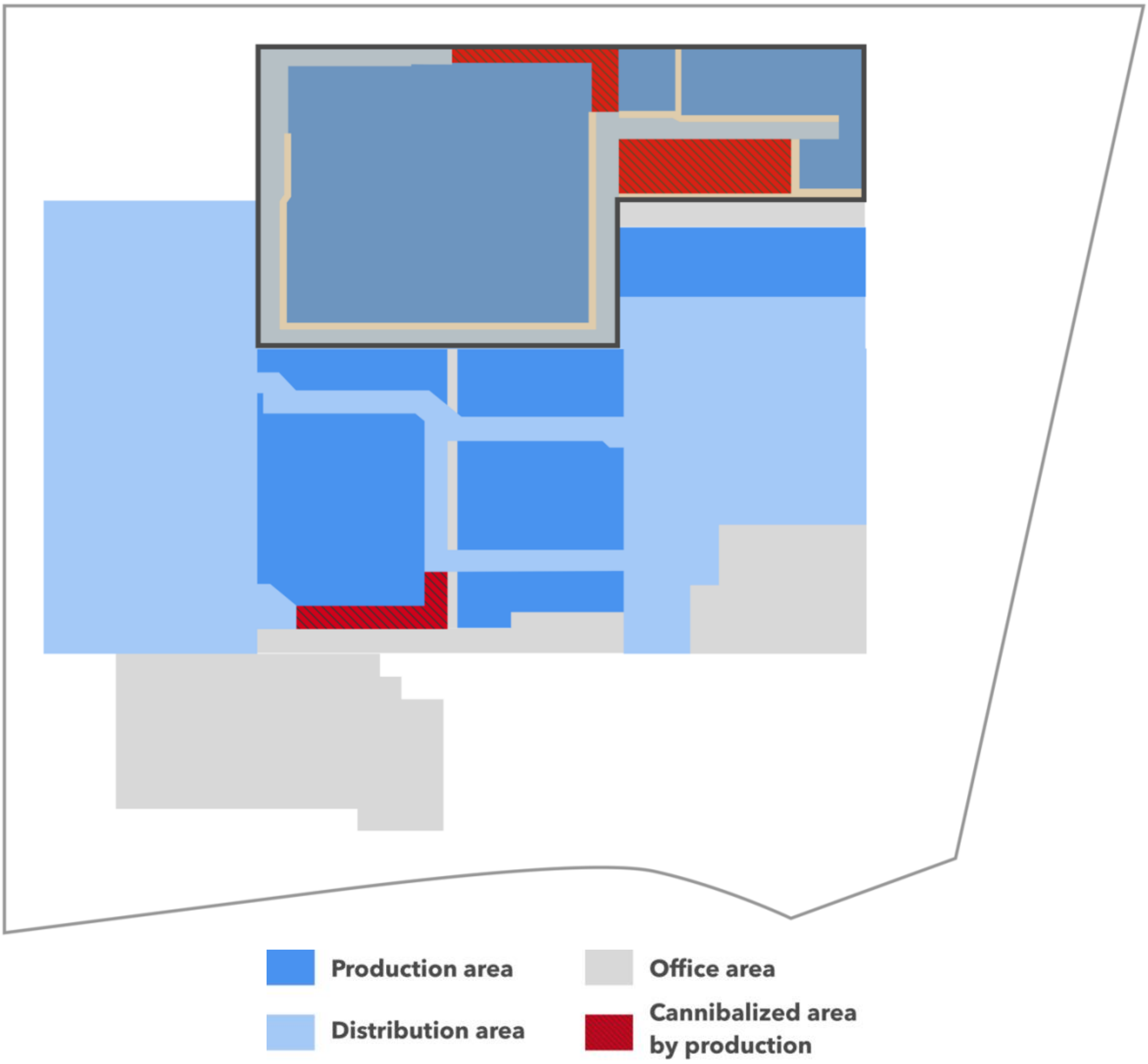


Figure 2: Factory layout with cannibalized area highlighted to increase production output

For the future efficiency of the production facility needs to increase when also making space for new products while balancing with unknown production quantities. Removing the second foaming step will most likely improve efficiency by increasing production capacity, decreasing factory floor usage and decreasing the amount of labor involved, as discovered by the feasibility study (Improvia, 2018).

Goal

To solve the stated problem a redesign of the fridge and with it a redesign of assembly and manufacturing are necessary. Where redesign should result in the following to be interesting for Thetford:

- reduced use of floor space to allow for new products
- reduction in direct labor to be less dependent on production personnel and double shifts
- increased capacity to cope with increase in demand
- increased production efficiency to have more output in less time

This can be achieved by looking at applying an DFMA analysis on the present product portfolio and proper (internal) stakeholder engagement while keeping the external customers unaware of the change. It is an internal manufacturing change that should have no effect on functionality, costs and aesthetics. The main goal of the assignment can therefore be stated as:

Redesign a Thetford RV absorption fridge to enable one-step foaming for mass production by focusing on the internal customers (production and automation engineering) in the design process by maintaining the integrity of the product for the external customer (OEM and end-user).

Figure 3: big campaign started by Thetford BV to hire more production and distribution personnel (Thetford, 2022). Original text in Dutch was: "Zeg, ken jij onze nieuwe verse college?"

Outcomes

The outcomes will be:

1. Redesign of the N4140 frideg (also called beaker) fridge where one step foaming is valid for mass production
2. A plan on how the changed key manufacturing and assembly processes will look like
3. Recommendations on factory changes like layout and distribution

Approach

The method to achieve the goals and wanted outcomes is to integrate additional aspects in the next step of the design process for one-step foaming. The additional aspects are understanding the present culture within Thetford of internal customer engagement in the design process and what can be most beneficial as method for the future. Understanding theory on DFMA and DFA, conducting interviews and sessions to understand internal customer engagement level and analyzing the present product design and production method will serve as input for the design process that generates the wanted outcomes.

Context

This chapter, the context generates the boundary conditions for the project and product design. It starts with understanding the key focus of Thetford and what value should be fulfilled by one-step foaming from the strategy. This is made more explicit by stating the promises of one-step foaming. How these promises are fulfilled as a product designer can be done with DFMA, but the key now is engaging stakeholders. The last part describes some important external influences that should be considered.

Figure 4: main product groups of Thetford, all for the RV market

Thetford and its strategy

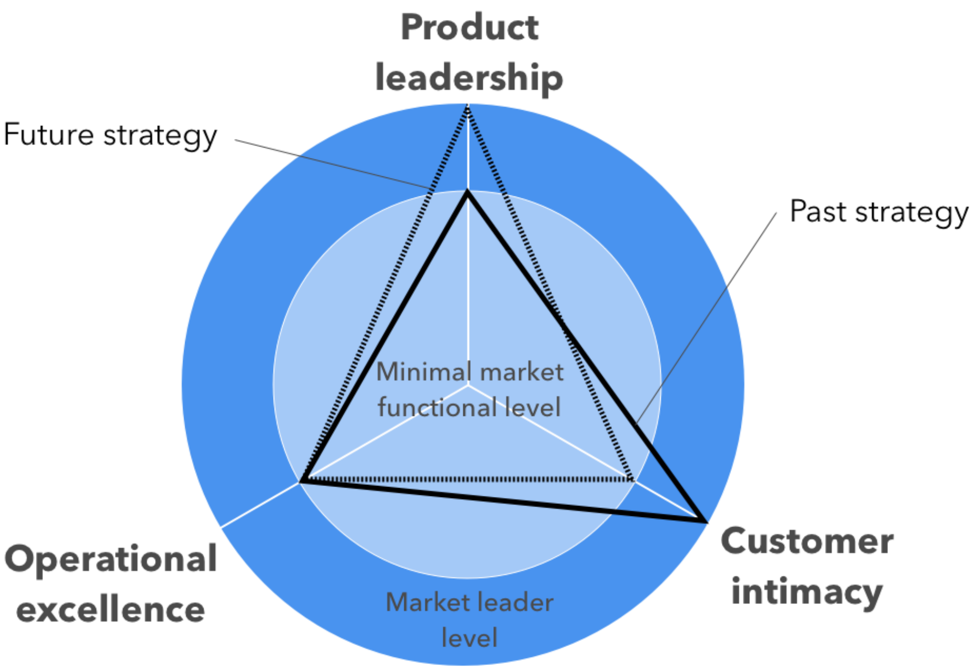


Figure 5: Thetford's change in Treacy and Wiersema strategy visualized (Treacy & Wiersema, 1997)

Thetford is an "international company that tries to bring total piece of mind to every recreational vehicle (RV) user in the world through great leisure products." (Thetford, 2019) They started by making the porta potti, a very popular chemical toilet. Their product portfolio slowly increased in the past 45 years to include cooking appliances, cassette toilets, toilet additives, absorption and compressor fridges. Though they make consumer products their customers are mainly RV's builders (like Adria, Fendt and Hymer, also mentioned as OEM) and resellers. They have various factories, warehouses and sales offices spread over the globe. Their head office is located in Etten-Leur, the Netherlands.

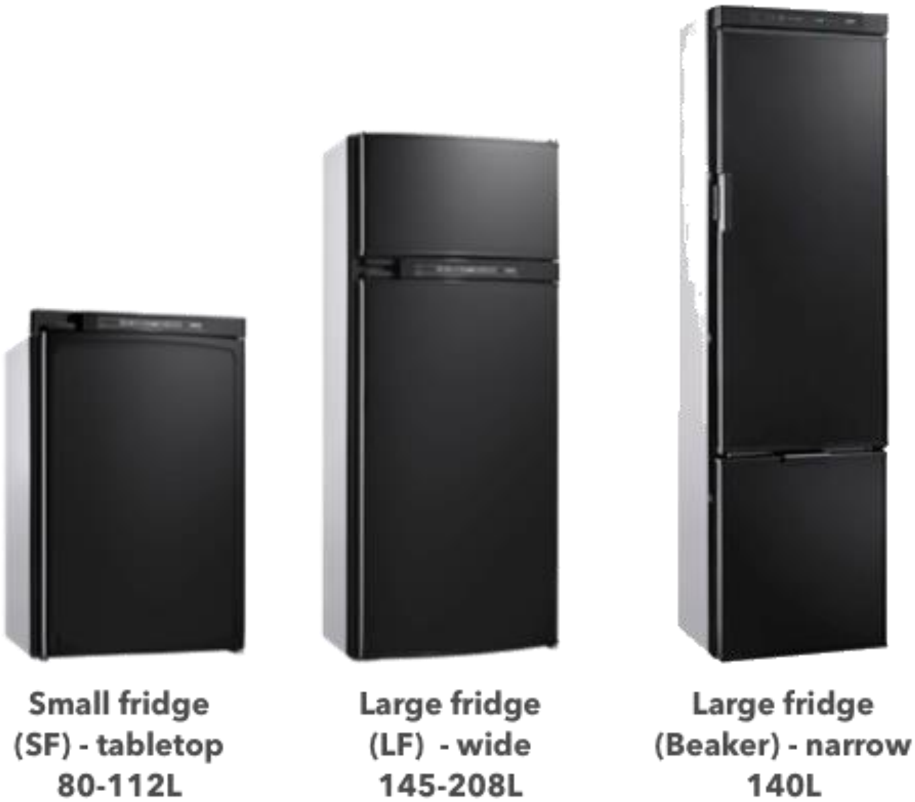


Figure 6: 3 main groups of absorption fridges produced in NL

The main strategy for Thetford has been to offer the best total solution to their individual customers. This strategy is seen by Treacy & Wiersema (1997) as being market leader by 'customer intimacy'. They've become this on various fields in the industry like cassette toilets. The customer intimacy of Thetford can be seen on special projects and the variation in production. However, due to upcoming competition the strategy of Thetford is changing to 'product leadership' which means offering the best product to become (or remain) market leader. Within their entrepreneurial spirit the iNDUS smart sanitation system is a first example of this strategy change and more will probably come (Figure 7). They won the Red Dot design award with this product (which supports the value of 'Passion for winning') (Red dot, 2021).

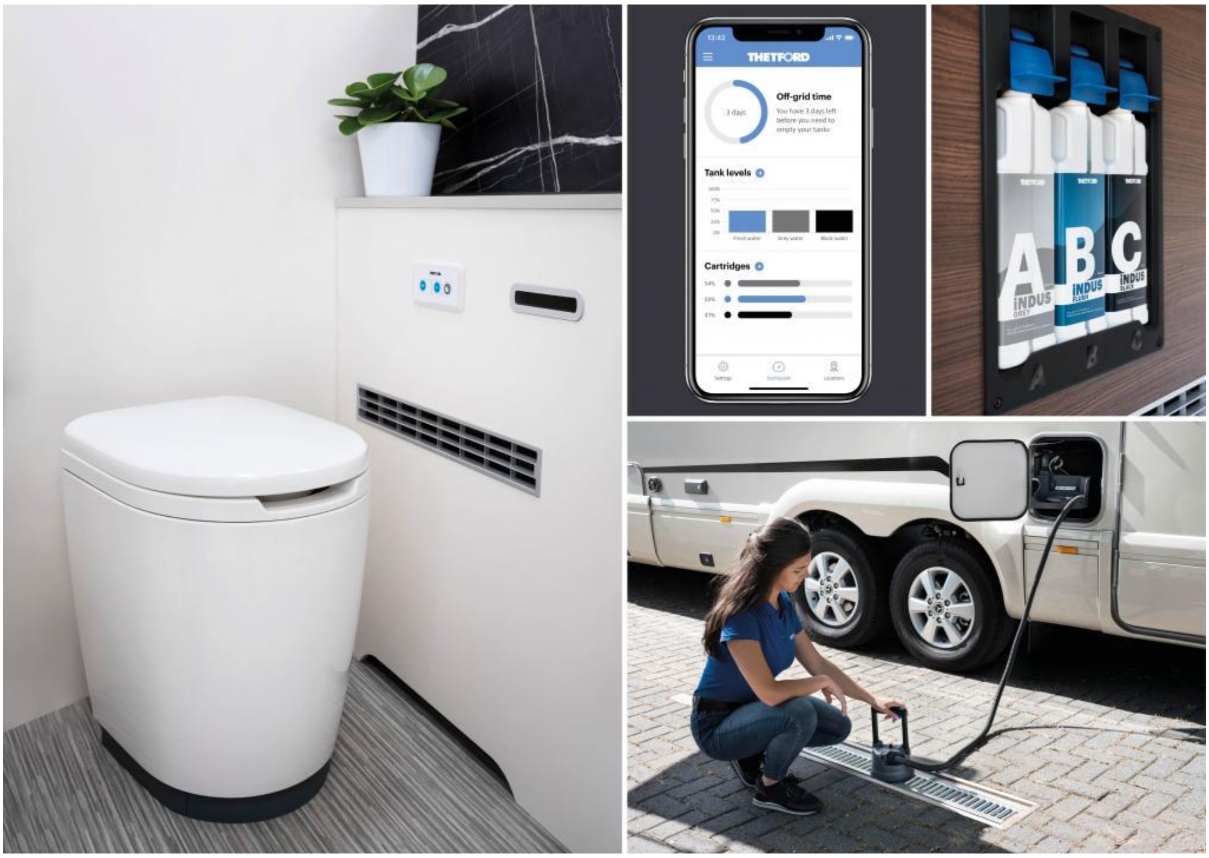


Figure 7: the iNDUS smart sanitation system. Through smart water management, that can be monitored through an app, and with the help of additives a user can be off-grid for up to 7 days.

Treacy & Wiersema talks about three strategy directions where the company must choose one to become market leader and let the other two stay at a market required minimum. The third is 'operational excellence' and means that they will offer products with the lowest costs for the customer (not only sales price, but also in hassle and other customer costs). As said, competition is rising, and they focus on offering lower costs. This is a growing challenge, but a bigger challenge arose with the start of corona: increase in sales quantities by 40%. Everyone wants to buy a RV now and there is no sight in decline for at least the coming 2 years.

The focus on 'operational excellence' will probably grow the coming years. Not because of the coming challenges and changes but because of a new owner. Up till November 2021 Thetford was in the ownership of the investment organization DKM for 30 years (DKM, 2021). A long-term relationship where the strategy of Thetford was formed. The new owner Monomoy states "We make equity and debt investments in middle-market businesses that can benefit from operational and financial improvement in the manufacturing, distribution, and consumer sectors." (Monomoy, 2021) This can, together with their vision statement on 'continuous improvement', to a shareholder that has more focus and knowledge on operational improvement.

Figure 8: Left Arana RV compressor fridge (a Chinese brand) (Arana Living Technology, 2021), right Thetford compressor fridge

When looking at the production facility in the Netherlands (producing absorption fridges, additives, cassette toilets, doors and iNDUS) this means they need to produce more at the same production floor space because no expansion possibility exists in this short notice. They solved this by hiring more people and work in double shifts (40-50% of production personnel are from an employment agency). This is not a sustainable solution because hiring more people showed to be difficult and double shifts is not a wanted norm within Thetford. The challenge becomes even bigger when new products will be introduced in the coming years requiring floor space combined with the uncertainty of sales decline of the present products. The strategy Thetford is aiming at efficiency increase to create more output on less floor space and automation to support efficiency increase and to reduce human dependency. Especially automation is interesting because 90% of the production process is done manually. One-step foaming could be the leap forward on all.

The promises of one-step foaming

Why can one-step foaming be a big leap forward? To answer this question, it is important to first understand the process of foaming in refrigerator manufacturing at Thetford. In industry the fundamental foaming step fills the (pre-foam assembled) fridge with isolation and stabilizing polyurethane foam (PUR). After the foam is inserted in the refrigerator cabinet's cavity it starts as a liquid and slowly foams due to a chemical reaction to fill all the cavities (see Figure 10). During this process a lot of force and heat is exerted. This is the reason why a mold is used which keeps the cabinet in shape and the process stable by integrated heat control (see Figure 9 for the mold of the 208L fridge).

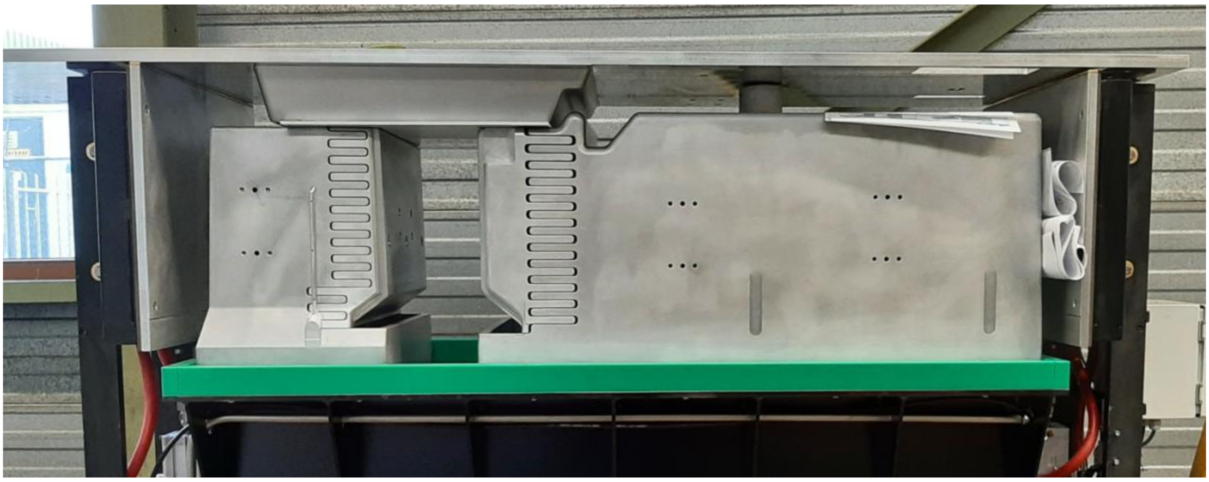


Figure 9: example of a foaming mold for the cabinet of the Thetford N4208 bounty fridge

With the industry standard compressor fridge this can be done in one foaming step because the compressor cooling unit (compressor CU) can be assembled after foaming. Thetford uses a different cooling technique called absorption cooling. This technique gives the end-user the freedom to choose between three power sources for their fridge cooling (RV 12V battery power, 230/110V mains power or natural gas) and is a lot quitter instead of one with the compressor technique. A high value for RV users because of their uncertainty of power source availability on vacation.

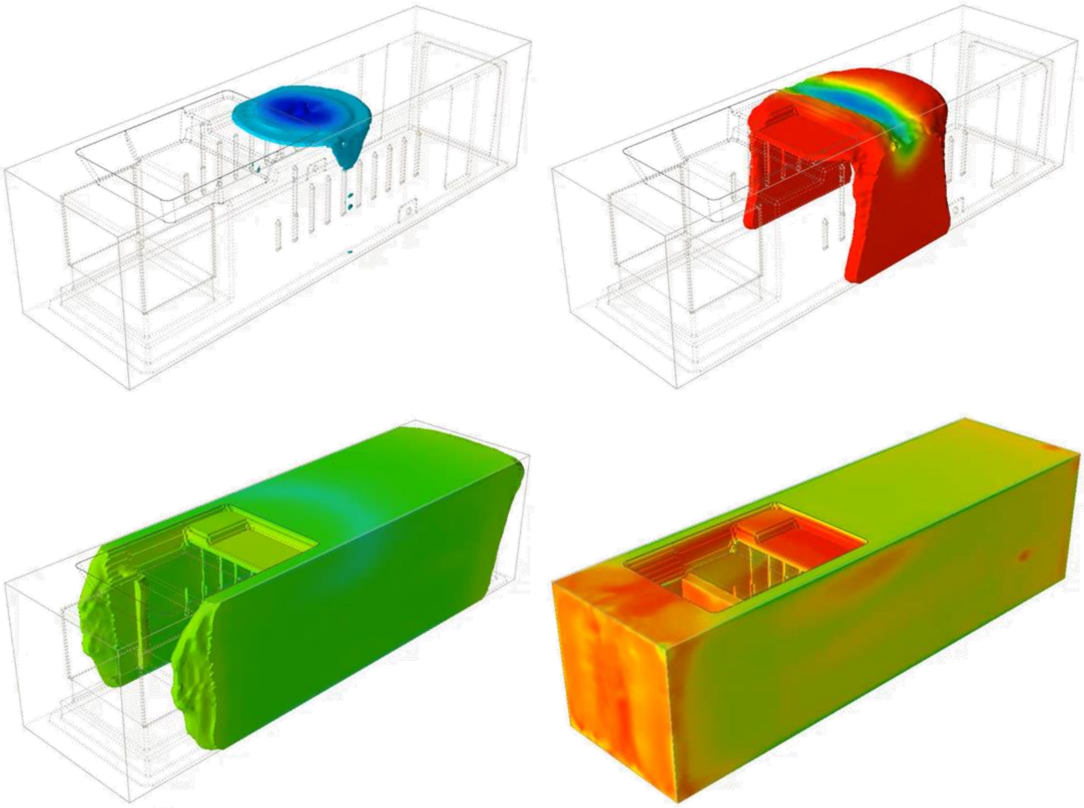


Figure 10: internal foaming flow starting with injection and ending with a full fridge. Total process time is 30 seconds and curing time 5 minutes. Coloring in process temperature

An absorption CU (ACU) is made of thick metal tubing which needs to be made before foaming. At Thetford a two-step process is used to fill the cabinet. The first step is a foaming shot is to ensure a stable cabinet (100L foam). The second step is a shot that embeds the heavy cooling mechanism (5L foam). The cabinet assembly could collapse in the present design when the cooling mechanism is added before the first foaming step. Also, the shape of the cabinet cannot be supported by the mold at all places resulting in possible unwanted deformations.

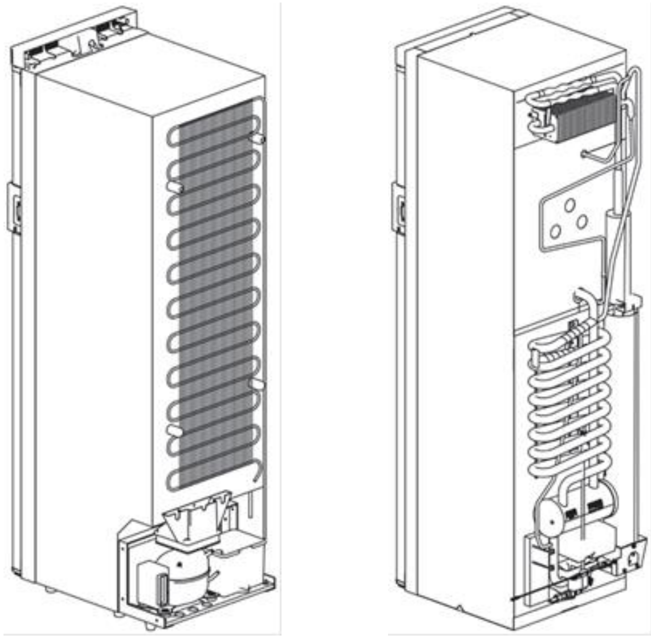


Figure 11: left compressor fridge, right absorption fridge. Both are Thetford fridges but the compressor fridge is produced in China, the absorption fridge in the Netherlands

The initial reason for this manufacturing choice was to exchange only the expensive cooling mechanism at the customer besides these process reasons to have a two-step process. This practice has been abandoned for quite some time now by Thetford in Europe and Oceania because it is faster, easier, and cheaper to change the whole fridge instead of the cooling mechanism. This practice is still applied by Norcold (US department of Thetford) and competitor Dometic as can be seen in Figure 12.

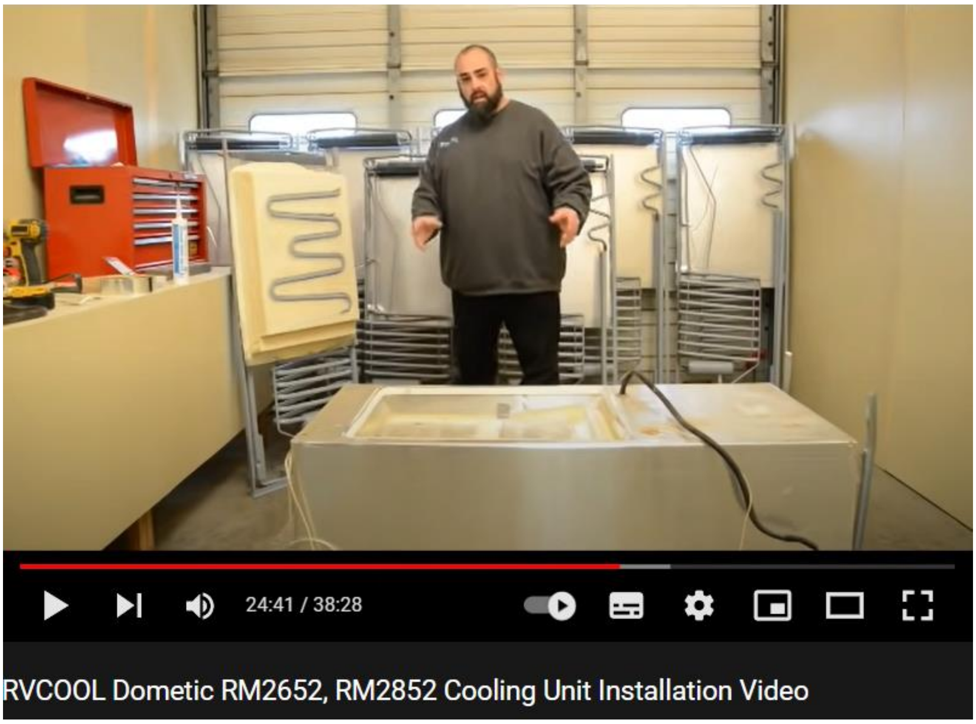


Figure 12: Videostill one of the many youtube movies explaining how to exchange a cooling unit Top and bottom are Dometic fridges, right bottom is Norcold (RVCOOL, 2022), (RVCoolAgain, 2022), (mrjschaffer, 2022) and (AZ expert, 2022)

If one-step foaming would be introduced, what would this mean?

1. Decrease of used floor space because one of the two identical foaming machine becomes obsolete. Only the molds in each foaming machine is different and needs adjustments.
2. Throughput time in production will decrease because one foaming step less in machinery.
3. All fridges can be produced on the automatic line in the future with necessary adjustments to the transport system and factory layout. There is presently an automatic line (mainly for beaker fridge production), semi-automatic line (for small fridge and bounty fridge production) and a manual line (large fridges). This will increase factory efficiency due to reduced handling. The best strategy is to start redesigning the beaker fridge in order to generate space on this line for the other fridge designs.
4. Possibility to increase efficiency, decrease costs and decrease floor space of the pre-foam assembly by altering the design and implementing automation. For one-step foaming a design change is necessary to enable the addition of the ACU before foaming. This enables the additional integration of improvements via the design.

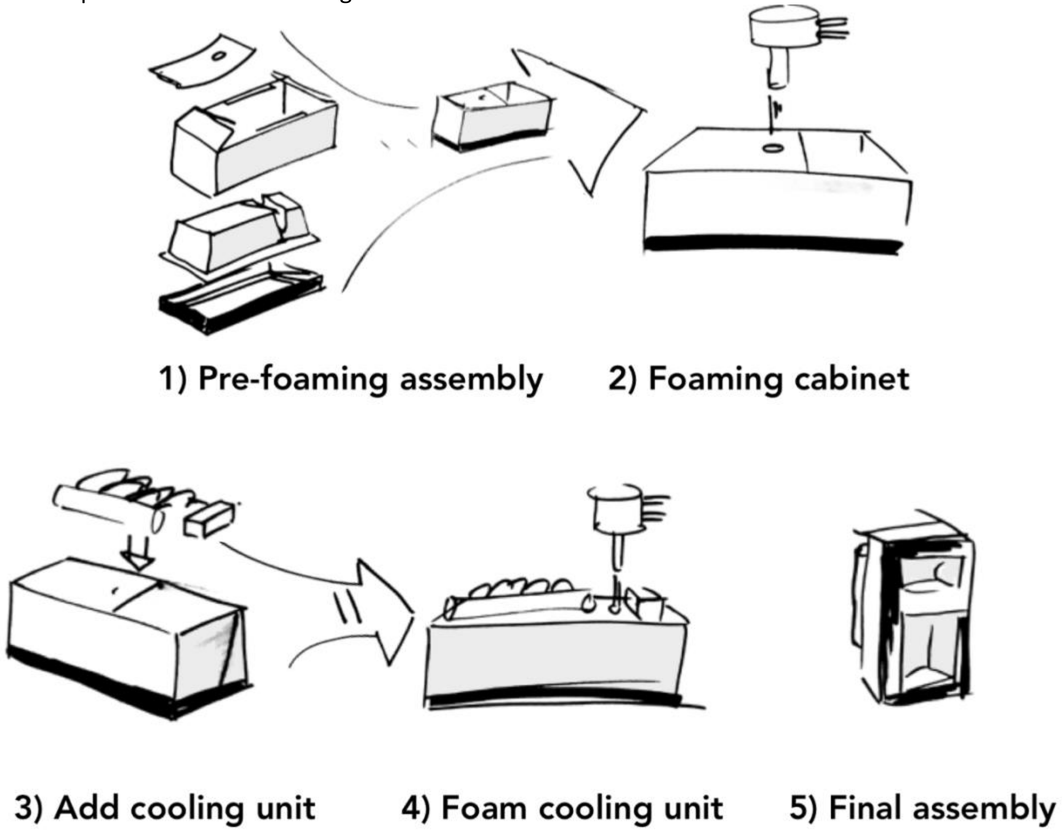


Figure 13: visualization of present production steps

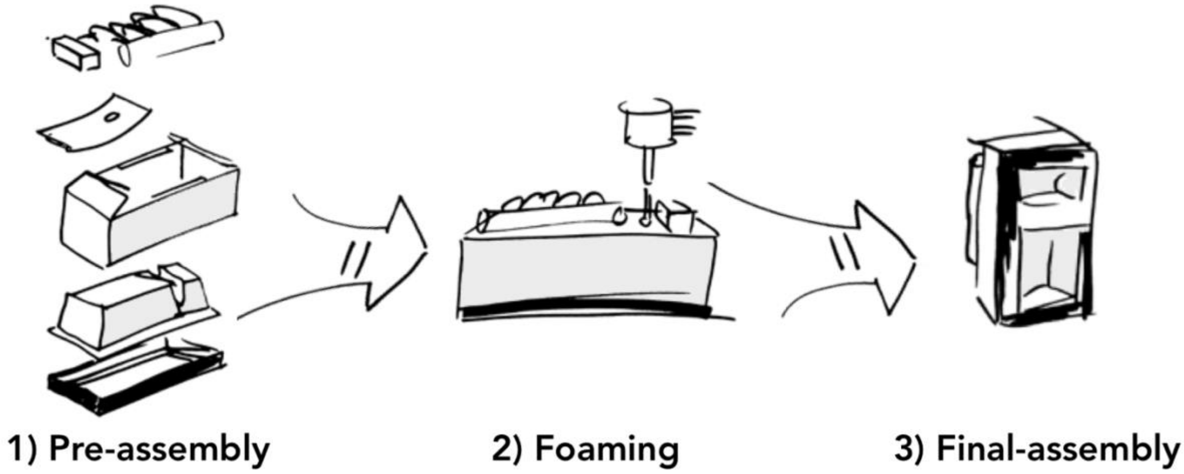


Figure 14: visualization of one step foaming

An internal feasibility study showed it is possible to combine the two steps into one (Improvia, 2018). It wasn't easy to show the feasibility of one step foaming but in the end, they managed to have successful test runs. The problems found were a more difficult and unstable assembly before foaming, increased final product weight and deformation at the back due to foaming. The next step is to tackle these problems through a redesign on the product design and connected to that production. More information on these problems will be discussed in the chapter about the analysis.

Stakeholder engagement and Design For Manufacturing and Assembly

To further improve the idea of one-step foaming through design the logical methodology to apply is DFMA (Design For Manufacturing and Assembly). This methodology focusses on reducing the amount of parts in the assembly, therefore reducing the assembly time. The parts that remain are provided with features which make it easier to grasp, move, orient and insert. This further decreases the assembly time and at the same time make it easier to automate. Details on these principles differ when comparing automated assembly to human assembly.

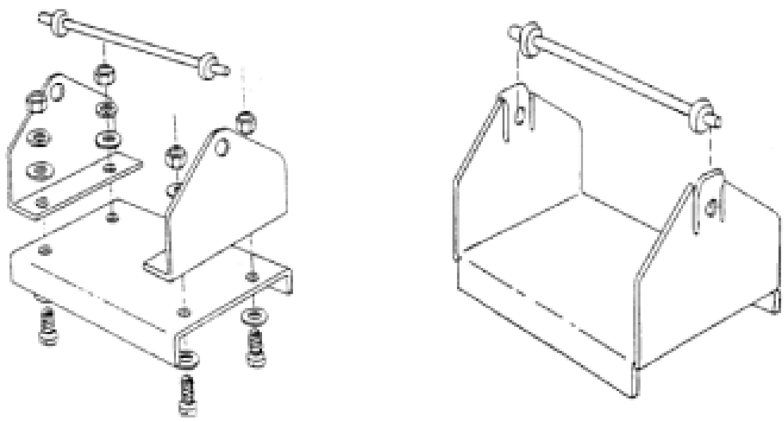


Figure 15: Effective application of DFA by reducing the assembly from 24 to 2 parts (Velling, 2021)

The application of DFMA methodology consists of applying rules based off the principles during the design process. Boothroyd and Dewhurst (2011) optimized the application of these rules up to a point that the designer can validate their design with the help of computer software. No stakeholder interaction necessary! This is helpful to quantify the assembly time and potential savings, but a design process involves many stakeholders that need and want to be satisfied. The engagement of stakeholders isn't described in this method but it is a reality that is integrated in projects and design processes. Stakeholders create the design rules in the form of requirements.

Which stakeholders are involved on what level depends on the goal and scope of a project? One-step foaming is an internal manufacturing change that shouldn't affect the external customers (OEM and end-user), thus moving them to the background. The stakeholders that come more to the foreground are production and automation engineering. For this project the customer changes from external to internal customers.

It is also the strong wish for Thetford BV to take big steps in Automation and Industry 4.0. Now it is best to describe the situation to be at Industry 2.0 because just 10% is done by machines! The transfer should not be a goal on itself, it should be focused on benefits for the business. This should be reflected in the final business case of the presented concepts.

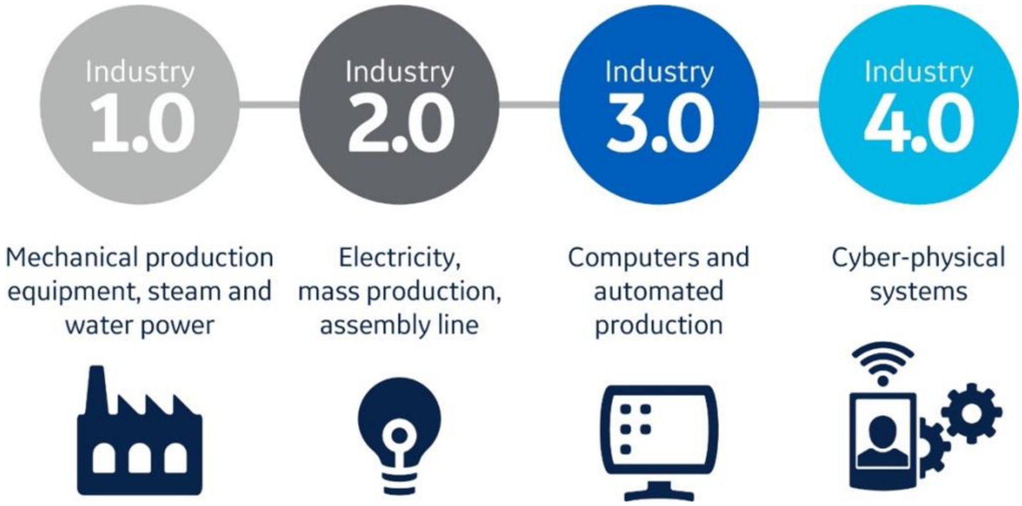


Figure 16: Industry 1.0 to 4.0, where does Thetford stand? (Cytiva, 2022)

How stakeholders are involved differs per company based on procedures, culture, hierarchy, individual agendas of people, relationships, etc. This influences the actual outcome of the project so understanding the present engagement of stakeholders, the outcomes and scope of past projects can help improve further product development. This can be a useful addition to DFMA method with the one-step foaming project at Thetford. Especially because of the unique situation for product engineers which can validate their design directly in the factory attached.

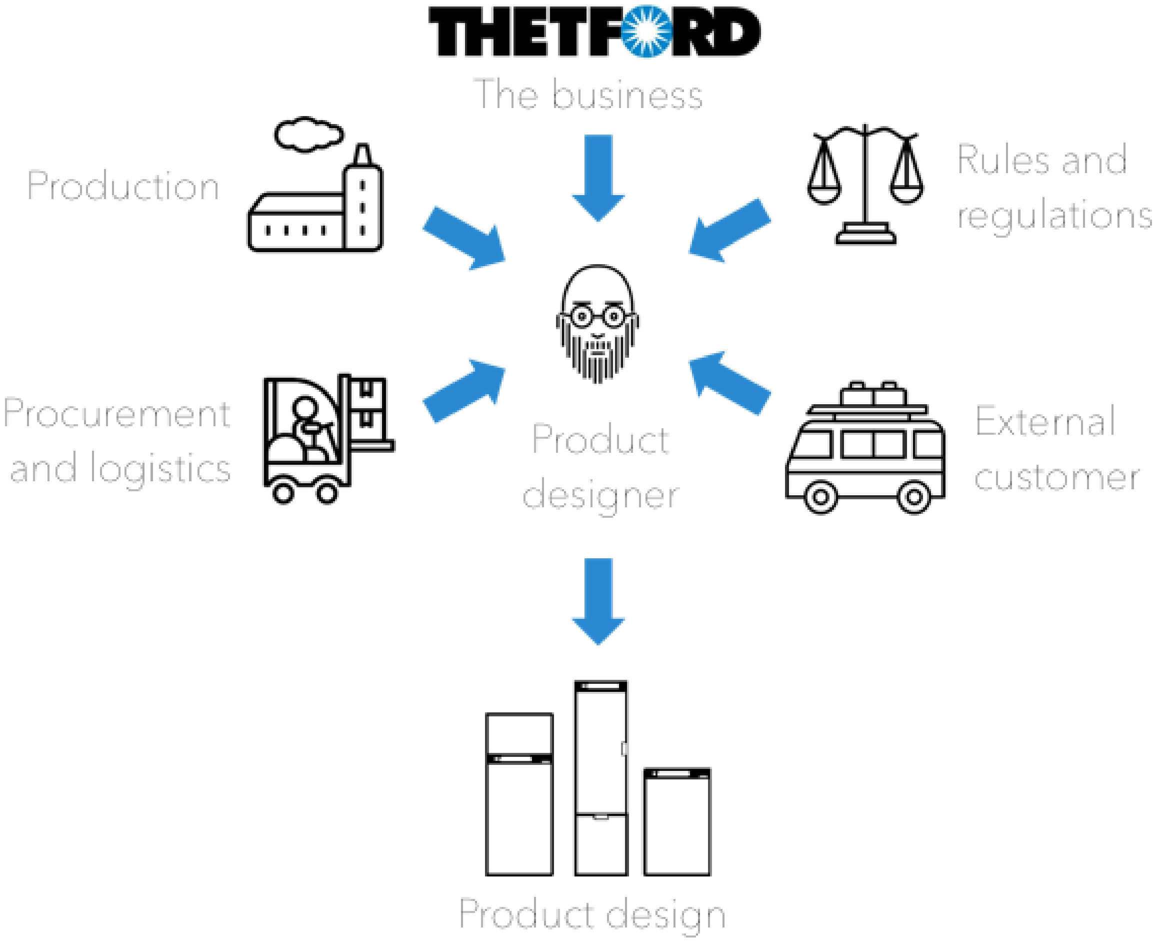


Figure 17: the product engineers will all its stakeholders

External influences on the redesign

Major external influences on the operations and sales have been identified for Thetford. There are, however, other influences that have influence on the design itself to comply to upcoming regulation. Now there are two big ones: possible regulation change on the encasing of domestic fridges in 2023/24 and high probability of upcoming regulation on sustainable design.

Encasement regulation

The outside of fridges needs to have specific encasing on the thermal isolating foam that can withstand or stop flames. The PUR used in domestic fridges is extremely flammable and the electronics used can become faulty. In 2017 a big fire caused by a faulty fridge shows the dangers of unsafe design and manufacturing of appliances. (Baker & Poulter, 2017) Australia changed regulation because of this major accident in 2018 (ERAC, 2018) and it is expected that the EU will do something similar in 2022 because they will implement the International Electrotechnical Commission (IEC) 60335-2-24:2020 standard (IEC, 2020). This standard state that the encasement either is made of a 5VA plastic, steel, or an approved multilayer sheet.

The impact for Thetford is big because they use a cardboard wrapping with a thin aluminum layer on the non-cosmetic sides of the fridge to reduce weight and costs. Most domestic refrigerators use a combination between steel metal sheets and fire-resistant plastic (according to 5VA norms). For Australia Thetford changed their wrapping to more expensive aluminum sheets. Internal validated testing showed, when regulation is applied, only the options shown in Table 2 are allowed. Those options also have their different advantages and disadvantages which can influence the design choices.

Table 2: wrapping options for Thetford

No	What	Required minimum	Advantages & disadvantages[1]
1	Multilayer sheets	Layered sheet of aluminum foil then impregnated cardboard and finally a plate of 0,2mm aluminum	- Best area/weight ratio - Worst area/cost ratio
2	Steel plating	At least 0,2mm	- Best area/cost balance - Bad area/weight ratio when making it structurally sound - Cutting danger in production
3	5VA plastic	Depends on fire retardant testing, overall 3 mm thickness is sufficient	- Worst area/weight ratio - Additional costing for molds - Less flexibility on changes in design

There is still a chance the regulation will be changed or dropped. This will be known in 2023 but for this project the assumption will be made the regulation stays as is to allow for better out-of-the-box design exploration for Thetford.

Sustainable design

A year ago, Thetford started to incorporate more sustainability thought within the whole company. This is both a necessity when looking at new directives that arise worldwide (ECEEE, 2022) and a wish to act consciously on their impact on the world. Directives from the EU focus on improving resource efficiency, reparability, recyclability, and durability (ECEEE, 2022).

Figure 18: fridges waiting to go into the shredder after removing valuables at Coolrec in Dordrecht, NL (NRC, 2011)

The fridges produced by Thetford already have higher standards on reparability and durability compared to domestic fridges. This is due to the high costs of repair (it costs Thetford 2x the sales price to replace or repair a fridge in Australia) and harsher use environment in which the fridge needs to operate (an RV travels around 320000 km in their lifetime of around 25 years (Storgaard, 2022) where the fridge needs to withstand changing environment and constant vibrations).

[1] These basic advantages and disadvantages arose from discussions with procurement and product engineers, exact numbers are used later in the business case for the concepts.

Figure 19: buildup of various shredders and seperators at Coolrec in Dordrecht, NL (Verrijt, 2019)

Thetford's fridges can improve on resource efficiency and recyclability. A visit to Coolrec in Dordrecht showed that recycling fridges is rather easy because they shred the fridges into pieces that can be separated and recycled. There are two requirements to the design which could make this easier: no use of carton and wood, non-magnetic metals and plastics are good if no different types of plastic attached to each other. Separating the PUR and ACU was no issue.


Figure 20: Cooling units are separated at Coolrec Dordrecht, NL

Conclusion

The context around the necessary redesign for one-step foaming of the beaker fridge design as described fulfills important strategy goals for Thetford (efficiency increase, less floor usage and decrease in human dependency). This can be achieved by applying DFMA through stakeholder engagement in the design process. During this process upcoming changes in regulation and sustainable design need to be considered and implemented into the design. The next chapter, analysis, will go more in depth to understand how one-step foaming can fulfill its promises.

Analysis

The goal of the analysis is to create a design space in which one-step foaming can be enabled for mass-production by going from the context to the main drivers and design problems. The logical aspects of the analysis are to understand the present product and with it the present assembly and manufacturing process. In the analysis they will be analyzed by applying DFMA method. Through that important aspects and lessons learnt will be shown of the product and processes at the end of the analysis. As a bonus DFMA is also applied to a product of a competitor. The end of the analysis will conclude with 5 main drivers for the redesign.

Figure 21: Beaker fridge: the fridge of focus in this project

The main parts to make a cabinet

There is a total of 85 parts from 45 unique parts divided into 17 sub-assemblies in the beaker fridge up to the final assembly. The total assembly of the beaker consists out of 186 unique parts resulting in 344 total parts. This is excluding different types of tape, the polyurethane foam, different number of stickers and hotmelt used in the process. Key-parts are cosmetic parts for the end-user, other parts are for protection and performance but there are also some parts that only serve a function during production. Not all parts can be altered, some can be slightly altered and some must be altered to enable one-step foaming. This paragraph looks into the key parts to build a fridge and analyzes them on the key features with the help of DFMA, feedback from production and automation possibilities.

The cabinet for one-step foaming consists out of 5 basic part categories: breaker, liner, wrapper, CU, and PUR foam. The total assembly can be seen in Figure 22 and in Table 3 the value and weight are stated. Weight is an important factor for RV fridges as it needs to be transported and OEM's tend to build RV's below 3500kg to allow more drivers with a regular driver's license to ride in the EU. Increasing the weight therefore inflicts the customer experience.

Table 3: value of the main parts of the beaker fridge

Part	Value	Weight	Percentage of total weight 37 kg
Breaker	Cosmetic front and magnetic counterpart of door gasket	2 kg	5,4%
Liner	Interior of fridge for external customer	4 kg	10,8%
Wrapper	Protective closure of fridge	2 kg	5,4 %
CU	Cooling mechanism for fridge	14 kg	37,8 %
PUR	Isolation to reduce power consumption	4 kg	10,8 %
Total weight cabinet		28 kg	75%

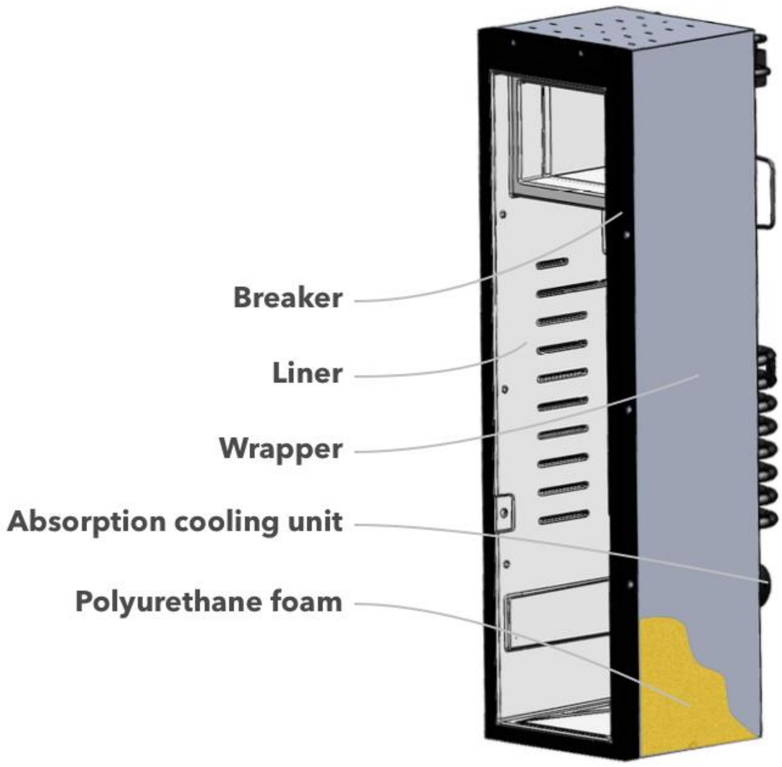


Figure 22: outside parts of beaker cabinet

When looking at these 5 parts: what can be improved in the sense of DFMA? Can it be automated? And what are the downsides of the parts in production? These questions are answered in

Table 4 based on discussions with production and automation engineers as can be found in Appendix 2

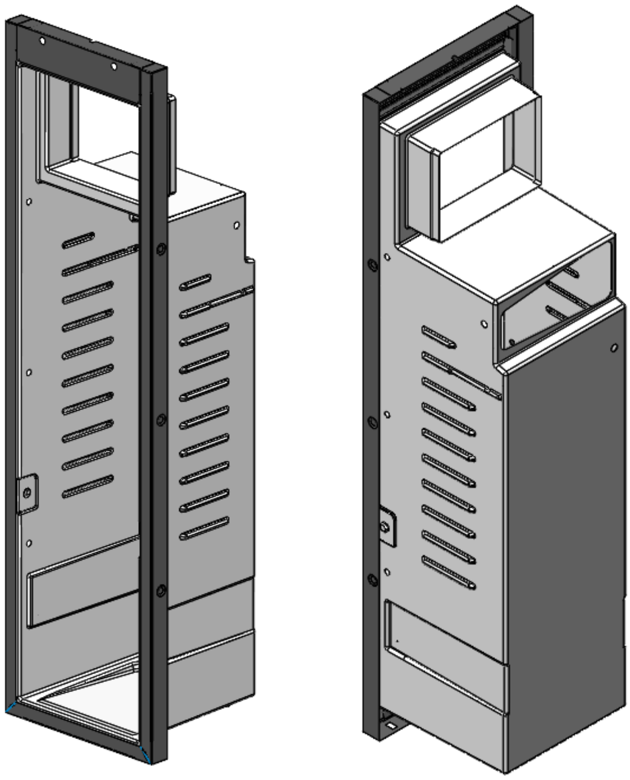


Figure 23: combined breaker (black) and liner (white)

Table 4: impact of parts analyzed through DFMA

Part	DFMA	Production	Automation engineering
Breaker + liner	3 pieces that can be efficiently connected to each other, but no natural closing on all corners	Lot of force and positioning necessary to assemble. Whole assembly process designed on cosmetic breaker which results in a lot of damages	Not easy to automate due to tolerances that are adjusted a lot by manual labor
Wrapper	Total of 4 pieces with the breaker (for the large fridge it's even 6 pieces). 2 pieces are because of two-step foaming.	Easy to handle because of light weight. Smart part reduction by symmetry.	Difficult to handle due to flexible parts.
Cooling unit	One piece with all functionality and right geometry, some tubing could be altered	Heavy to handle	Easy to automate and handle due to many grasping locations and sturdy design
Polyurethane foam	One of the best cost-value ratio products for isolation	Leakages do occur from time to time. Present scrap rate is below 2%.	Already automated transport and injection

Knowing what the value and impact is of the main parts, what can be altered by the industrial designer?

- Breaker and liner (**Error! Reference source not found.**, Figure 24 and Figure 25): The breaker and liner are the main visual areas the end-user uses. Changing these can therefore have a huge impact on the customer. Changes on these parts need to be considered well, but with smart redesign problems like breaker damages could be solved.
- Wrapper (Figure 26): Thinking of the new encasement regulation as discussed on page 21, the whole wrapping needs to be changed. This opens big opportunities for one-step foaming. It is inevitable to avoid the weight and BOM costs increase because of this new regulation.
- CU (Figure 27): The main tubing cannot change (or very limited), but additional parts can be added at the factory they are produced (Thetford China).

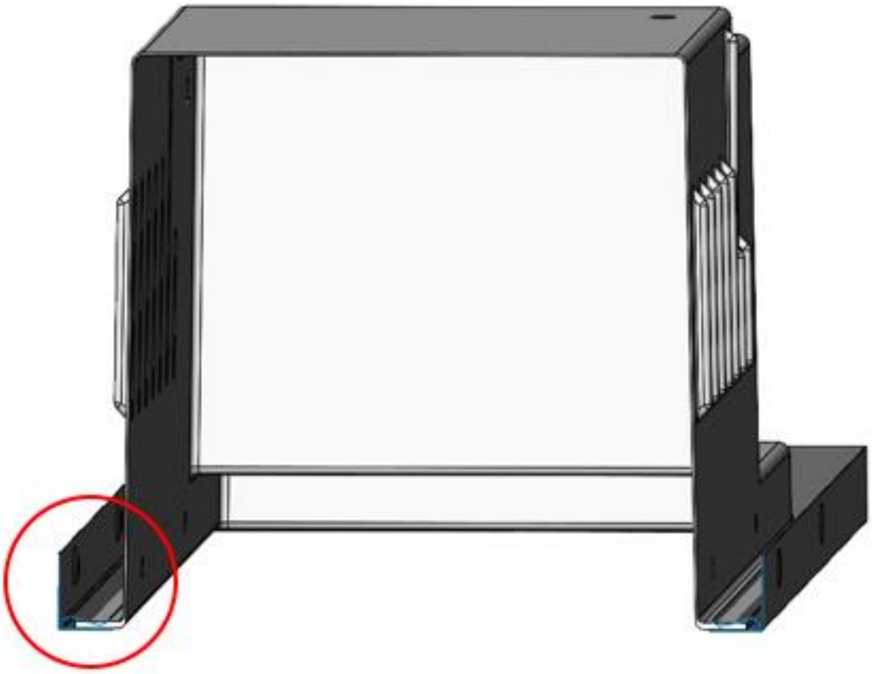


Figure 24: cut through for detail on breaker-liner connection

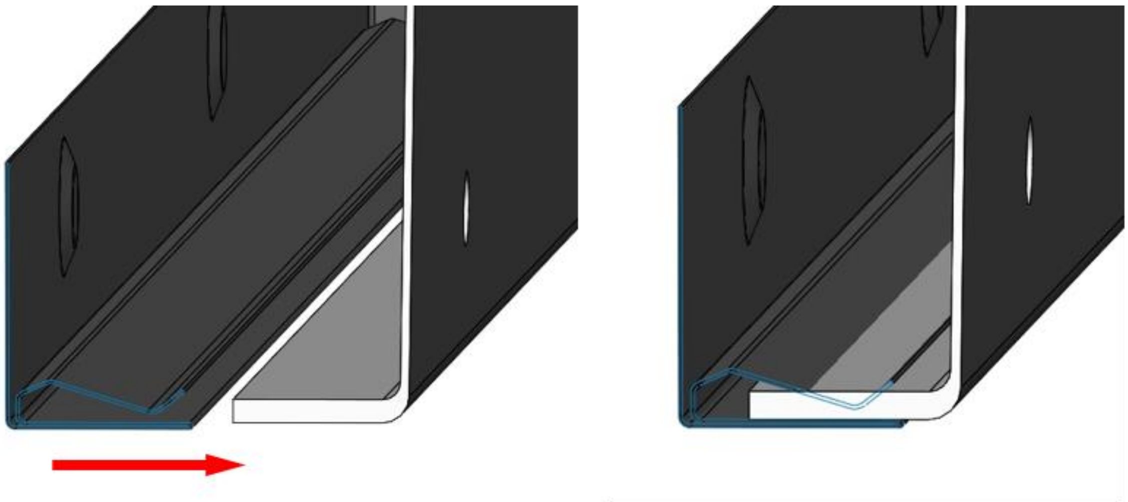


Figure 25: breaker-liner connection detail, the breaker is sliced over the liner

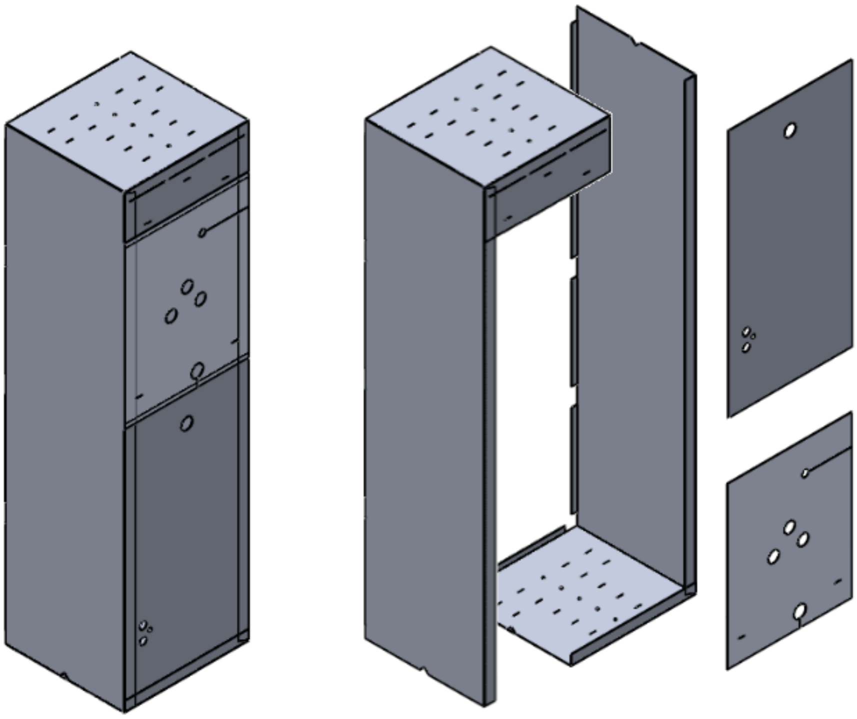


Figure 26: the wrapper combined and in the 4 different pieces, the orientation is focused on the back of the fridge

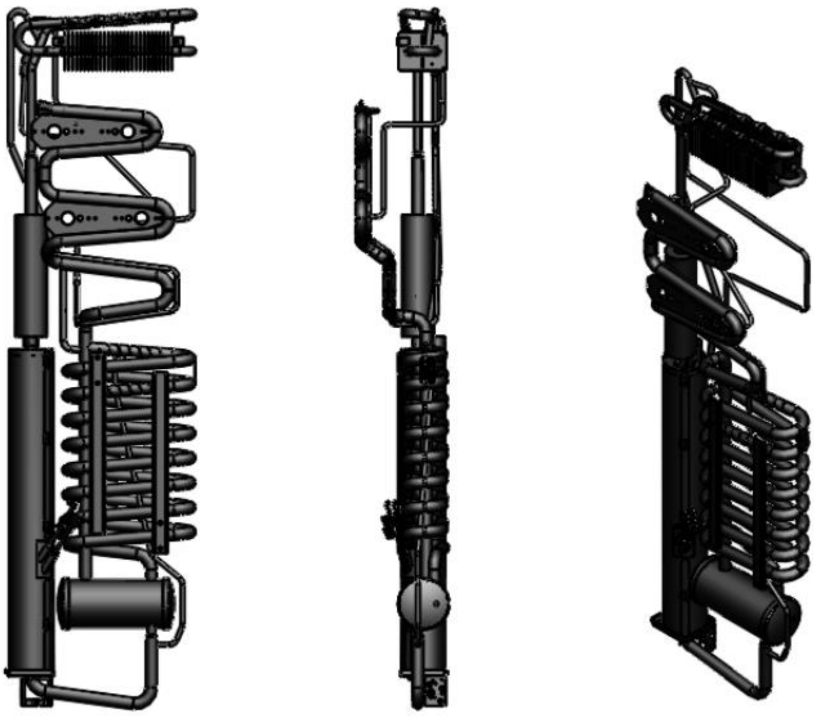


Figure 27: different perspectives of the absorption CU of the beaker fridge

Present manufacturing route

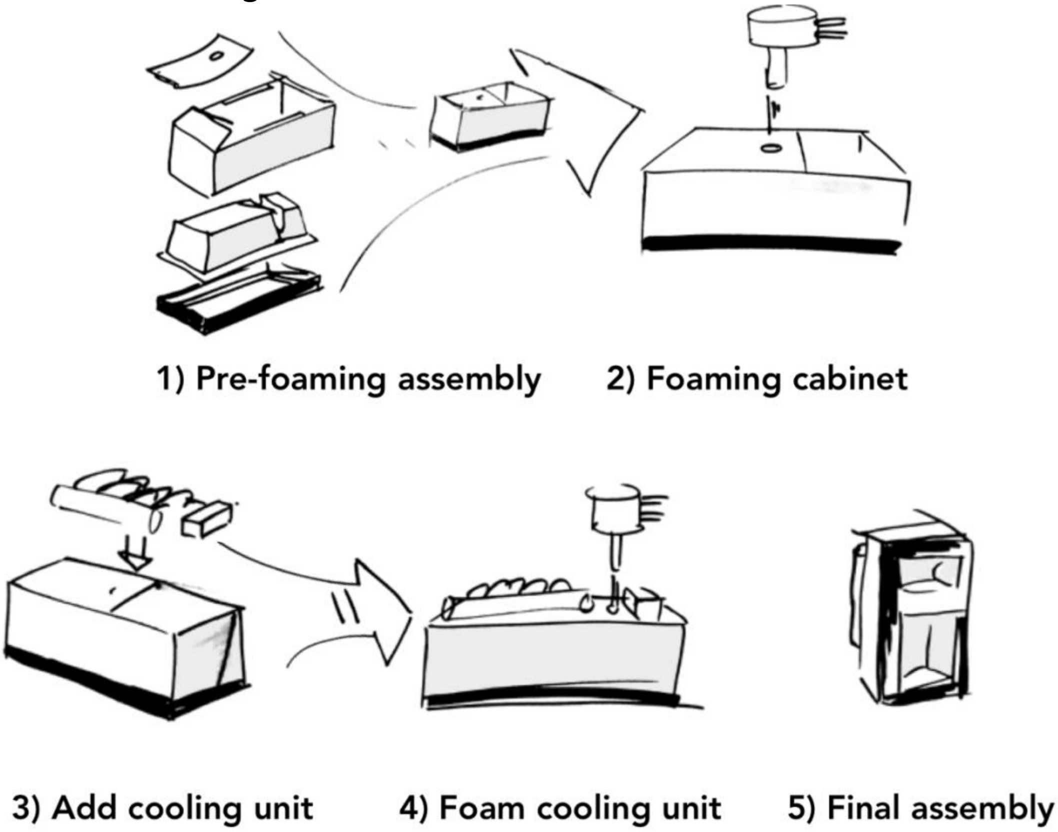


Figure 31 shows a basic overview of the production steps together with **Error! Reference source not found.**. The focus will mainly be on the pre-foam assembly, CU-assembly and the two foaming steps within this project. There are

Factory layout

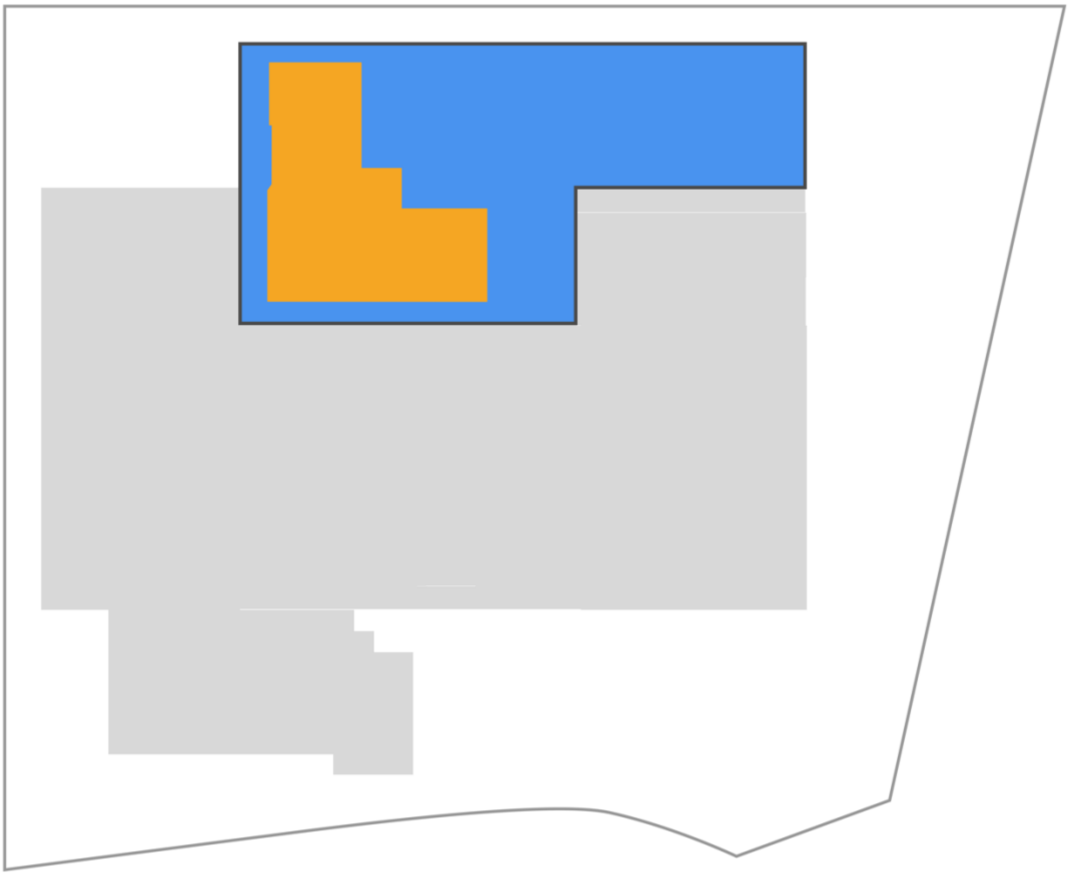


Figure 28: map of factory with highlighted area of fridge production (blue) and beaker fridge location (orange)

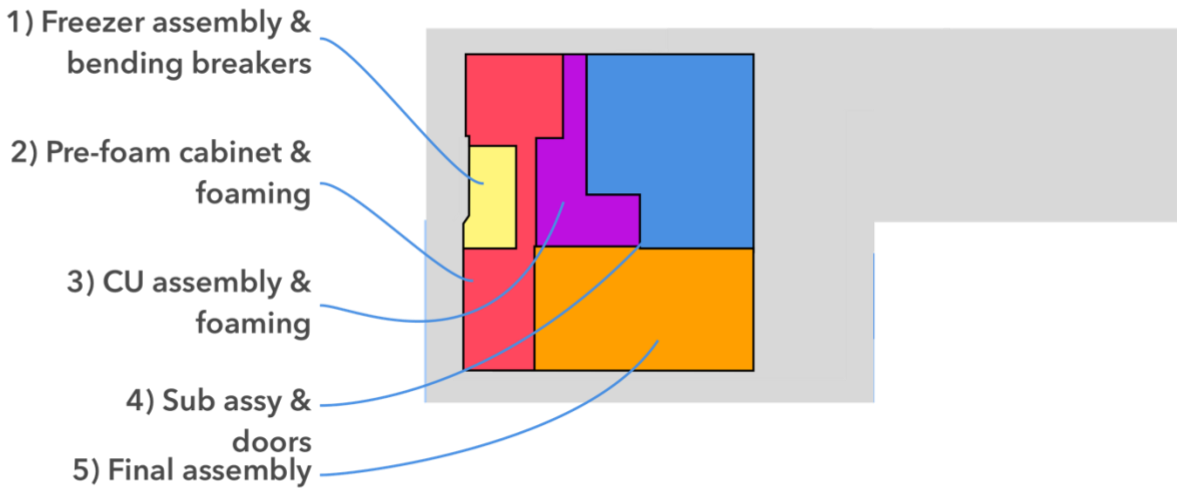


Figure 29: location of the production steps for the beaker fridge (door and sub-assemblies not shown)

Lessons learn from feasibility study of one-step foaming

In 2018 a project was started at Thetford to explore the feasibility of one-step foaming (Improvia, 2018). Together with Improvia they chose for one concept direction from three concepts. The three concepts can be seen in Figure 31, Figure 32 and Figure 33. What was unique on each of these concepts?

- Concept 1 – use a PUR plate as back. Problem: isolation and impact on design.
- Concept 2 – complex transport pallet. Problem: huge impact on production
- Concept 3 – metal backwrapper. Problem: increased weight.

In the end they chose for concept 3 as this showed the most promise to allow for one-step foaming. They didn't know it was possible with this big a CU. The next step was therefore to test feasibility in the equipment.

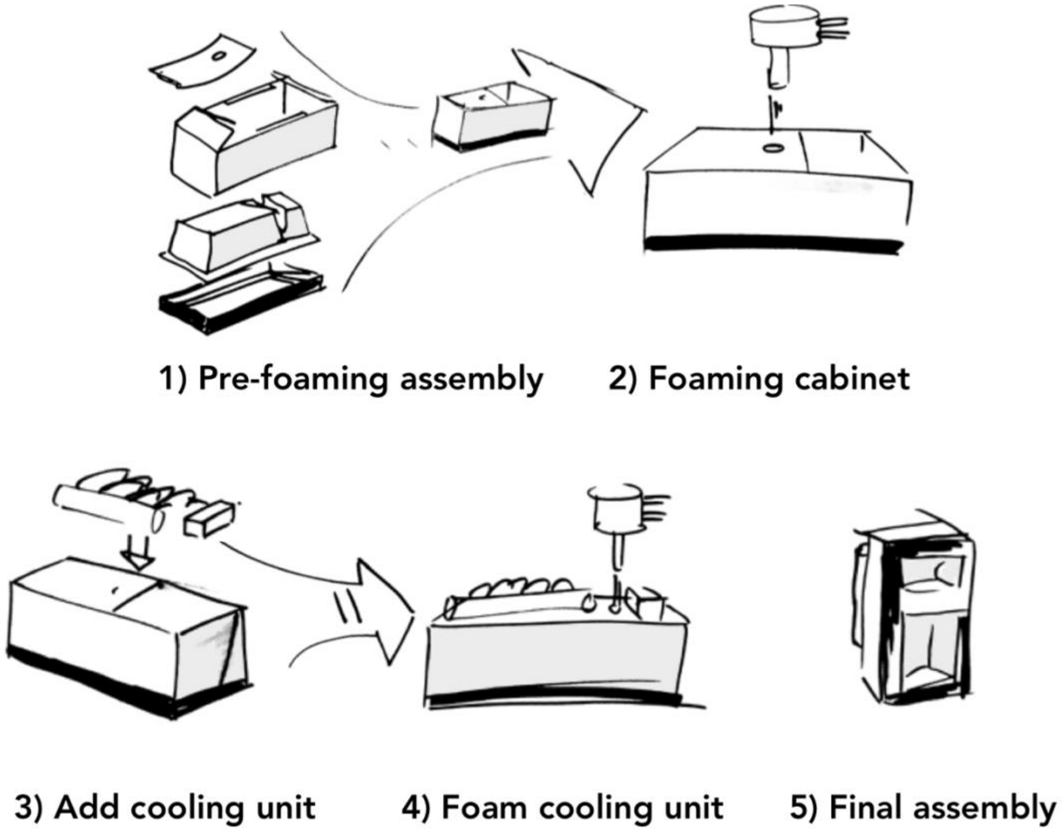


Figure 30: visualization of present production route

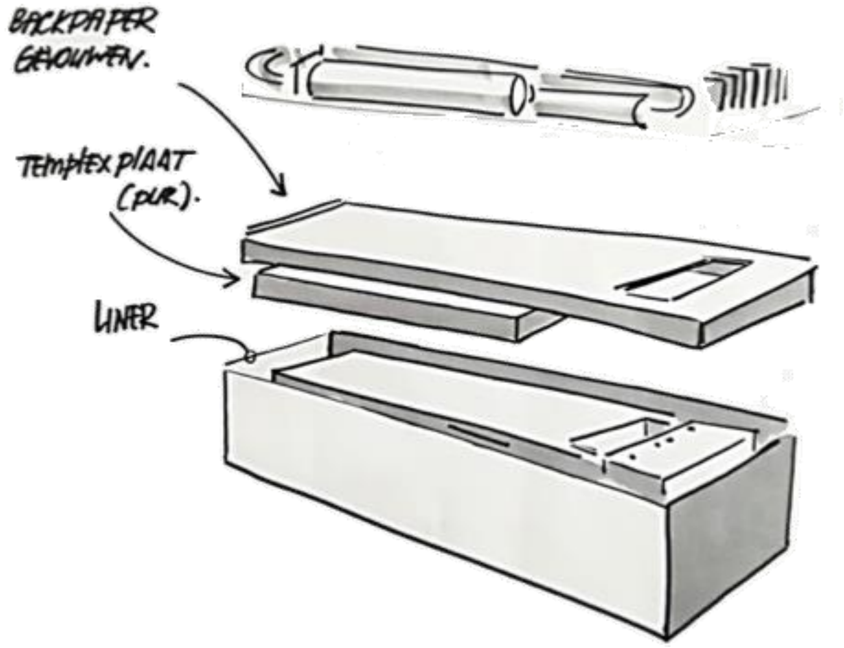


Figure 31: concept 1 from feasibility study

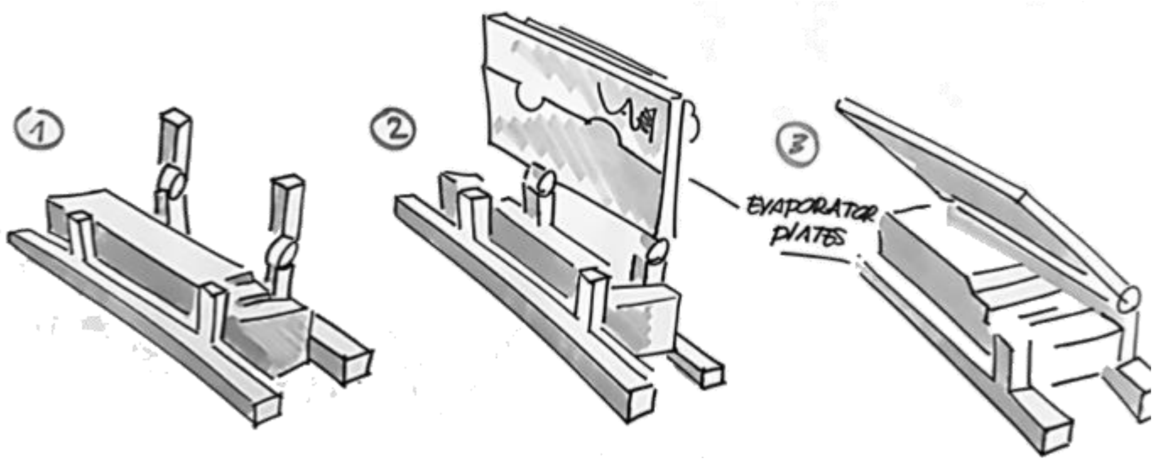


Figure 32: concept 2 from feasibility study

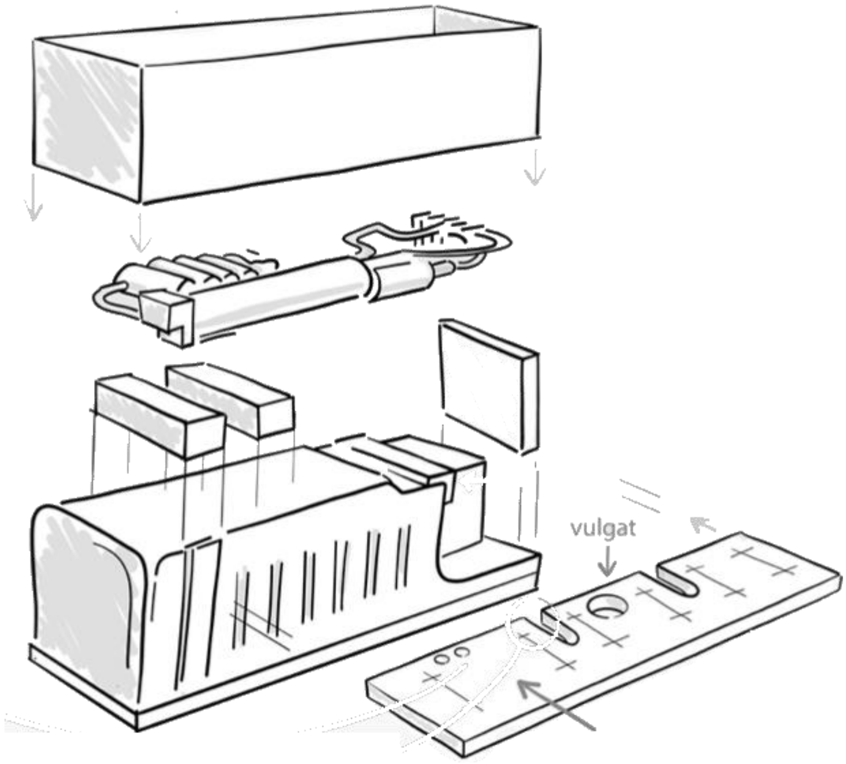


Figure 33: concept 3 from feasibility study, the winning concept

Feasibility testing one-step foaming

Two test runs were done with an aluminum backplate. The results were very promising as they were able to foam each fridge successfully and even improved the performance. Some impression is given on these test runs with the help of the following images.

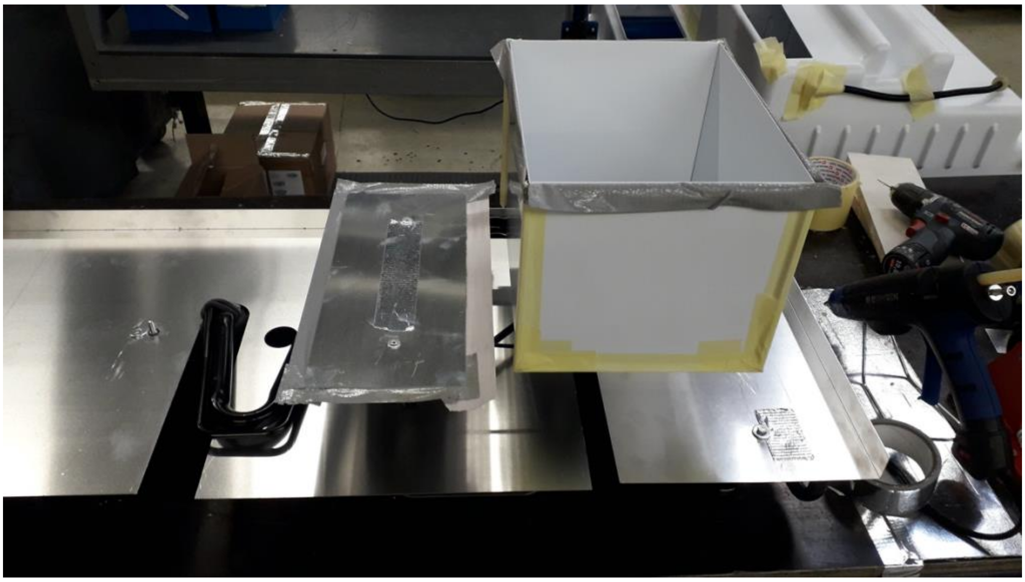


Figure 34: detail on method of assembly of certain parts

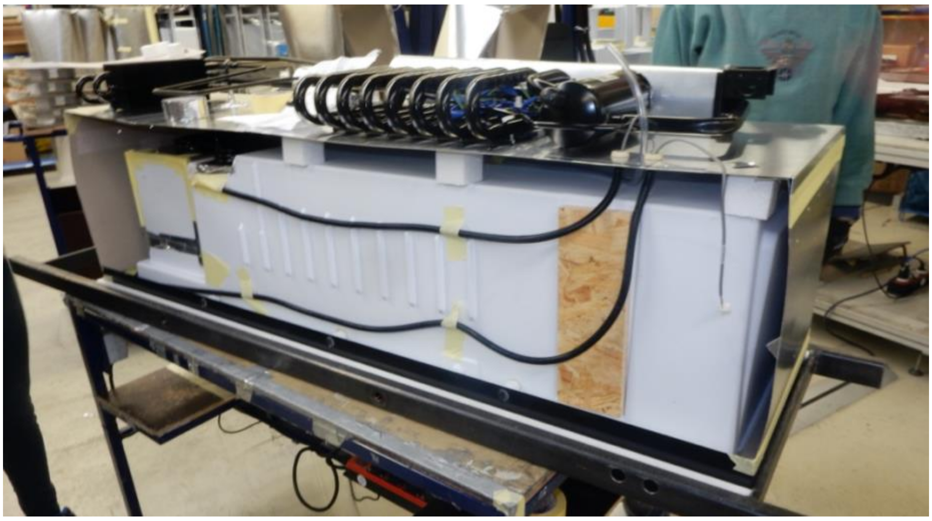


Figure 35: internal assembly of one-step foaming cabinet

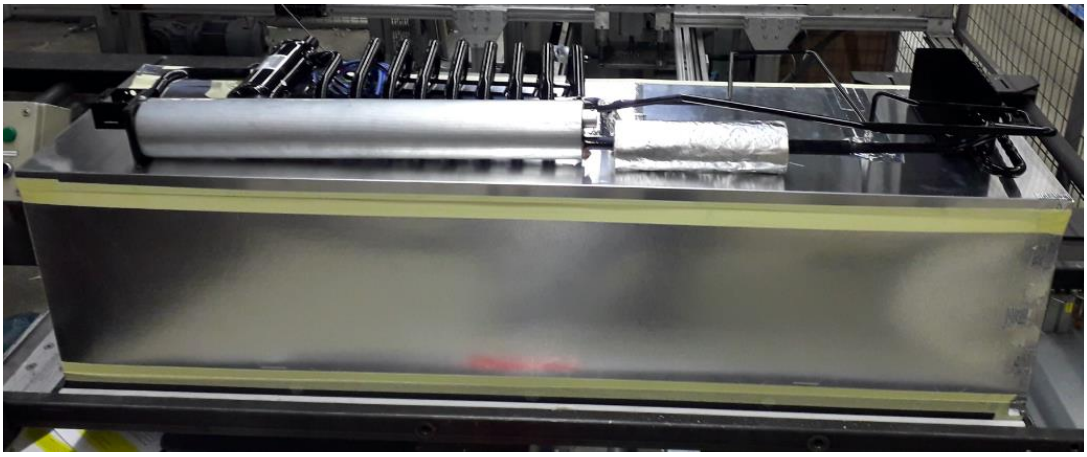


Figure 36: full assembly of one-step foaming concept before foaming

Figure 37: finished fridge after foaming


Figure 38: internal changes to machinery during feasibility run

What were the main design considerations that need to be considered from this study?

1. Counteract foaming force (at essential location like the powerboard)
2. Pre-foam assembly needs to be stable enough to be foamed
3. Assembly needs to allow for proper access to assemble all parts (especially the wrapper)

There were some other lessons learnt from the feasibility study that need to be considered next to these design considerations. The cost price and weight increase are too high to continue. Also the assembly needs to improve a lot to make it feasible for mass production. For now the design is not feasible to be mass-produced, only the principle of one-step foaming was proved.

DFMA on present product

In Appendix 3 an extensive DFMA analysis was done on the most influential production steps for this project (consisting of the pre-foam assembly and CU assembly as can be seen in step 2 and 3 in

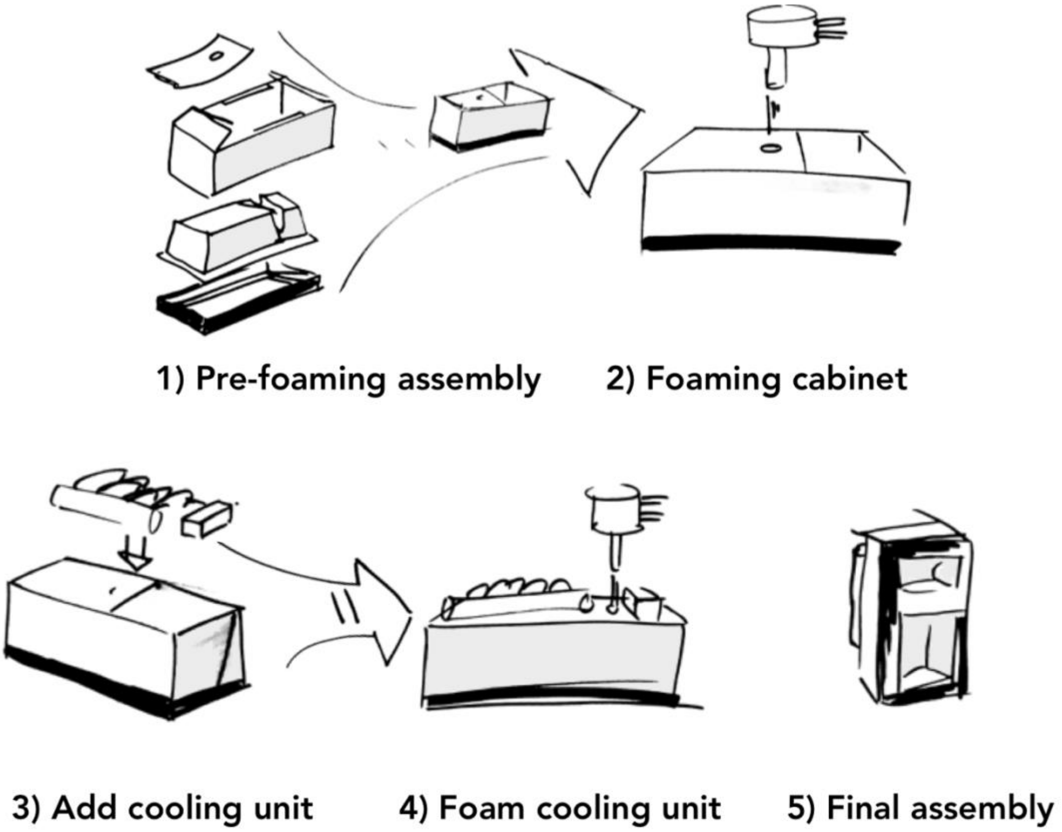


Figure 31). This paragraph will go through the highlights of this analysis and end with its conclusions. The goal was to discover principles of improvement from the the present design from the viewpoint of DF(M)A and 8 wastes of LEAN.

The analysis was done by going through work-instructions present at Thetford and seeing the actual production. An analysis was made to see what savings in assembly time were minimally and maximally possible based on the discovered principles and when thinking of the initial concept of one-step foaming compared to the full potential implementing DFMA and decreased wastes. The vision generated from this analysis is for the production worker to add the most value in its work for the assembly of the product. Ideally this should only be assembling the parts described in the paragraph "The main parts to make a cabinet" but that's probably too ideal.

The 5 design rules for pre-foam assembly

What are the design principles that came from the analysis?

1. **Don't use tape!**
2. **Don't allow for double work!**
3. **Don't use nutplates (when metal is around)**
4. **Don't assume it will only be assembled by humans**
5. **Hotmelt helps in cases of emergency only**

A lot of these principles have something in common and in that sense support each other. So one principle does not stand on its own.

Don’t use tape

The customer doesn’t need tape, Thetford needs tape. Tape only functions at Thetford as a joiner (of parts), sealer (to make it foam tight) and protector (prevent breaker damages). Thetford spent €286.427 on tape alone for their fridges in 2019 and this is probably higher in 2021 and 2022! This is excluding the manual labor necessary to apply all this tape (which is more than 56 million meters!) and the tape used for packaging.

The joining is for example done with the wrapper, where they use high quality (and therefore rather expensive) duct-tape because it needs to be fire retardant (see Figure 39). Why not let a wrapper be joined at the supplier who is specialized in joining cardboard for their box industry? Why not design the metal wrapping for the new encasement regulation in such a sense that tape isn’t necessary?

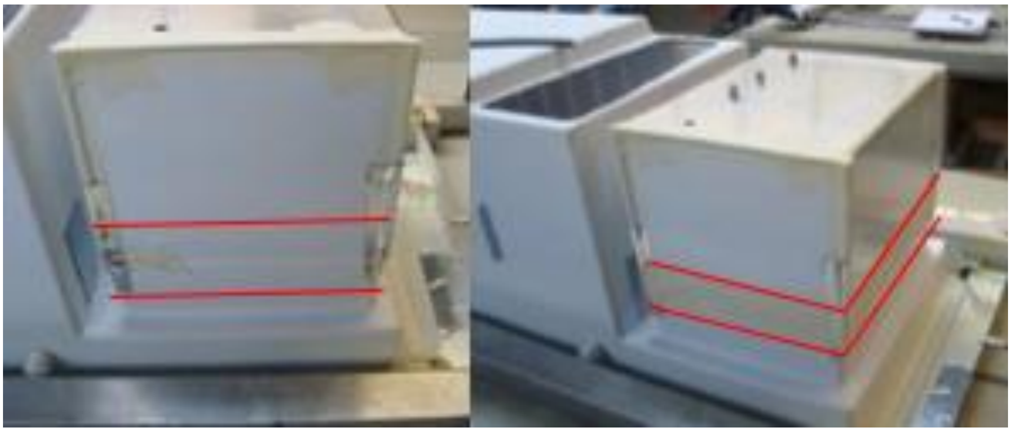


Figure 39: freezer is placed on liner. Tape is necessary to make it foamtight (red lined, left is not taped yet, right is). It is designed this way.

Using tape as a sealer is necessary, as described in previous paragraph, to make the product foam tight (see **Error! Reference source not found.** and Figure 40). Tape is just one sealant (besides hotmelt) that is applied when the joined parts don’t have a natural sealing connection. The tape used for this is masking tape which isn’t expensive to buy. In this case tape could be used as an addition to prevent foaming leakages, but aren’t other methods possible?

Figure 40: the wrapper is taped to the breaker to make it foam tight (masking tape is highlighted by red)

Figure 41: all the location where the expensive fire retardant duct tape is used (yes, this is the only the wrapper)

With the present design tape was designed with it. An internal study at Thetford showed that taping is impossible to automate in a profitable manner. Tape is a big waste because it adds no value to the customer, it is expensive and impossible to automate. For one-step foaming this needs to change to not using tape (only as a last resort or to mitigate certain risks it might be used)!

<u>Don't allow for double work</u>

Nobody wants to do something just because. Reversing the action makes it even worse. There are a couple of actions in the cabinet production that seem like these kind of tasks (also thinking about the future situation of one-step foaming). These tasks are using extra certain foam-tightness by applying all possible measures (Figure 42), using process plates (Figure 43), placing plastic sheet for two-step foaming (**Error! Reference source not found.**) and more. Could these double work tasks be eliminated with one-step foaming?

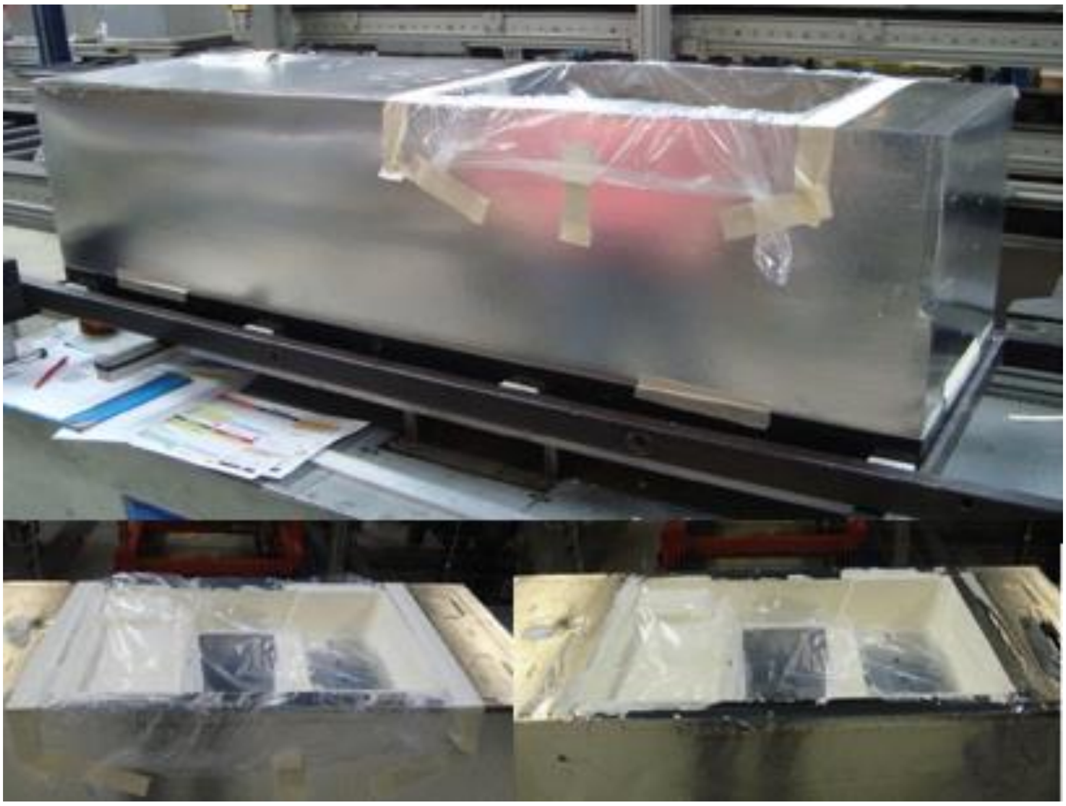


Figure 42: foil is applied to allow for two-step foaming. This is later cut and made to size (bottom-left)

Figure 43: process plates are placed and removed because foaming doesn't allow for placement of the necessary part beforehand

Don’t use nutplates

Nutplates are used to allow for joining parts to the cabinet after foaming with a screw (see Figure 45). The design of the fridge is optimized in weight and material is chosen (cardboard wrapping and thin-walled breaker material) as material making it hard to join (heavy) parts properly in an environment where there are constant vibrations.

Figure 44: application of nutplate in the corner of the breaker. First hotmelt is placed then the nutplate.

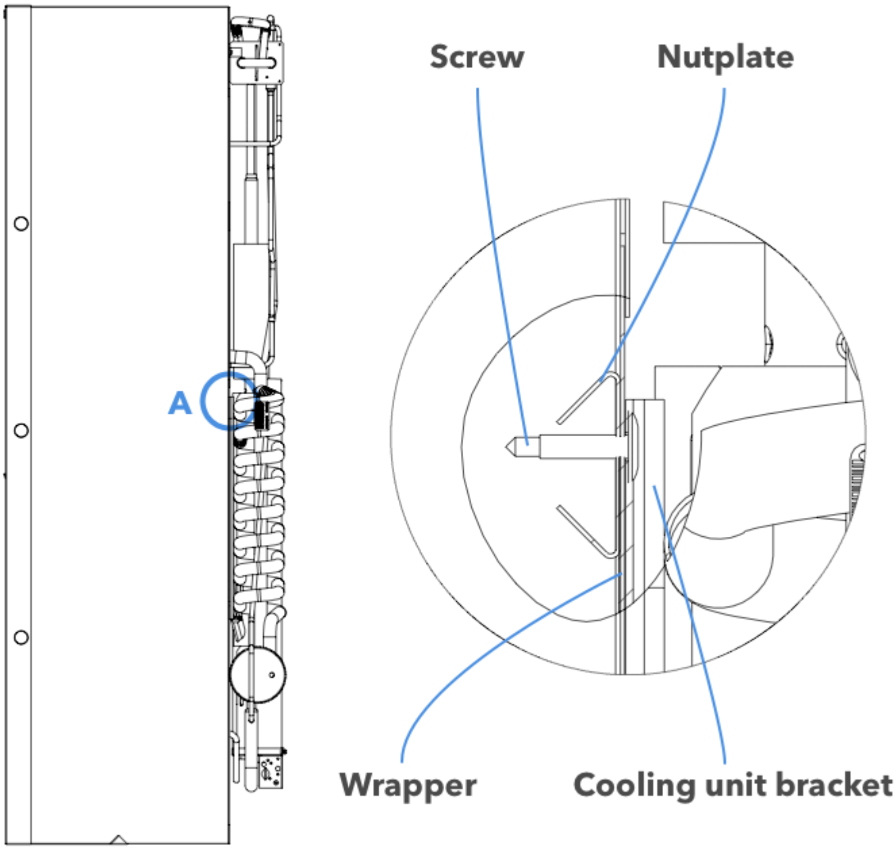


Figure 45: the function of a nutplate (the fridge is viewed from the side, the application is the joining of the CU to the back of the fridge)

The question to answer is whether the nutplate is the best cost-efficient method when metal wrapping is going to be applied and when there are solutions where screws from aerospace are used in thin-walled metal application (TR Fastening, 2022). The method now is to hotmelt a piece of metal to the required joining location (see **Error! Reference source not found.**) and there are a lot of places where nutplates are placed. And there isn't one type, there are many types of nutplates used.

<u>Don't assume it will only be assembled by humans</u>
This is something new for Thetford but fits the future perspective they have for their factory. The present design is not feasibly to be optimally automated. This can be seen in the application of tape but also in certain handling that is made with human hands in mind (see two examples in Figure 46 and Figure 47). Human hands are different then robotization as can be seen in interview results in "Present DFMA implementation and stakeholder engagement at Thetford".

Figure 46: holding of a cable (by hand) and then taping (by hand) to keep it in place

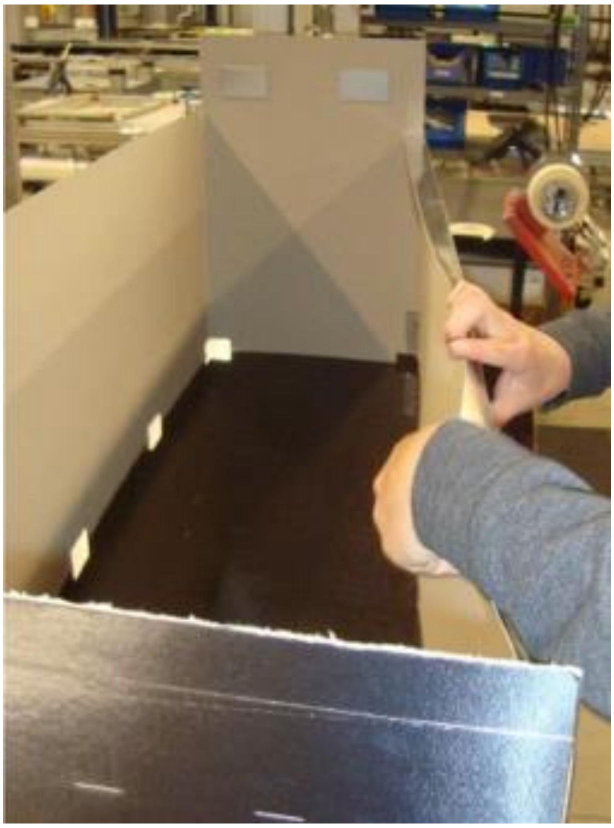


Figure 47: wrapper is easy to handle by hand but absolutely not by a robot

<u>Hotmelt helps in cases of emergency only</u>
In contrast to applying tape, hotmelt can be automated. This doesn't, however, mean it could be eliminated. In 2019 almost 8000kg of hotmelt was bought for the fridges at a cost of roughly €90.000. Again, the same reaction applies here as it does to the tape: it's not for the customer, only for Thetford. Especially at cable applications (as seen in **Error! Reference source not found.**) but also for other sealing locations (as seen in

Error! Reference source not found.) it is the result of design choices that hotmelt needs to be applied. So how can these parts be eliminated to stop using hotmelt?

Potential savings when optimizing value through DFMA

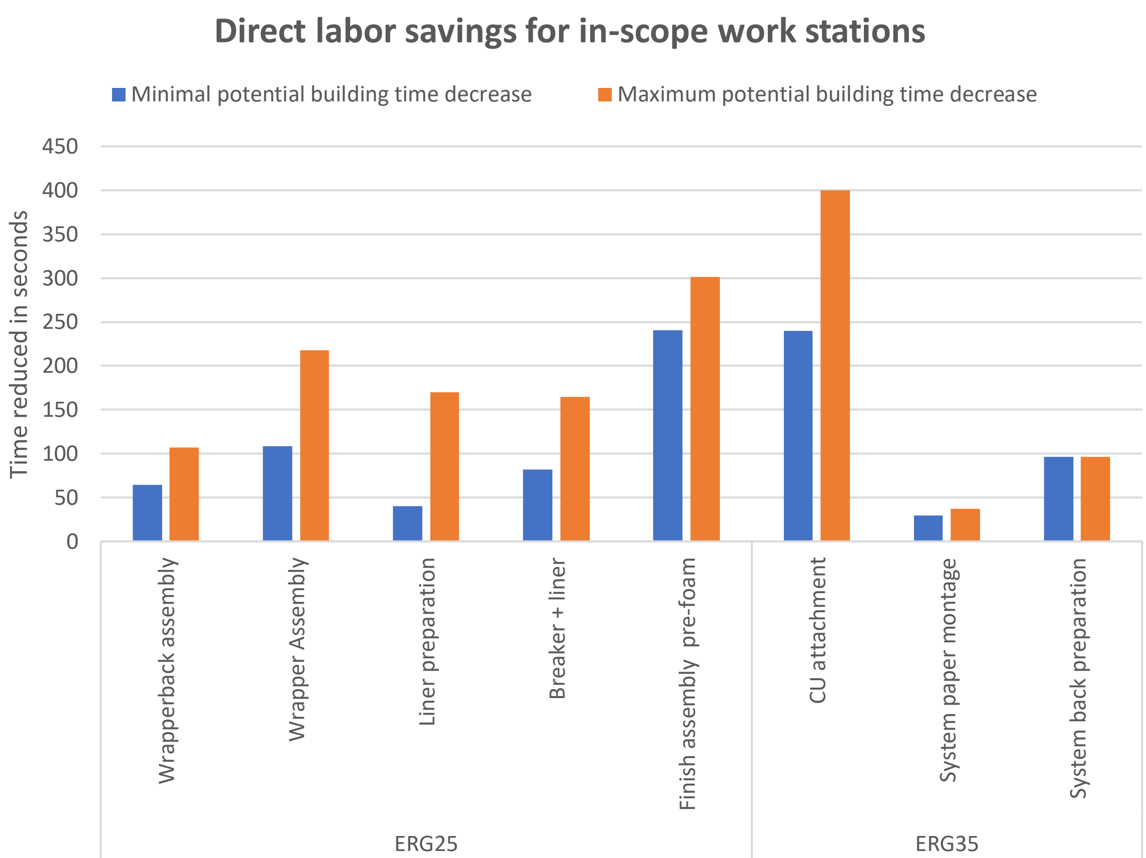
As discussed, the 5 design principles will result in an optimal situation but what is a realistic situation. The second step of the analysis was to go through each little step of the assembly process in scope and define what elements will be eliminated with one-step foaming and what could be eliminated when going for full design optimization. There are basically 3 categories with each their requirements to meet the category.

- **Value adding work or non-replaceable work** – either placing or moving the main parts of the cabinet assembly and joining them without additional tooling and parts
- **Waste solvable by one-step foaming** – eliminating steps that move to other locations or what is solved by basic integration (like metal backpaper)
- **Waste solvable by fully optimizing design and keeping automation in mind** – optimizing everything mentioned: no hotmelt, no tape, no nutplates and hopefully easy automation solutions. Solve the problem by redesigning all parts without impacting the customer much.

The minimal savings are defined by only applying the decrease in direct labor from the waste reduction by one-step foaming. The maximal saving is defined by the combined decrease in direct labor for both reduction by one-step foaming and optimizing the design.

The saving potential is high and worked out concepts can validate the analysis. In Table 5 the savings per workstation in time is showed. The potential biggest savings are the 'wrapper assembly' and 'finish assembly pre-foam'. For the concepts it is wise to focus on these biggest savings first and then the smaller savings like 'liner preparation'. CU attachment is a free saving as one-step foaming eliminates it almost fully like the rest of the CU assembly (ERG35).

Table 5: calculated labor savings from cycle times. ERG25 = pre-foam assembly, ERG35 = CU assembly



How do these savings reflect decrease in building time (= total direct labor time necessary to produce 1 fridge including supervisors and operators) and cost price? In Table 6, Table 7 and Table 8 the savings in time and cost price are shown.

Table 6: total hours building time difference

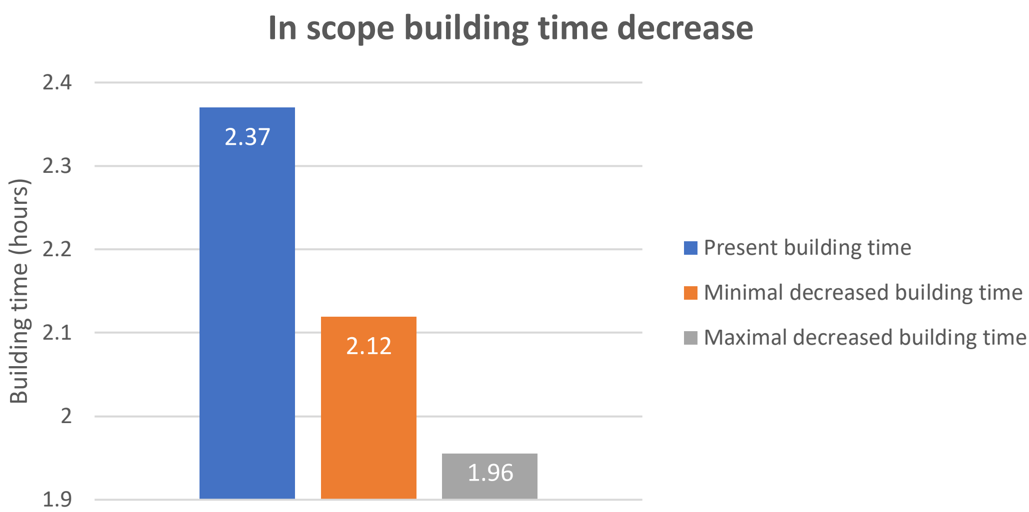


Table 7: percentage of building time decrease compared to present situation

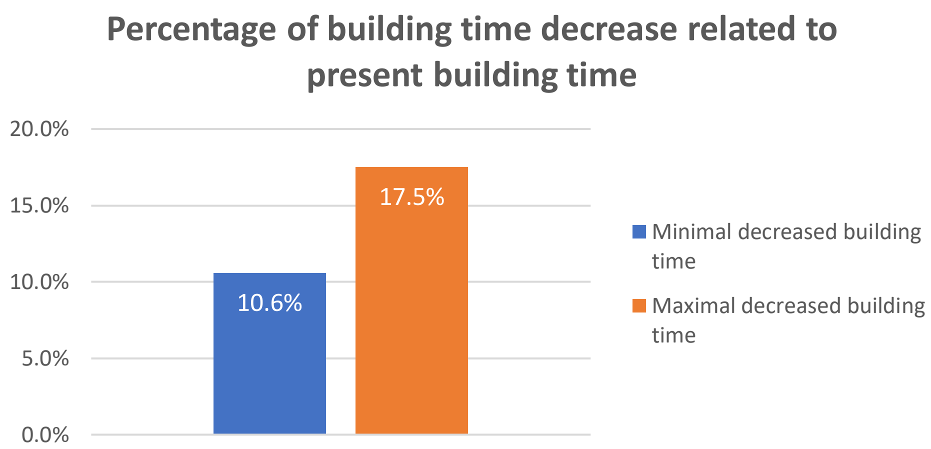
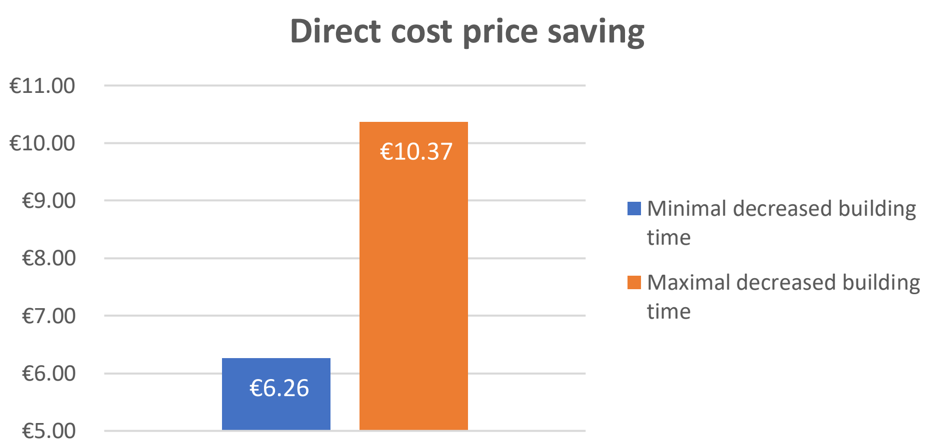


Table 8: cost price decrease on direct labor



The savings mentioned are optimal savings. In the chapter on Concepts more detail needs to be given on potential savings from the concepts.

Maximal present factory potential

Let's turn the focus of savings around to look for the possible maximal output potential of the factory. The focus now was on saving labor but it depends on how people are placed in the line to have a certain output. Foaming equipment is a physical limiter that isn't flexible enough to suddenly have more output when more is assembled. The assembly from labor and the equipment effectiveness need to be aligned.

Table 9: Overall Equipment Effectiveness of the beaker line in 2020

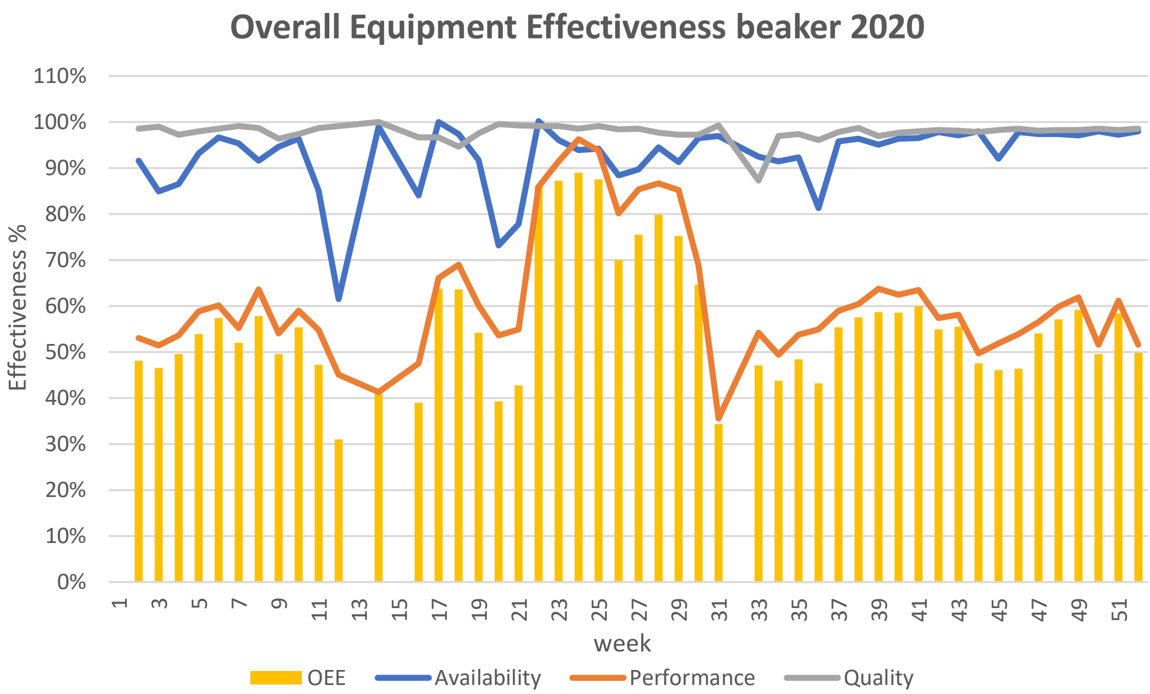
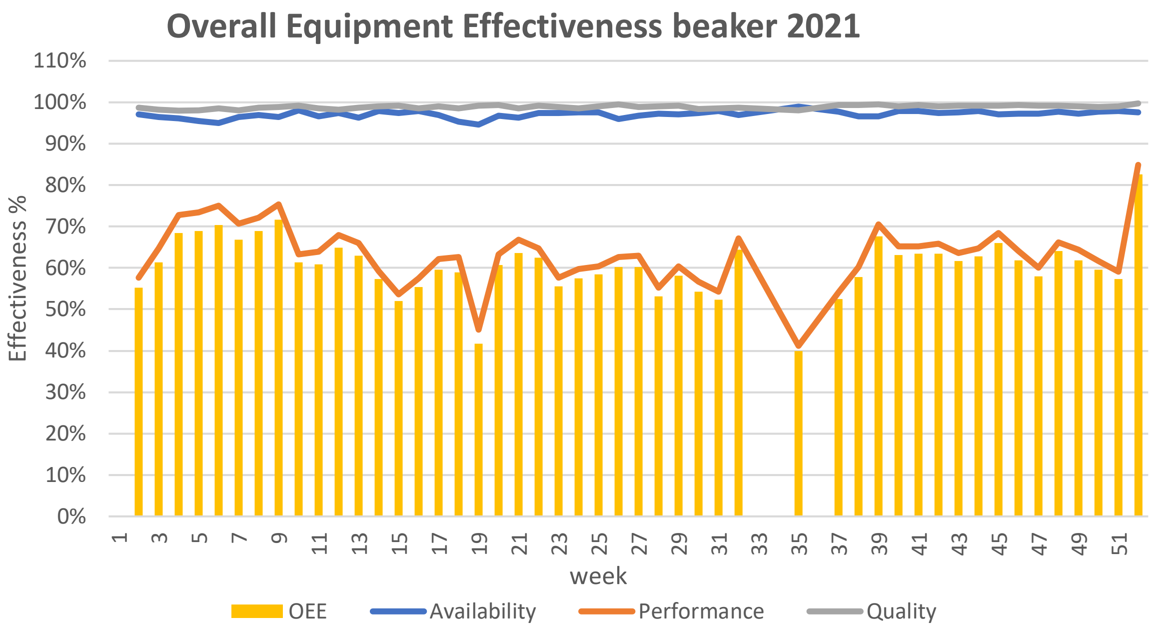


Table 9: Overall Equipment Effectiveness of the beaker lineTable 9 shows the OEE (Overall Equipment Effectiveness) of the foaming equipment on the beaker line in 2020. This number is a multiplication of the Availability (beschikbaarheid = time the machine is available), performance (prestatie = how much is produced in the time available) and quality (kwaliteit = amount of defects) and gives a good indication whether the equipment is used to its full potential.

An OEE of 85% is seen as world class, 60% as typical and 40% as low (Limble CMMS, 2019). The present OEE of around 50% can and needs to increase as Thetford delivers high quality products world-wide and is looking to increasing their efficiency. For Thetford the OEE is mainly low because of the performance. The other two (availability and quality) are high enough. Could the performance at Thetford rise to 90%, to have this 85% world class OEE? This would mean an output increase of 40%!

The OEE of 2020 shows something interesting around week 22 to 28 because during that time it rose to a little above 85%. What happened? Of course corona hit and Thetford approached the first wave and uncertainty by letting all the people go from the employment agency, leaving only the hired workers. These workers are highly skilled, fast and they are in the company for a long time. The data supports that the work of taping, hotmelt and placing nutplates requires skill. Skill the 40-50% people from the employment agency initially lack which is shown in the rising graph in week 33 to 39. In 2021 the line is stabilizing to 60% as can be seen in Table 10.

Table 10: Overall Equipment Effectiveness of the beaker line in 2020



So, what can be the efficiency increase while keeping the maximal potential in mind? 20% increase in output should be possible with design and manufacturing optimization.

Competitors and their fridge design and manufacturing approach

Finding solutions yourself to optimize the design and manufacturing approach at Thetford is not the optimal approach. Competitors and suppliers can help in finding solutions. This is especially the case for metal wrapping with whom Thetford is unfamiliar. This paragraph tends to give highlights of differences and limitations in approaches others took. More detail is given in Appendix 4 and 5.

IKEA VINTERKALL demolition

During this project an IKEA fridge was bought for design exploration in another project. The opportunity to learn from it for this project arose when it was no longer needed. In Appendix 4 a more detailed analysis is done. Some highlights and the conclusion from this analysis will be shared. Important questions were: How do they make metal wrapping connections foam tight? What other lessons can be learned (because we don't know what is hidden in the foam)?

Figure 48: IKEA VINTERKALL

<u>Foam tight connections with metal wrapping</u>

There were some interesting methods used to make the cabinet foam tight. First, they had a very loose connection between the liner and wrapping. Where the wrapping was also the cosmetic breaker side. No foam leakage was discovered.

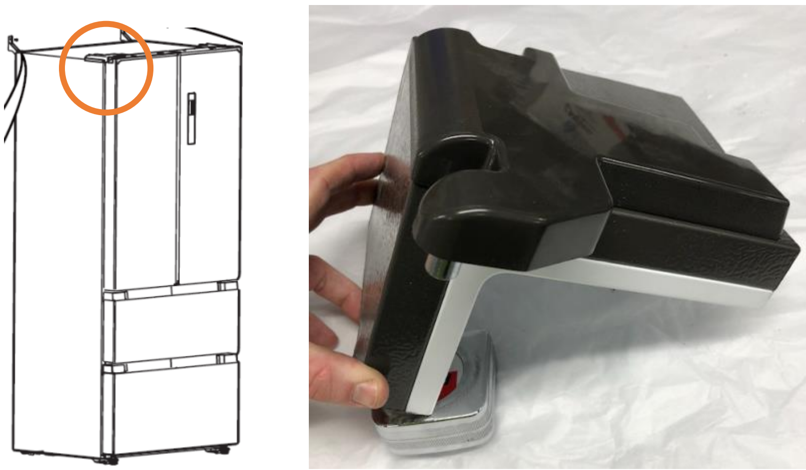


Figure 49: a piece of the fridge's top left corner

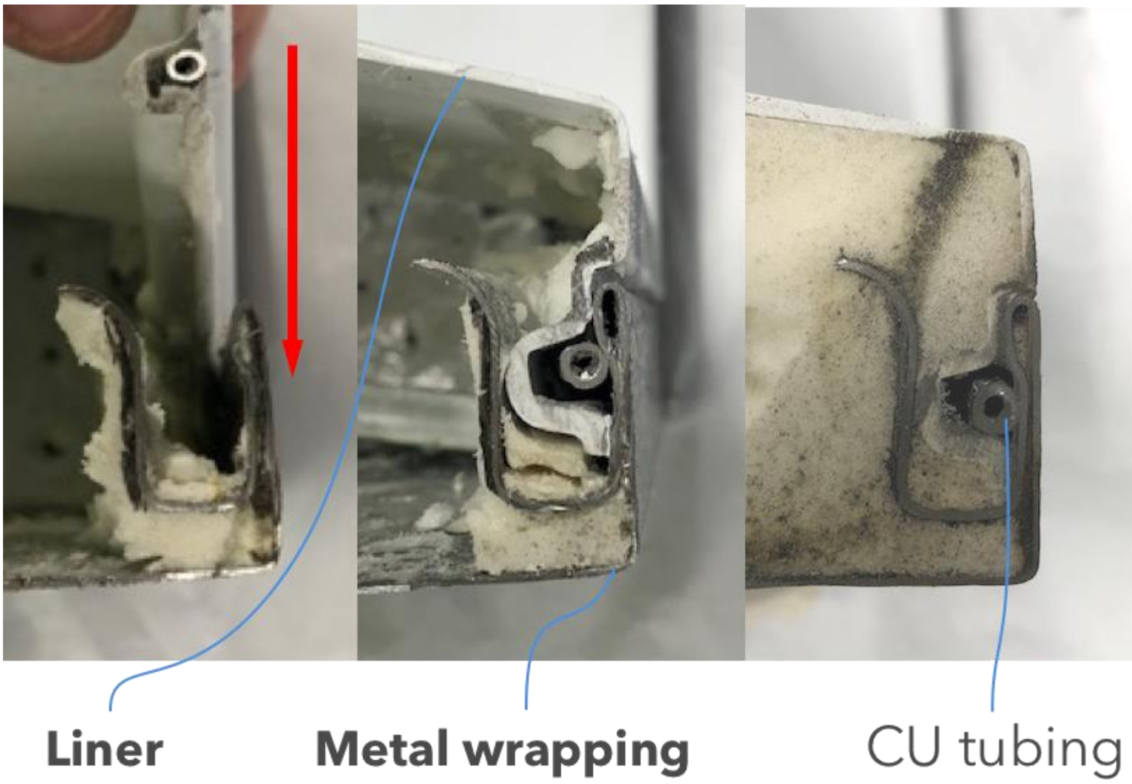


Figure 50: method to connect liner to metal wrapping

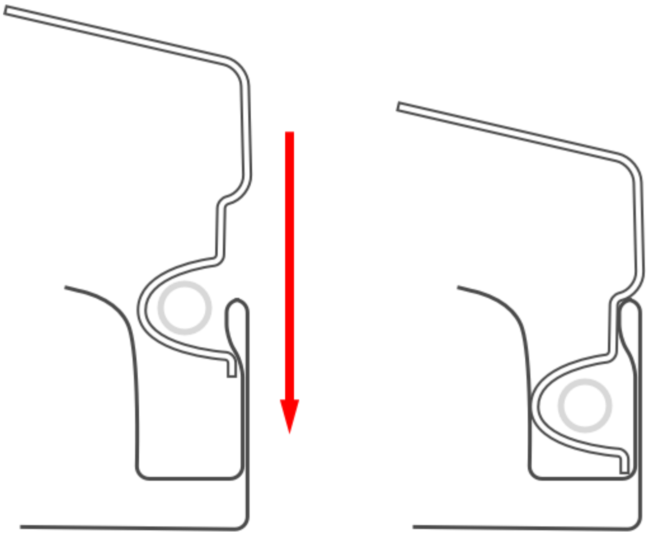


Figure 51: sketch on connection liner and wrapping

Instead of taping and hotmelting the corner they used a simple flap and little piece of foam to make the connection foam tight (Figure 52 and Figure 53)

Figure 52: corner flap

Figure 53: little piece of foam in the corner

Different connections exist at the IKEA fridge. The bottom feed show a ‘dry’ connection between the bottom metal sheet and cosmetic side part. A little piece of foam pas placed in between those layers (see Figure 54, Figure 55 and Figure 56).

Figure 54: bottom left corner of IKEA fridge

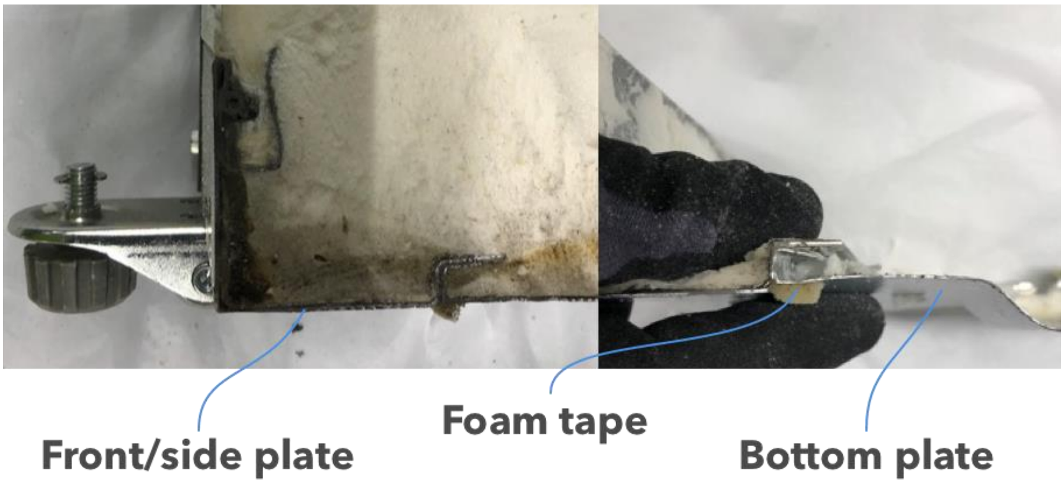


Figure 55: bottom plate and side plate connection with foam piece

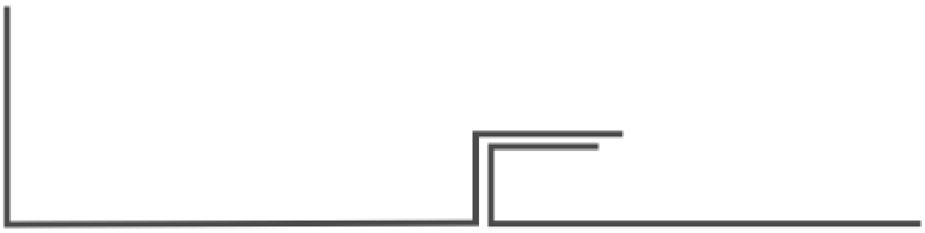


Figure 56: simplification of connection between plates

The latest interesting connection is at the back (Figure 57). Here a thinner walled metal plate was attached to the front/side piece (Figure 58 and Figure 59). This was one of the hardest connections to detach from each other. Also, a little piece of foam was used to make it foam tight in the corner (Figure 60).

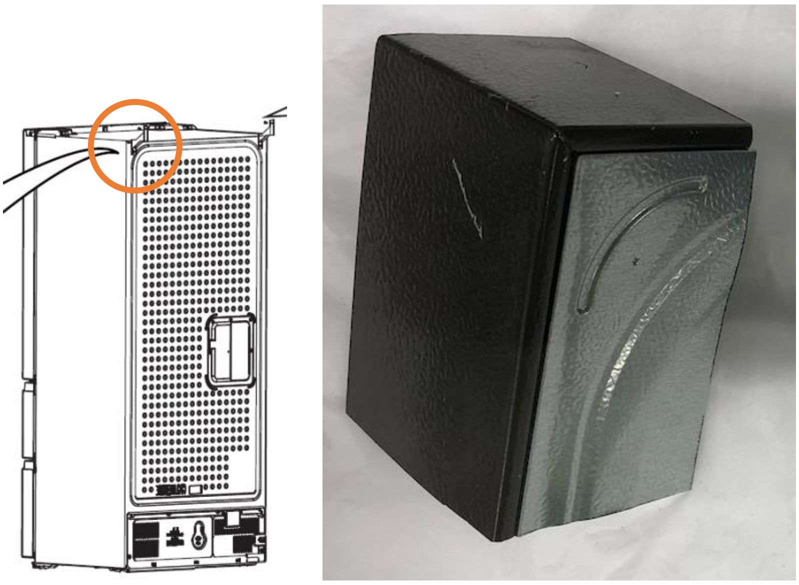


Figure 57: corner at back of IKEA fridge

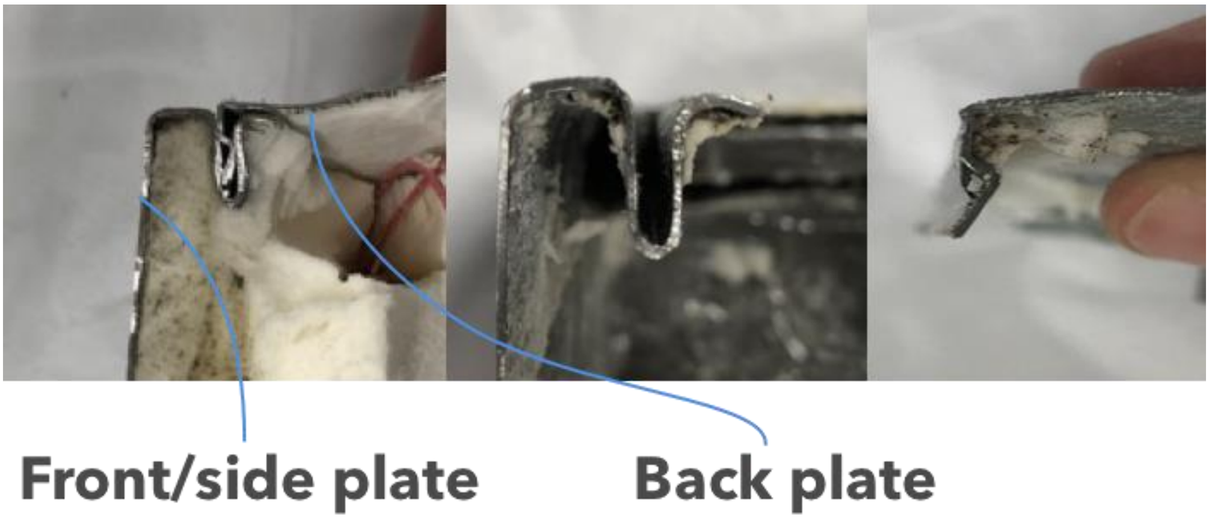


Figure 58: connection between front/side plate and back plate

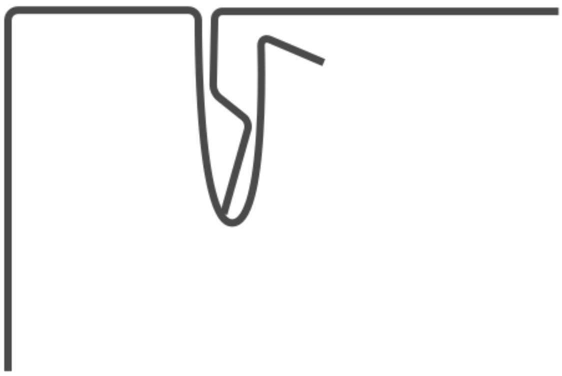


Figure 59: simplification on connection between plates

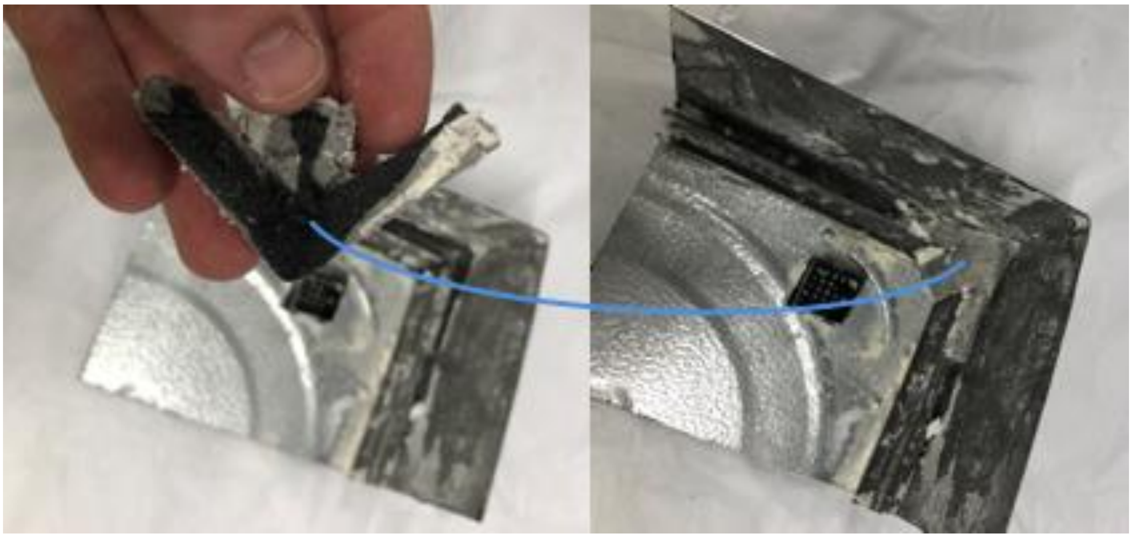


Figure 60: Foam piece in corner at the back

<u>Other interesting things to learn</u>
The first interesting learning point is the 'nutplate' they used. It was a simple plastic part with double sided tape on one side. It could be placed over a hole and would connect to the foam (Figure 61 and Figure 62).

Figure 61: placement of nutplate on metal wrapping

Figure 62: 'nutplate' with screw from IKEA fridge

One of the most mind-blowing learning point was the grommet used for the cable connection. Just a simple placement and twisting motion does it all (Figure 63, Figure 64 and Figure 65). No tape or hotmelt used like done at Thetford and cable (routing) could even be automated.

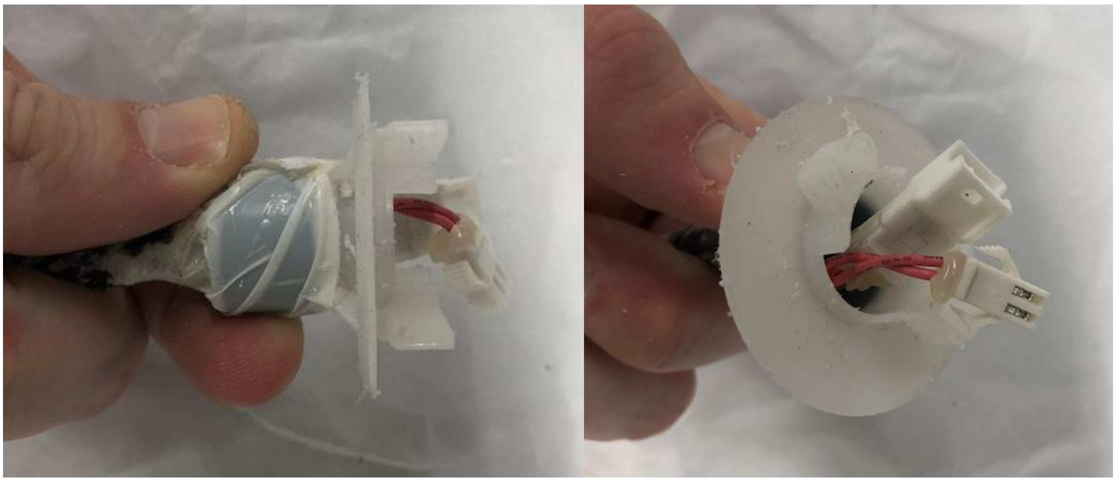


Figure 63: detail of cable grommet at IKEA fridge

Figure 64: the cable grommet is placed over the geometry of the hole

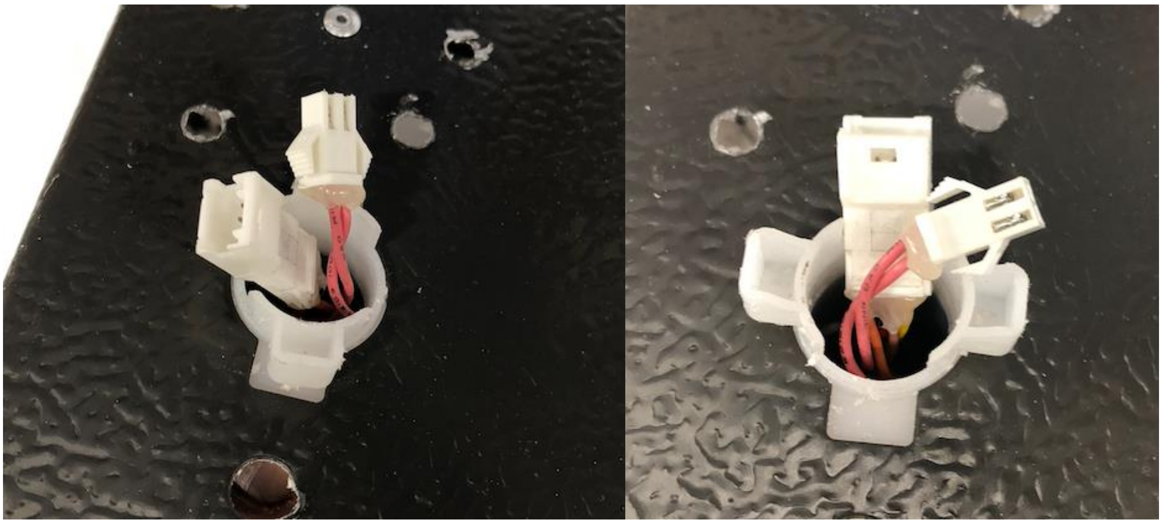


Figure 65: a simple twisting motion connects the cable to the wrapping

Did IKEA use tape? Yes, but not a lot and only 1 type: some kind of thing aluminium tape. They used tape on parts that were valuable like the display and to cover some holes. They did not use tape as Thetford did. More details can be found in the appendix.

Figure 66: examples of applications of tape in the IKEA fridge (the top image doesn't show a lot of tape, but originally the whole black part was covered in tape)

Domestic fridge design and automation approach

What are things that can be learned for the redesign from the market? A little study has been done which add a little to the direction for one-step foaming. Some talks have been conducted with suppliers and an internet research are the source of the information for the conclusions.

During a business meeting with Hennecke-OMS (the biggest supplier of foaming equipment in the world) the question was asked if they've seen a lot of automation in domestic fridge manufacturing. Their answer was peculiar as they said most fridges are still manually assembled but only some steps and the foaming equipment is automated. A similar answer came from people of the company BASF (a big foaming component supplier) which shows it is not a problem of Thetford.

Figure 67: fully automated foaming equipment at Haier (Plastics.gl, 2011)

An interesting lesson was the method of foaming applied at Thetford. They foam, what they call in industry 'door down' while it is more common to foam 'door up'. With 'door up' transport doesn't have to be done on a cosmetic side of the fridge. This is a big problem at the factory of Thetford where 20% of the large fridges and 11% of the beaker fridges goes to rework only for scratches and dents on the breaker.

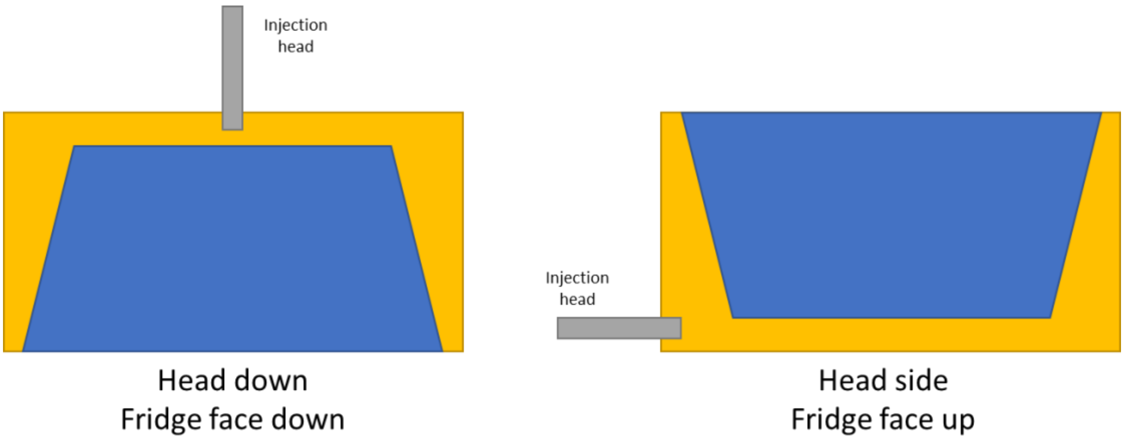


Figure 68: fridge orientation and injection position

Automation, however, is applied. There are examples of partial and almost fully automated domestic fridge factories. At Norcold small steps are automated as can be seen in Figure 69. More research could be done by Thetford to discover automations techniques for their fridge plant.


Figure 69: automation at Norcold

Present DFMA implementation and stakeholder engagement at Thetford

Understanding the present stakeholder engagement will be done from the perspective of the product engineer and other stakeholders. For this project the process engineer, production and automation engineer are the most important stakeholders. Different conclusions from interviews, talk and my role ass process engineer within Thetford are stated for the product engineer and stakeholders. The conclusions are focused on the two questions stated in the introduction of this chapter.

There are three types of projects for product engineers within Thetford:

1. Issue and Request Board (IRB) - Small improvements on present products which are mostly related to (certification problems, customer issues and safety).
2. Product lifecycle (PLC) projects – Present product portfolio improvement in the spirit of customer intimacy. A recent example is a new Australian fridge that is an enlargement of the existing 175L fridge to 208L. One-step foaming also falls within this category.
3. New product development (NPD) projects - New product development as in the spirit of product leadership. A recent example is the iNDUS smart system and probably others will come as well.

For this analysis the statements originate from the PLC and NPD projects. At Thetford these projects are split in the product engineering department by the PLC and NPD engineering manager. In Figure 70 the organogram of the important stakeholders for this project can be seen.

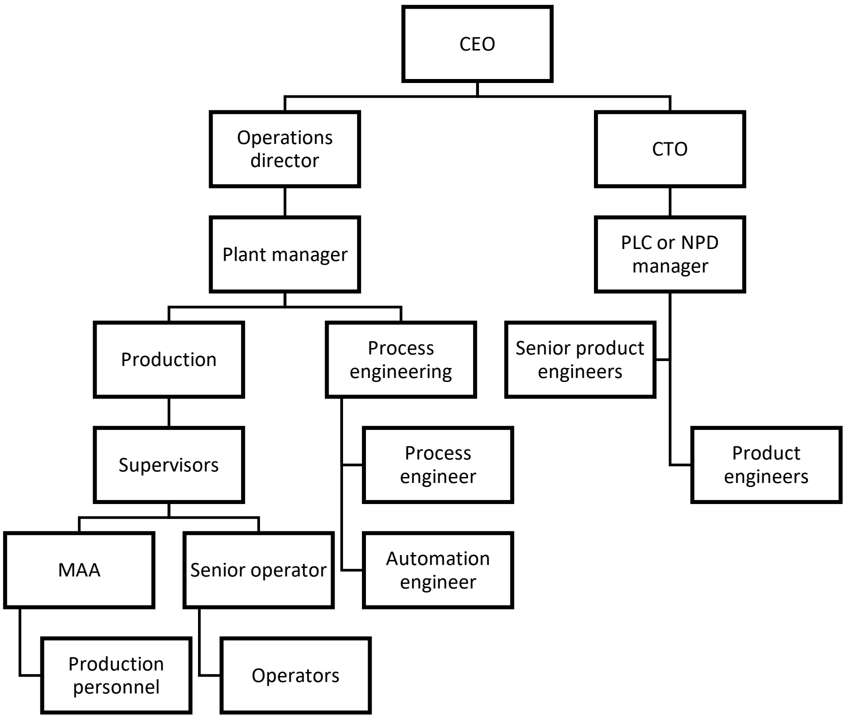


Figure 70: organogram of production, process engineering, automation engineer and product engineers

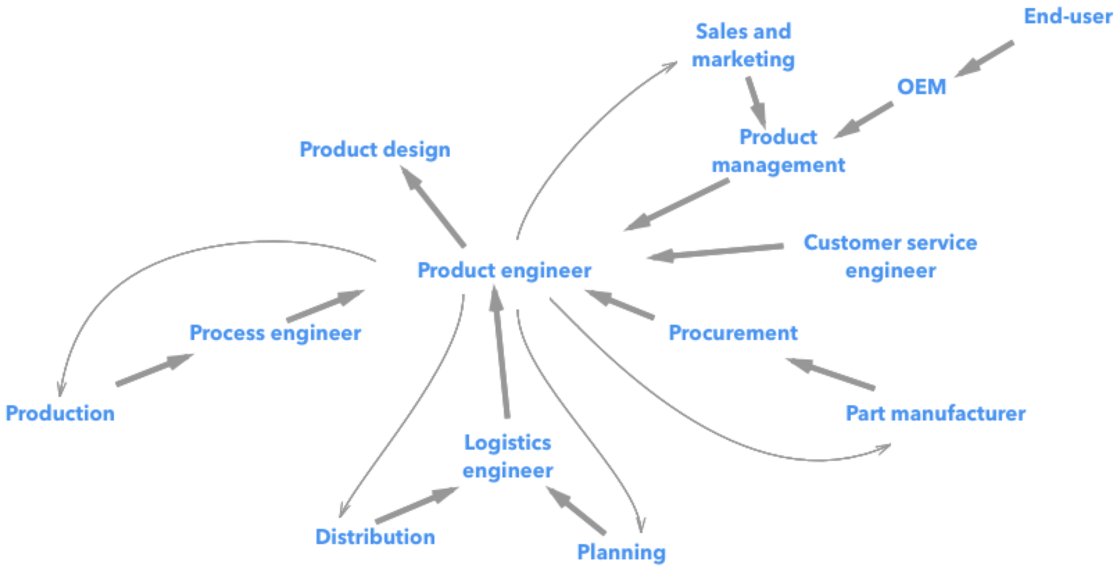


Figure 71: interconnectivity of various stakeholders of a product engineer

Implementation of DFMA with stakeholder engagement

It is the responsibility of the product engineer to engage DFMA and all the necessary stakeholders in the design process. Though there are good procedures on how to implement and use them within Thetford it is up to the product engineer to oversee it. So, what are some of these procedures?

1. *Requirements* are gathered and evaluated in the ITS. This is the sole responsibility of the product engineer to gather and evaluate them though other stakeholders can list their requirements in this shared document as well.

2. *Design reviews* are planned with process engineering until the moment where tooling is made for individual parts.
3. *Evaluation of designs* by senior product engineers before quotation release.

"It's in the character of the product engineers how to involve people" - project manager, so how do the procedures go in reality?

- "I was involved too late in the NPD project and alterations to the design which could ease assembly a lot weren't possible anymore." – process engineer
- "Why did they make this design so complex? If they would've done it like this it would've been much easier to assemble." – production worker
- "Why do we need to glue and screw so much?" – supervisor
- "Production workers don't want to work at that line anymore." – plant manager and PLC product engineer on a line with history of not involving production (workers) on the redesign of the product

Conclusions from the DFMA implementation at Thetford analysis are:

- The application level of DFMA is low thus resulting in unseen improvements which exert when the project is transferred from the project to the production (in project management theory this is explained as the transfer from project organization towards line operation).
- Implementation of DFMA at Thetford is human dependent and not procedure or method dependent. This is probably caused by a lot of younger product engineers that lack the real-world effects of their design choices.

Engagement of production

Is there value in engaging production into the product design process? For Thetford "It's the task of the process engineer to represent production in projects" – CTO. The process engineer needs to translate the product design into a production line design. Like the design reviews with the product engineer this is done through assembly reviews with production.

How does production presently experience their involvement?

- "We had a brainstorm together with engineers and put a lot of ideas on the table, but nothing was done with the ideas." – supervisor
- Production workers look up towards product and process engineers. They don't always feel appreciated by them because of their attitude. "Look there an engineer walks with his head raised through production. I'm really not going to talk to him." – operator
- "My relationship with production workers is quite good. I know them by name. They talk to me and are quite direct about their opinion." – PLC product engineer
- "I only once was at a meeting together with product and process engineers for an NPD project. This made us feel heard because otherwise it would've been much more difficult. This was a good method!" – supervisor
- "If it's good you don't hear them but you'll definitely know it when they dislike it" on reactions production personnel gives on product or line changes – MAA

Production is a very broad term and talk about a lot of people: supervisors (they are responsible for all the production personnel and operators at the factory), MAA ('meewerkend afdelings assistent', an assistant of the supervisor and responsible for a specific production line), operators (they operate machines like the foaming equipment), production personnel (mainly assembly workers that assemble the product). They all report to the plant manager just as the process engineer, this can be seen in Figure 70.

Conclusions from the engagement of production at Thetford analysis are:

- You get specific responses from production personnel depending on your relationship with them and how big the problem is in their perspective.
- The value on product design given by production personnel is limited to their perspective of the problem. They don't oversee the whole design space thus their response only involves a certain part of the design. This can be either very valuable or not.

Engagement of automation
Automation engineering is something quite new at Thetford BV. The first automation engineer was hired in 2018 and presently two automation engineers work at Thetford. The projects they've delivered are two robots, some small projects and a roadmap on automation. The goal for the coming years is to deliver at least 2 automation projects per year. These projects are all within the process engineering department and focused on the present product portfolio. As already concluded earlier, there is not an optimal implementation of DFMA. This is even bigger for automation because no thought was given on how this could be implemented in the product design. It could be said that automation is reactively done and not active.

All projects with product development don't have automation engineers in them. This doesn't mean automation is impossible but it could be much better when automation requirements were implemented earlier in the process. "If it is easy to assembly by a human it normally is by a robot as well" – automation engineer. For one-step foaming there is an opportunity to look at how automation can immediately be integrated into the design.

Conclusions
- Implementation of DFMA is not optimal at Thetford. Better implementation could result on higher assembly efficiency and easier automated assembly.
- Stakeholder engagement is human dependent. This is in the sense of relationship between product engineer with production and/or process engineering, but also related to the experience level.
- Product engineers have a huge influence on the design but have the least effect on what happens on the production floor in the sense of their design (see Figure 72).

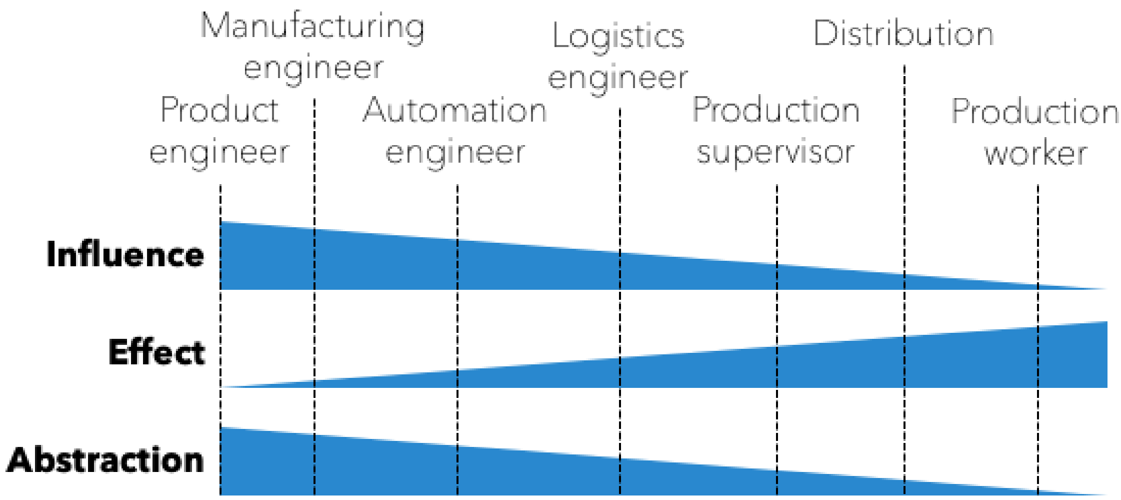


Figure 72: influence, effect and abstraction level on product design for various stakeholders

Conclusion: the main drivers for one-step foaming
The analysis is converged into 5 main drivers for the redesign that will enable one-step foaming. Each of these main drivers will be explained in this paragraph and they will be used in the concept chapter to choose the right concept.

The 5 main drivers:
1. +20% output with -20% floor space
2. Same customer experience
3. Cost neutral
4. Increased production worker value
5. Future proof

Implemented one-step foaming

+20% output with -20% floor space
Increased efficiency, decreased human dependency and more floor space are necessary for Thetford to remain competitive and optimally serve the customers. The OEE of the foaming equipment showed there was still a possibility to increase the output of the factory by 20%. Stopping with the second foaming step with eliminating the handling allows for at least 20% less utilization of floor space. The handling could be eliminated by effectively applying the design rules derived from the DFMA.

Same customer experience
The customer shouldn't notice this internal manufacturing change. This means the following:
- Cosmetic areas and therefore final assembly remain equal
- Same dimensions
- Performance needs to remain equal or improve
- No increase in weight (with the new encasement regulation in mind)

Cost neutral
The customer isn't going to pay more for a fridge after one-step foaming is introduced. The benefits (reduction in FTE and increased output) should therefore equal out to the rise in cost price and investments. For this project this calculation could be different because new encasement regulation can result in a different comparison because the expected design

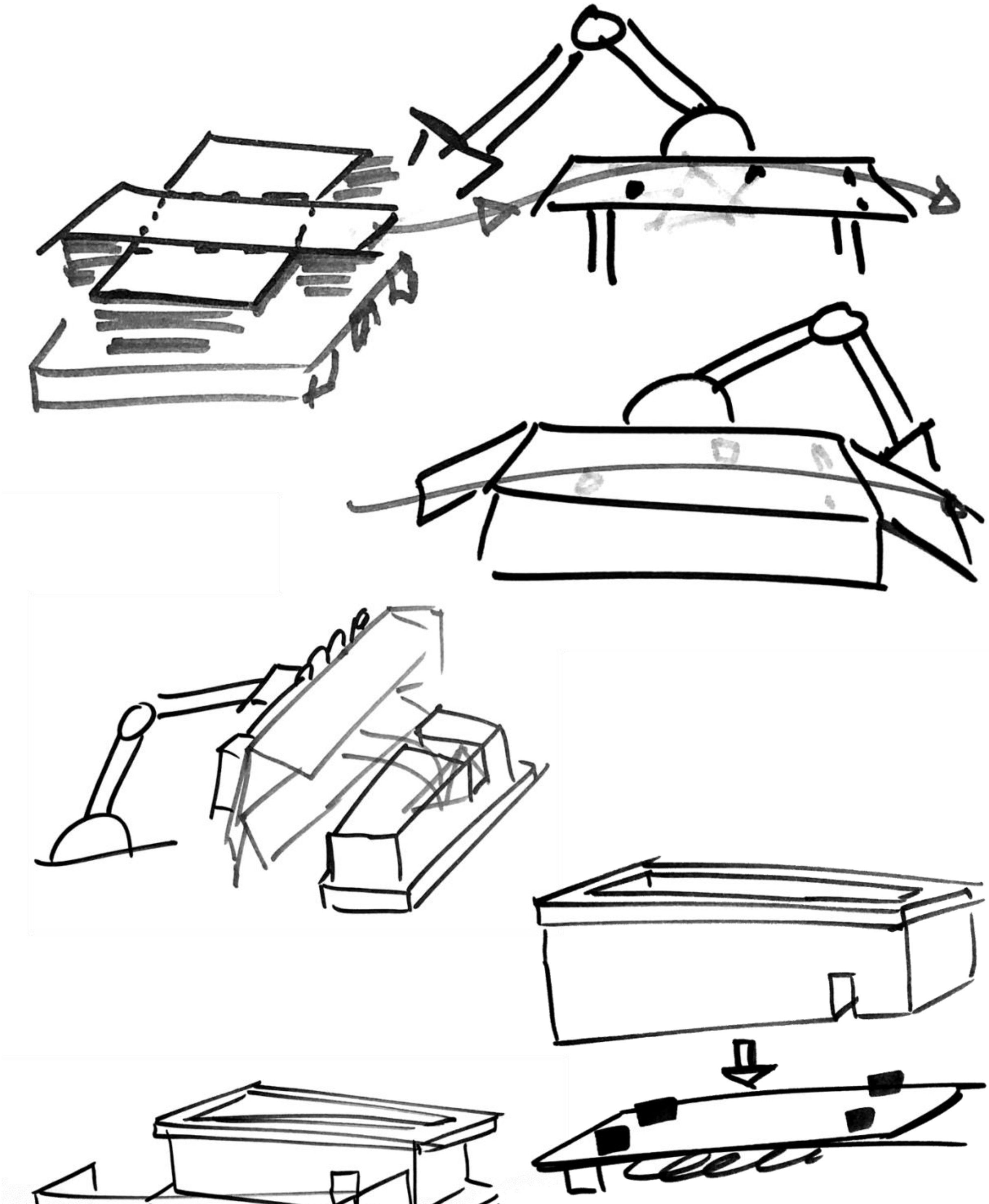
Increase production worker value through one-step foaming
Production workers add a lot of value to the product, so how can they add more? They do a lot of work that has little value (like taping) as shown in the DFMA analysis. This is partly in line with decreasing human dependency because with increasing value less people are necessary, and their work has more direct addition to the product value.

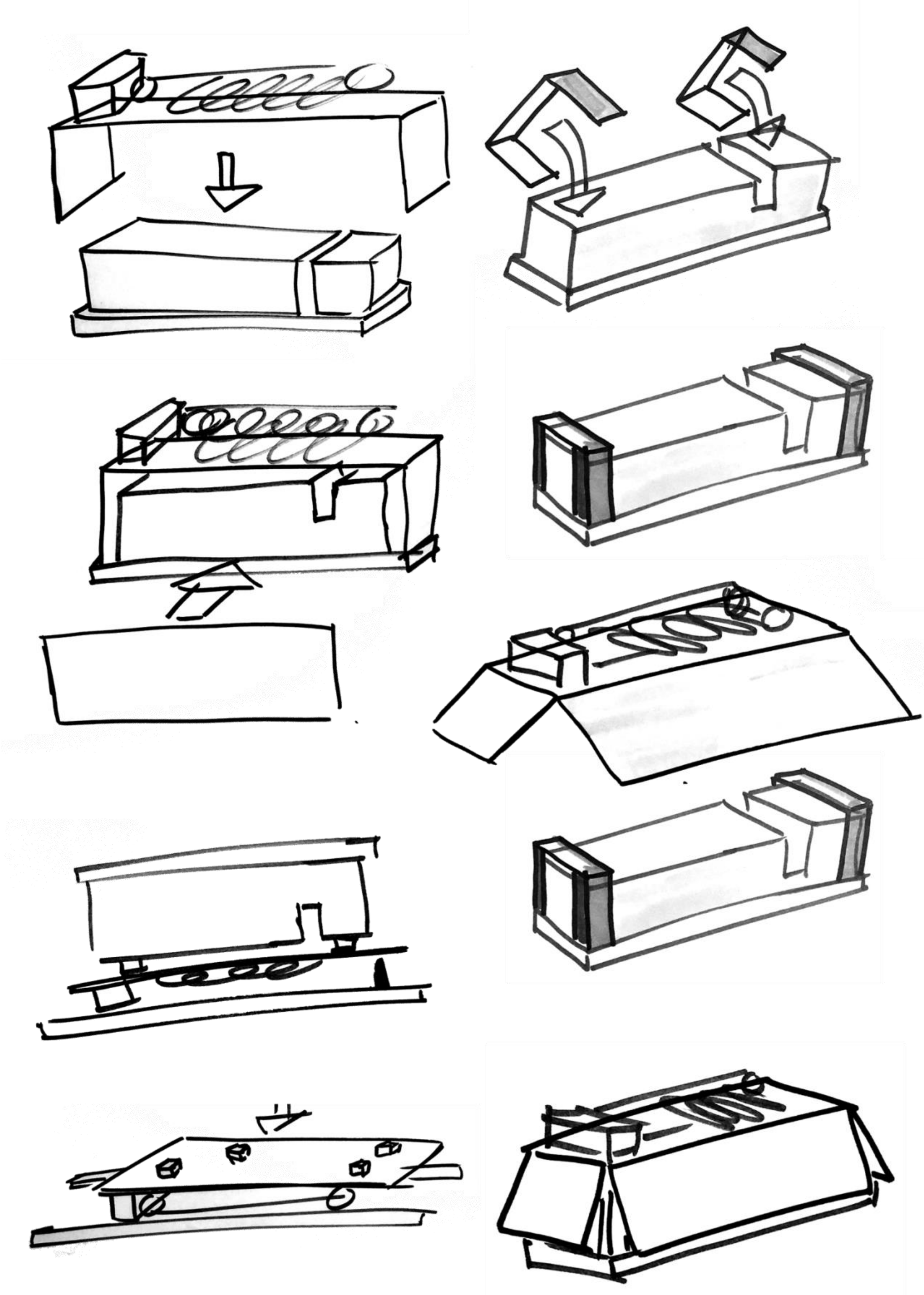
In the analysis simple design principles were generated that help fulfill this driver:
1. Don't use tape!
2. Don't allow for double work!
3. Don't use nutplates (when metal is around)
4. Don't assume it will only be assembled by humans
5. Hotmelt helps in cases of emergency only

But they won't necessarily allow for one-step foaming. Other requirements are necessary as shown in the feasibility study. These requirements are:
1. Pre-foam assembly needs to be stable enough to be foamed
2. Counteract foaming force (at essential locations)
3. Assembly needs to allow for proper access to assemble all parts (especially the wrapper)

Future proof
The future, as seen by the new encasement regulation, is nearby. There are a few new things the new product design needs to incorporate. Those are:
- Implement encasement regulation
- Implement design requirements to make recycling easier
- Optimize the design to allow for (full) automation by engaging automation engineering
- Implementation of one-step foaming on other products like large fridge and Bounty.

Ideation





Concepts

Three concepts were created from the design space generated by the context and analysis. Each of these concepts has unique aspect but that doesn't mean certain design choices can be applied to other concepts. The goal of each concept is to open discussion into possibilities for Thetford. So what are the main characteristics of each concept?

- **Concept 1: business as usual** – a small iteration on the present design and the one from the feasibility study of one-step foaming. The idea is that this concept can be applied quickly without a lot of change on equipment and design.
- **Concept 2: flip the fridge** – foaming door up solves multiple problems like no transport on a cosmetic side, no additional rotation and better stabilization of the pre-foam assembly for one-step foaming.
- **Concept 3: N5000 series** – The present N4000 series can have multiple upgrades, so why not approach it holistically? Allowing for fundamental redesign can solve more than just one-step foaming thus increasing the total value even more by the redesign.

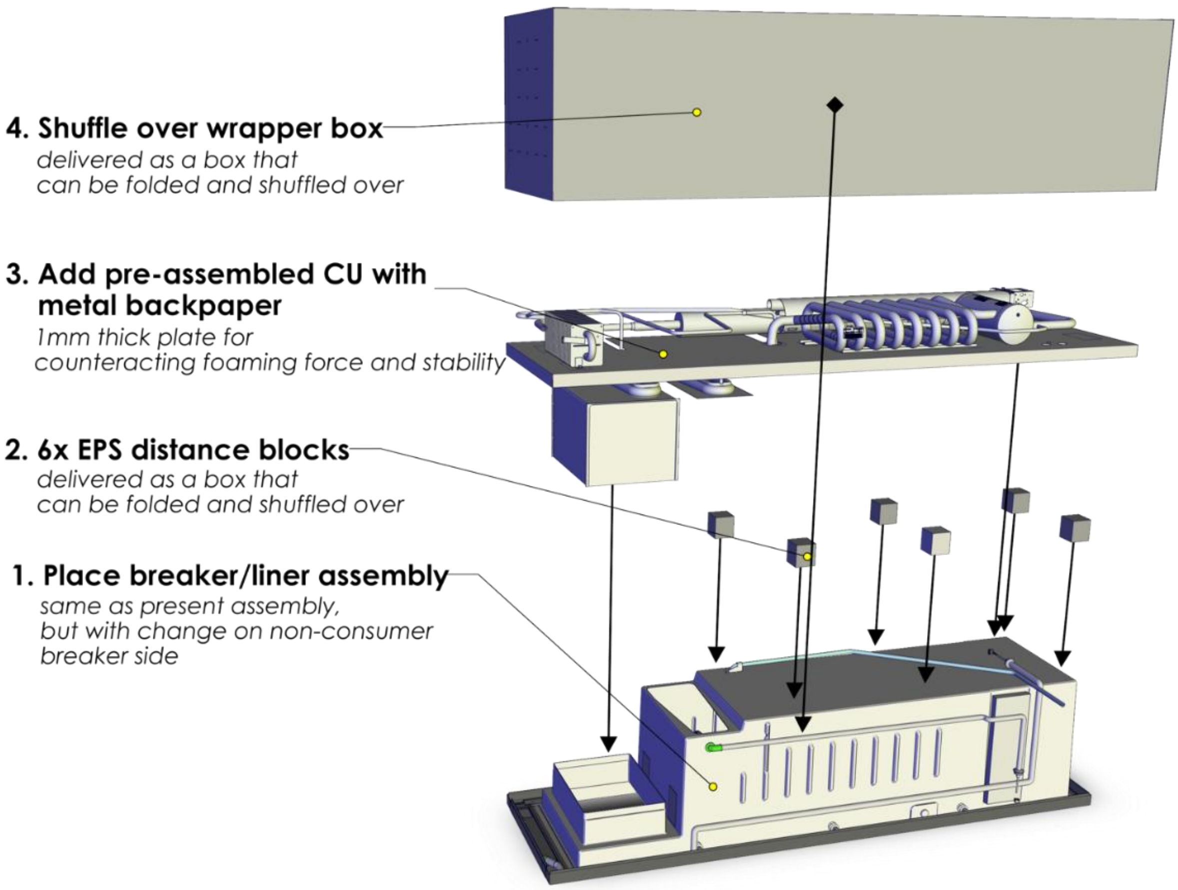


Figure 73: exploded view of design beaker for one-step foaming

Concept 1 – business as usual

The initial design for one-step foaming basically needed one change to make it much easier for one-step foaming: move the wrapper from inside the breaker to the outside. This would still require a lot of tape to make it foam tight between wrapper & breaker and wrapper & backplate. This concept strives to look one step further than just a little improvement but to also incorporate the focus on increasing value adding work.

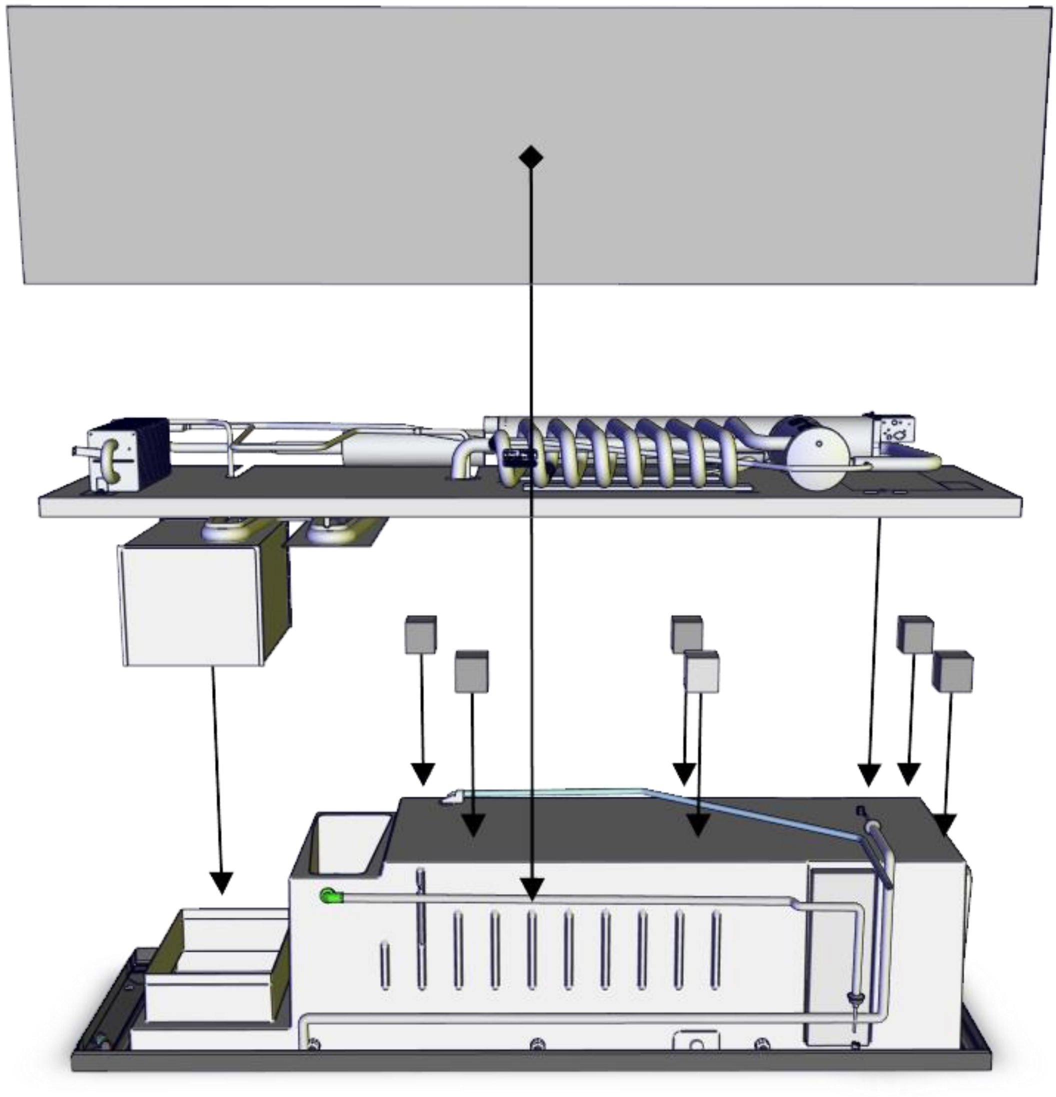


Figure 74: exploded view concept 1

Figure 74 shows the exploded view and **Error! Reference source not found.** shows a general overview of assembly steps. So, what are the major changes that make this design? In Table 11 the design changes to product and machinery are noted, they will be individually discussed in this chapter.

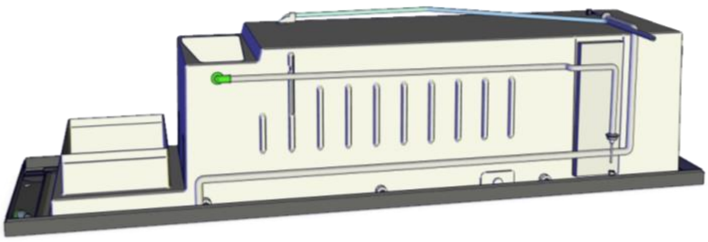
Table 11: notable changed elements concept 1

Category	Element	Change and approach on element
Product design	Breaker	Geometry added to allow for tapeless assembly of wrapper on breaker (except corners).
	Back plate	Metal plating as in one-step foaming feasibility with added geometry to allow for tapeless assembly of wrapper
	Wrapper design	One piece as a box that can be folded over, so reduction from 4 to 1 part.
	Wrapper material	Multilayer wrapper, some changes need to be made on breaker and backplate to allow for sheet metal.
Machinery design	Foaming equipment	Only change top plate, no other changes need to be made
Assembly	Joining CU with backplate	Multiple options possible to join: with nutplates, with screwing bus, directly unto backplate.
Requirements	Stability	Placement of EPS blocks already used because of price and possibility to automate
	Use of tape and hotmelt	Elimination of duct tape, but internally masking tape still needs to be used. No elimination of hotmelt.
	Foam tightness	Only corners form a risk of leakage as the new plate at the CU. Tubing CU needs to be taped on backplate.
	Dimensions	The design is made to allow for movement of the wrapper respective to the breaker in the foaming equipment. It is expected that the liner will deform which causes the depth of the fridge to be out-of-spec. This will solve the issue.

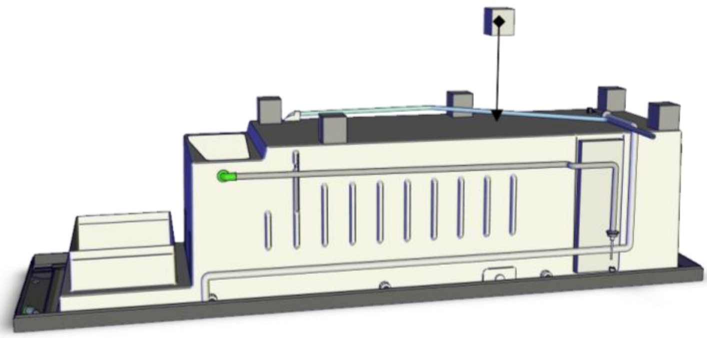
Assembly steps concept 1

The assembly consists out of 4 main steps as can be seen in **Error! Reference source not found.**. However, these steps contain far more detail than can been seen in the following steps. These are explained in Figure 75.

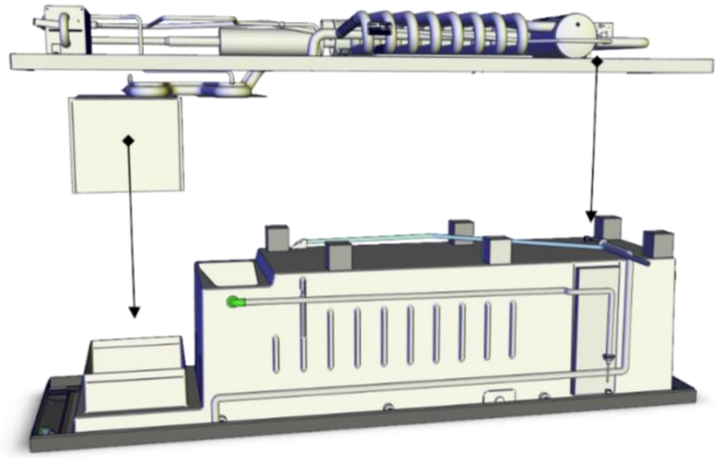
1 Prepared breaker-liner as presently done with cables, hotmelt, etc. Only redesign in breaker.



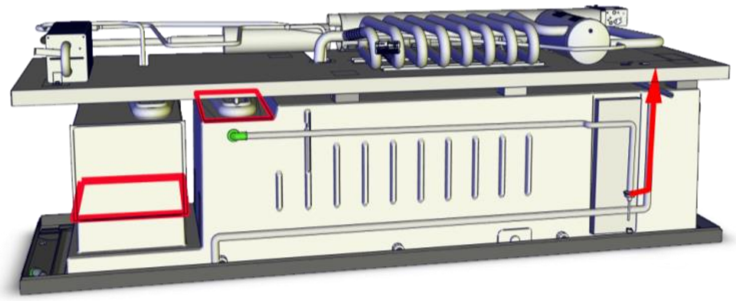
2 Place 6 EPS-blocks on designated locations



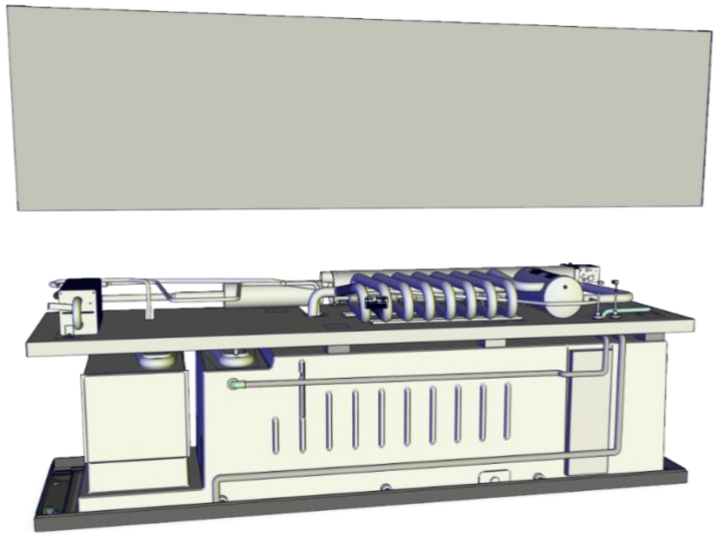
3 Place CU sub assembly with freezer attached.



4 Tape the freezer and CU plate with masking tape, join the cables with the backplate



5 Slide over wrapper box and join in geometry of backplate and then breaker. Tape corners if necessary or use foaming tape.



6 Tape top location of CU tubing. Now the assembly is ready for foaming.

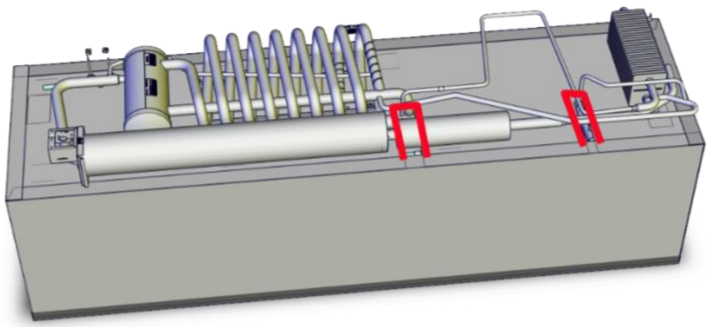


Figure 75: assembly steps of concept 1

Notable product and machinery design choices for concept 1

There are a couple of detail that are fundamental for this design.

1. **Wrapper box** - just one wrapper piece instead of 4. The wrapper is already prepared by the supplier to be easily prepared for pre-foam assembly.
2. **Insertion of wrapper into backplate** – No tape should be necessary to assembly the backplate with the wrapper.
3. **Insertion of wrapper into breaker** – Additional geometry is added to the breaker to allow for natural assembly.
4. **Free movement during foaming** – the liner will deform because of the added weight by the CU. By allowing movement by the design in the mold the required dimensions and form can still be achieved.
5. **Necessary machinery changes** – only the top plate needs to change to allow for enough support of the assembly in the mold

The wrapper box

The choice here is to go from 4 pieces to one. Only 1 pallet contains all the necessary wrappers, already connected as a box. A couple of folds define the box as will be put over the assembly in step 5 of the previous paragraph.

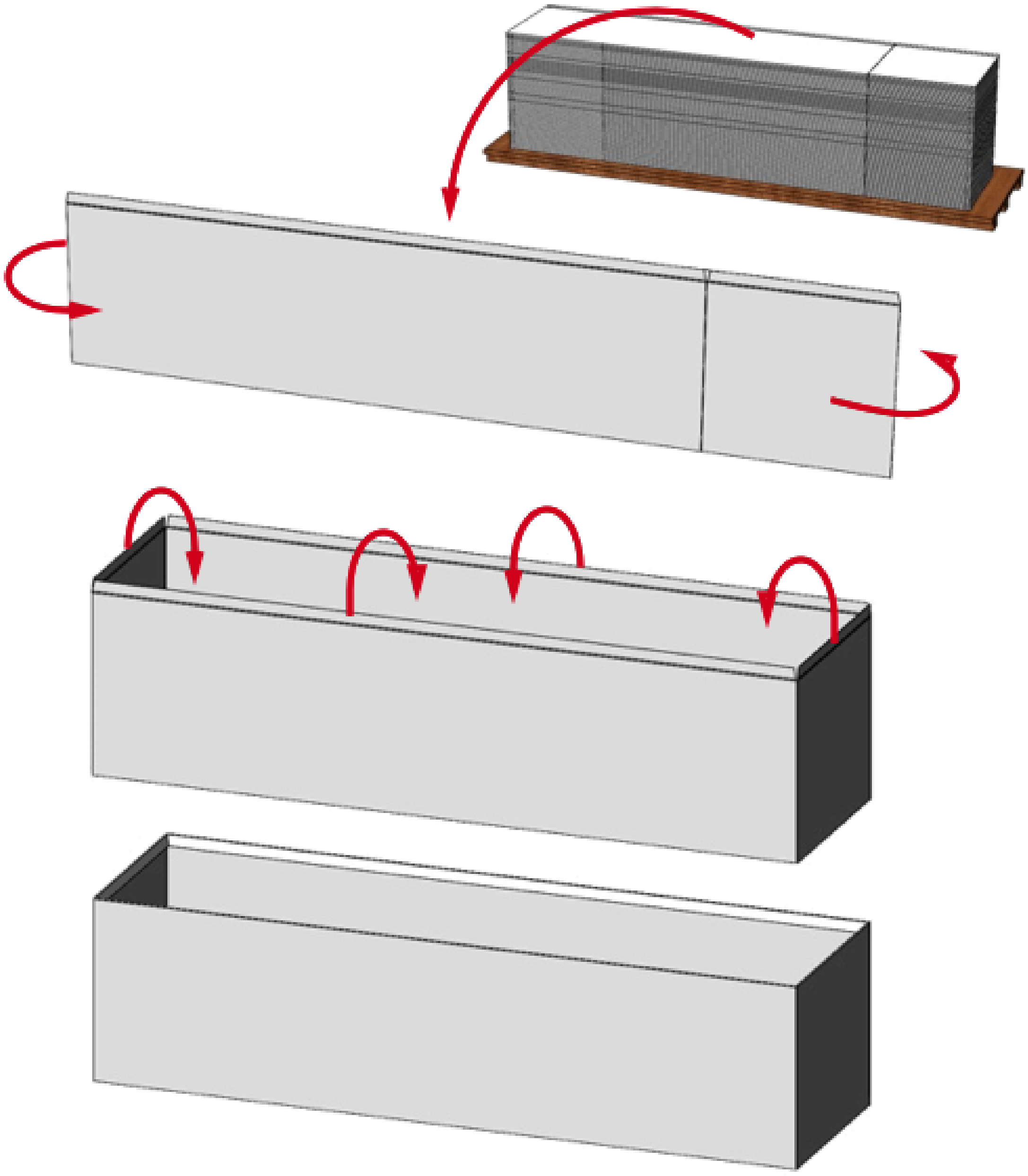


Figure 76: design of the wrapper box

Inserting the wrapper into the backplate

Geometry is designed in the backplate to allow for structural strength but also to allow for tapeless assembly. During the assembly as defined in step 5 of concept 1 the wrapper can be slided into the geometry (Figure 78).

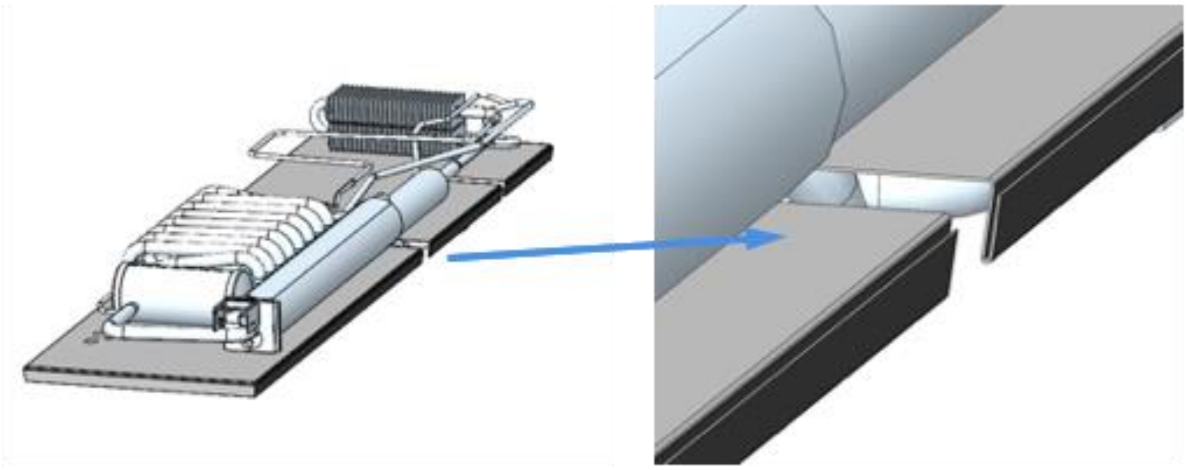


Figure 77: detail of fold in backplate concept 1

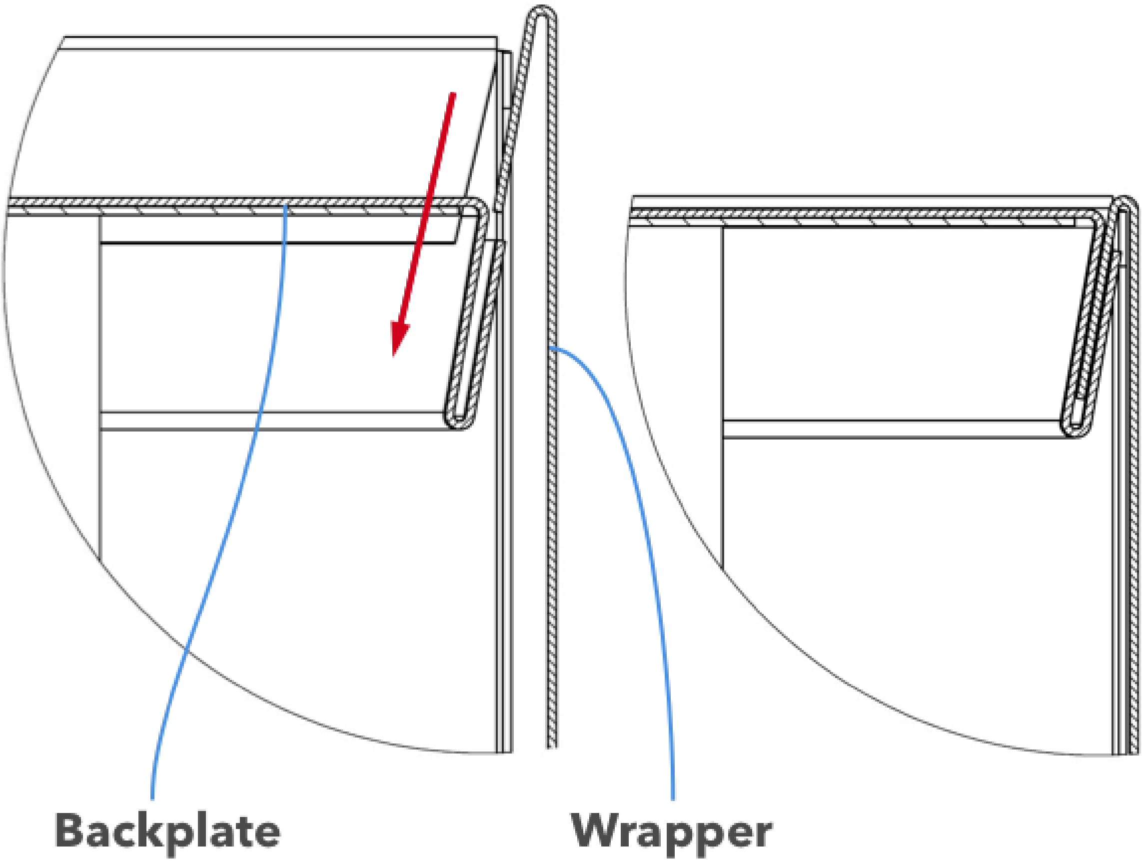


Figure 78: method of insertion of wrapper into backplate as in assembly step 5 concept 1

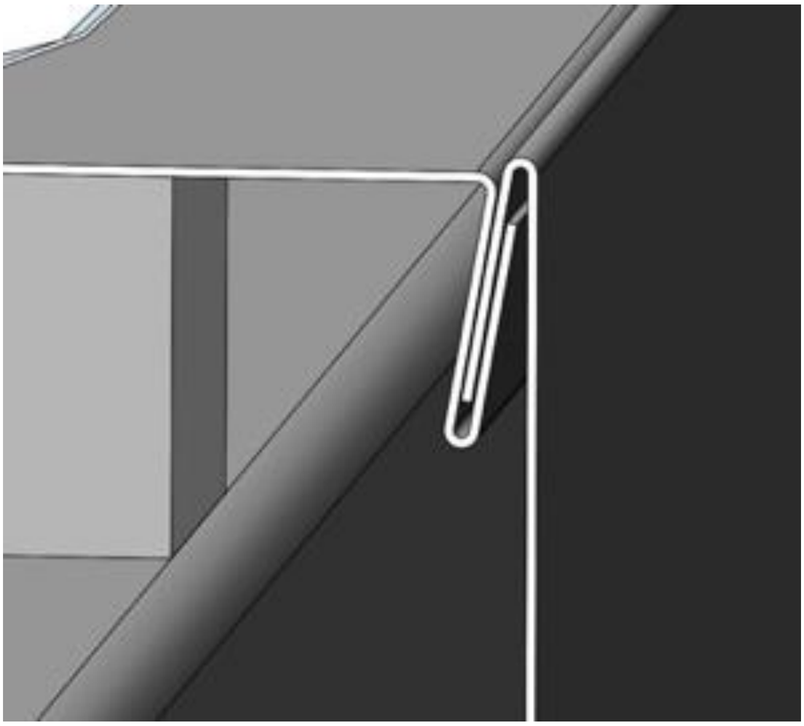


Figure 79: joined wrapper and backplate concept 1

<u>Inserting the wrapper into the breaker</u>

Though this concept was made to be implanted easily, this design is probably not. Concept 1 shows an even easier method. The reason this model still has this geometry is because of the big potential it has from validation (see Figure 80). With a simple slide in motion the wrapper is joined with the breaker without any tape (Figure 82 and Figure 83). The geometry of the foaming test is adjusted to allow for easier assembly.

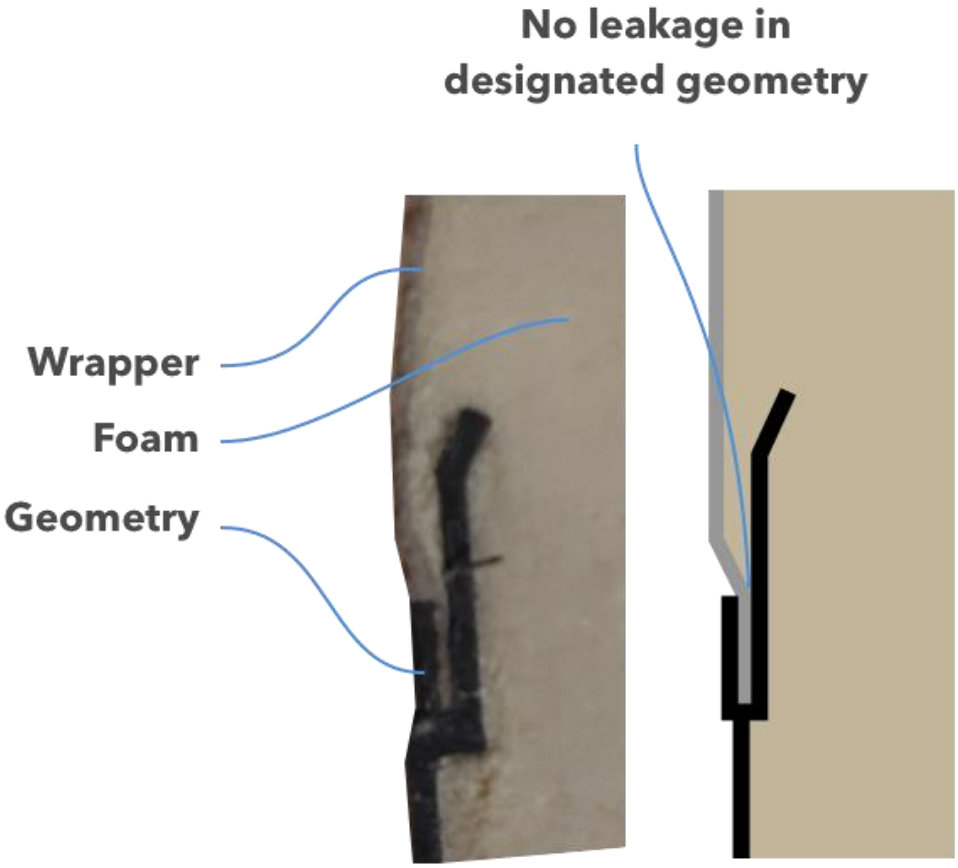
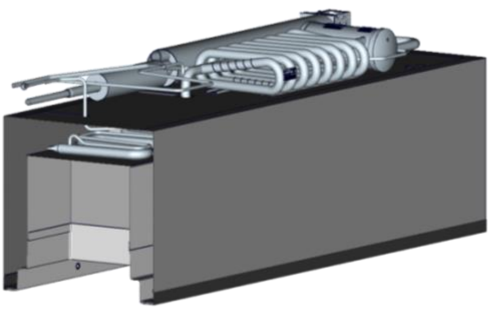


Figure 80: foaming test with similar geometry (left sample detail and left visualization)

Figure 81: the added geometry goes around the breaker



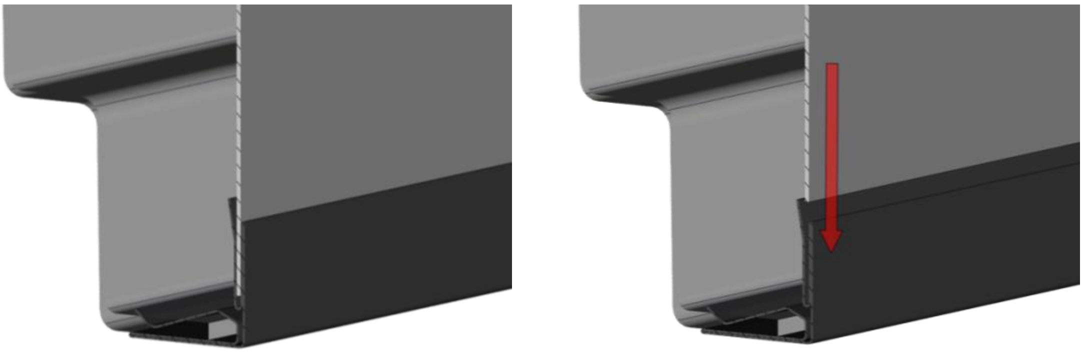


Figure 82: detail on breaker geometry change with wrapper insertion

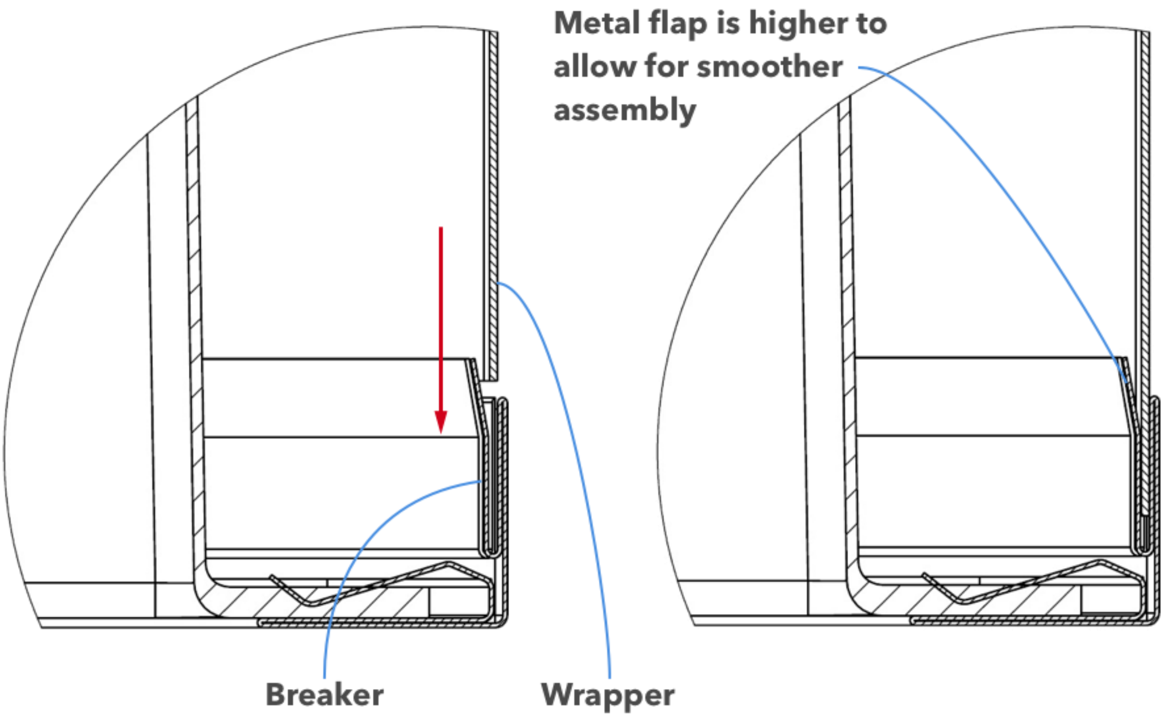


Figure 83: detail on insertion of wrapper into breaker concept 1

<u>Allowance of movement</u>

The liner will deform when putting the CU on the liner with the EPS blocks. Movement is therefore designed to prevent the final shape to be out-of-spec. The movement will occur in the mold when the contra form generates support on the EPS blocks and while foaming when all the walls are pressurized into shape. The two connections of the wrappers allow for the necessary movement.

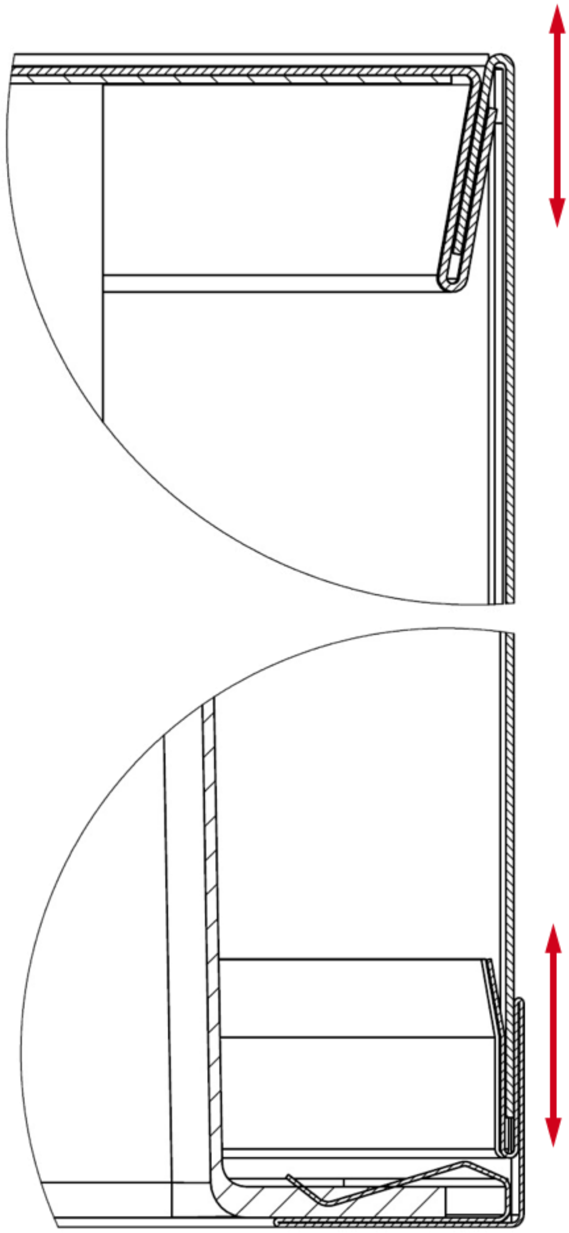


Figure 84: allowing movement in the mold through design

Machinery changes

The only change to the machinery is a new top plate. All other geometry remains the same or is changed in a way no new investments need to be made. An impression of how the new top plate needs to be shaped is seen in Figure 86.

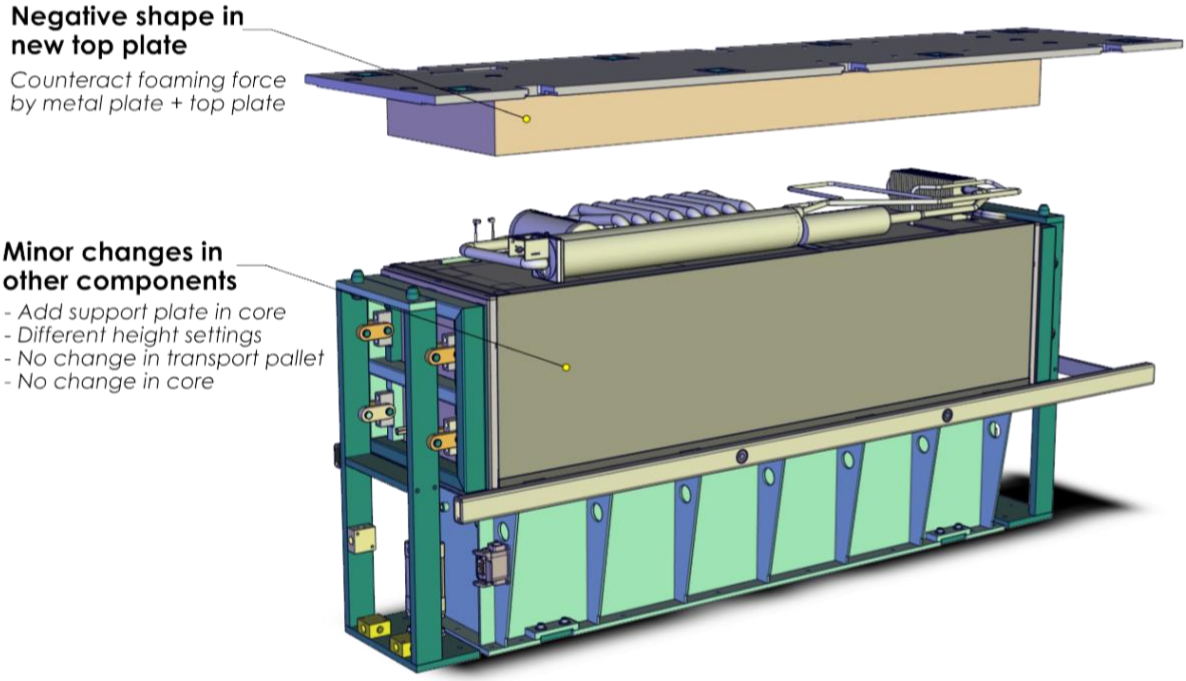


Figure 85: mold changes for concept 1

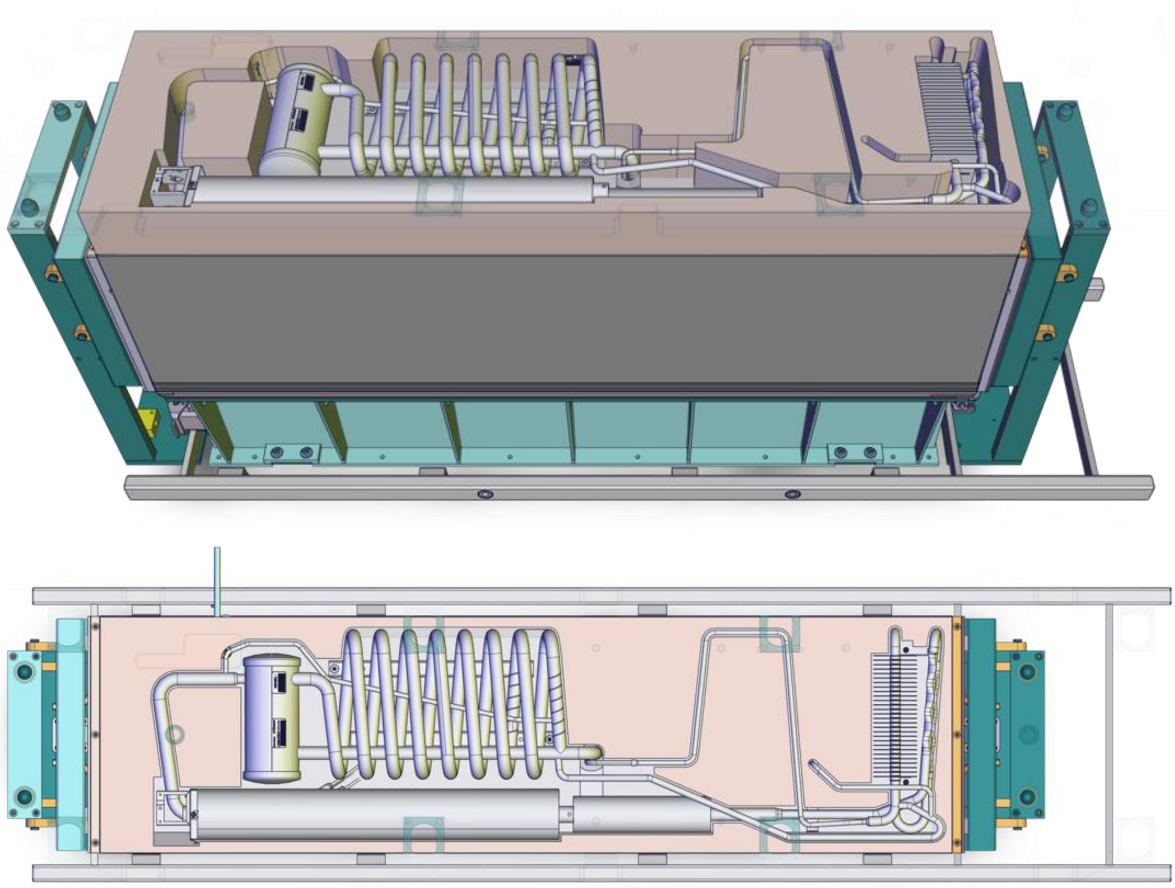


Figure 86: details on contra-shape in top plate of mold

Concept 2 – flipped fridge

What if the fridge is flipped in the foaming machine? No additional flipping is necessary at pre-foam and final-assembly and the assembly is better stabilized at pre-foam. This concept tends to explore how to allow for a fridge that is flipped as can be seen in Figure 87. In Table 1 the notable changes are mentioned.

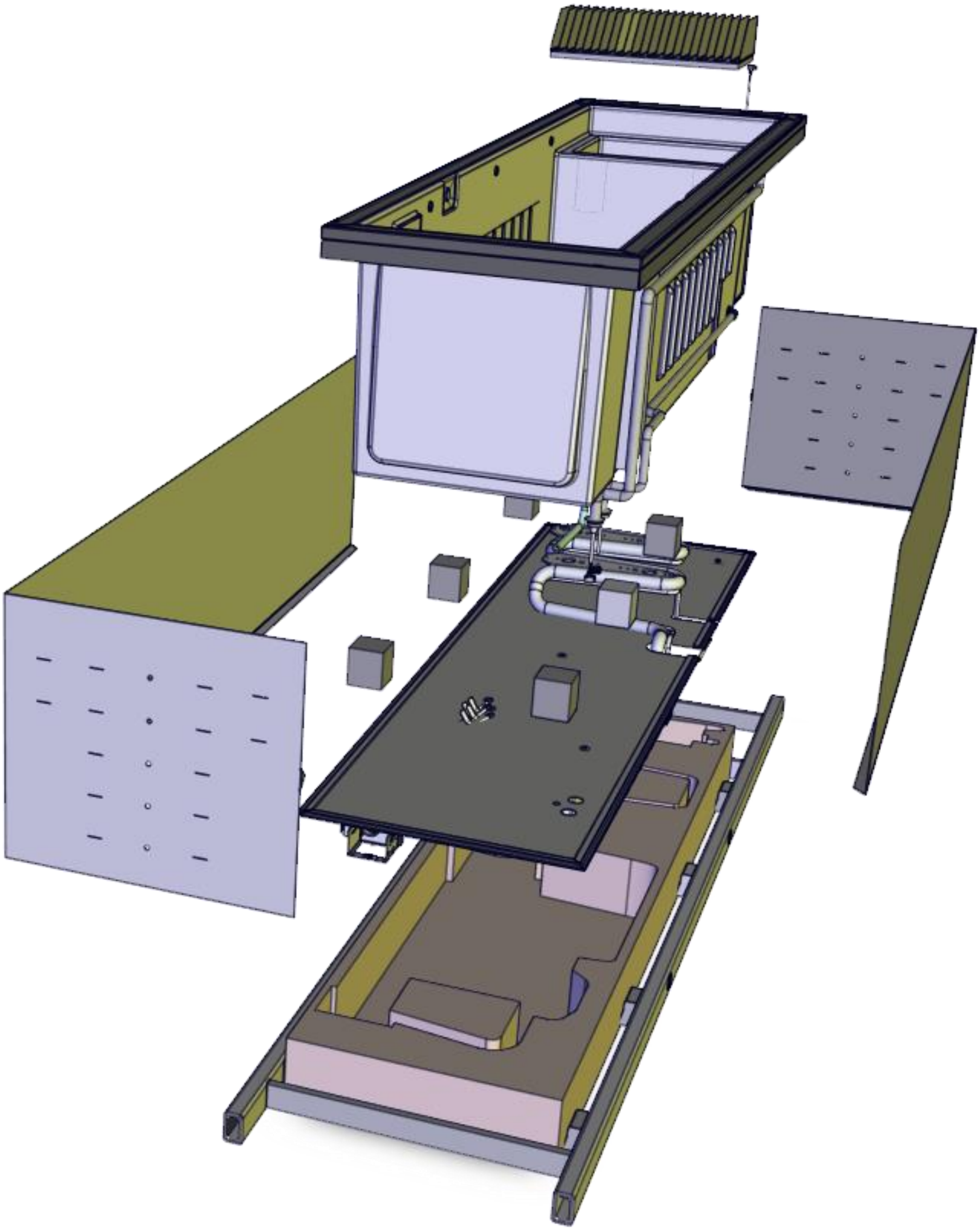


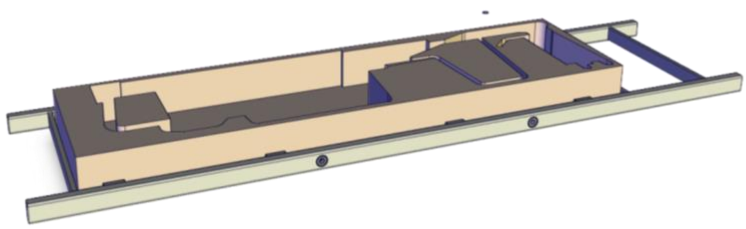
Figure 87: exploded view concept 2

Table 12: notable changed elements for concept 2

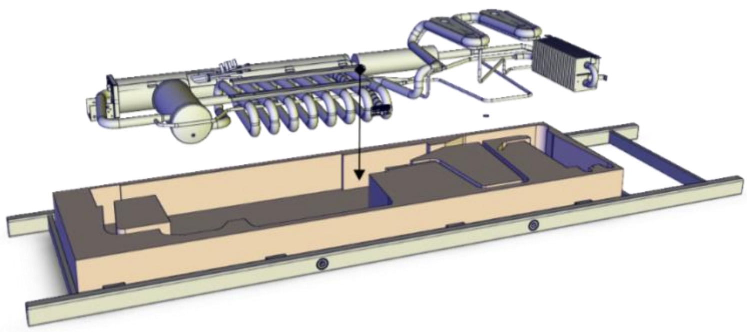
Category	Element	Change and approach on element
Product design	Breaker	Geometry added to allow for tapeless assembly of wrapper on breaker (except corners).
	Back plate	Metal plating as in one-step foaming feasibility with added geometry to allow for tapeless assembly of wrapper
	Wrapper design	Two pieces that are slided onto breaker/back plate from the side
	Wrapper material	Either multilayer or metal, small geometry changes necessary that are rather small.
	CU tubing	CU tubing is changed a bit to allow for less tape to be used and to allow for easier assembly on one side
Machinery design	Foaming equipment	Impact is high because the principle of foaming needs to change from door down to door up. This means new movement of head, change core and mold.
	Transport pallet	Redesign of all 20 transport pallets to allow for support of CU in pallet instead of foaming jig.
	Core	The core needs an additional cut-out for the fins that are attached earlier. This doesn't have effect on moving parts in the core.
Assembly	Joining CU with backplate	Screw backplate from inside to outside. Screw thread and connection strength comes from CU instead of backplate.
	Fins placement	Fins can already be placed beforehand instead of final assembly reducing handling.
Requirements	Stability	Flip the fridge causes the mass middle point to be very low. Not the CU needs to be supported but the lightweight liner/breaker assy. EPS blocks are used again as spacer.
	Use of tape and hotmelt	Elimination of duct tape, but internally masking tape still needs to be used. No elimination of hotmelt.
	Foam tightness	Only corners form a risk of leakage as the new plate at the CU. Tubing CU needs to be taped on backplate.
	Dimensions	The design is made to allow for movement of the wrapper respective to the breaker in the foaming equipment.

Assembly steps concept 2

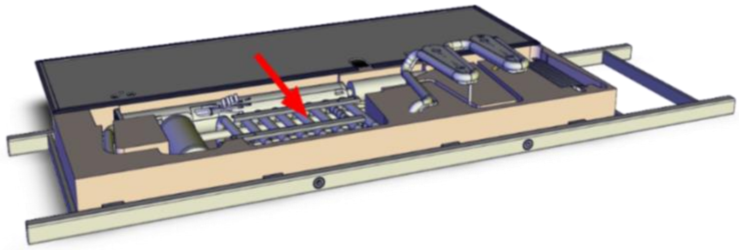
1 The pallet is located at the workstation. The pallet already contains geometry for the CU to fit in.



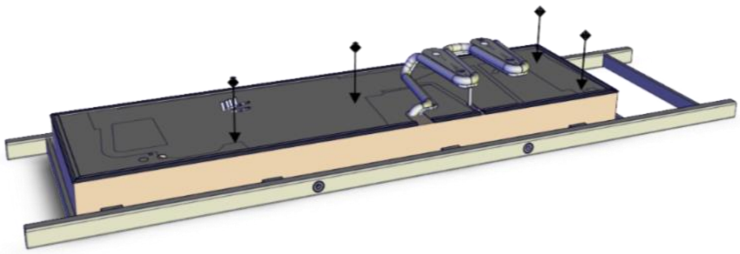
2 The CU is placed in the pallet.



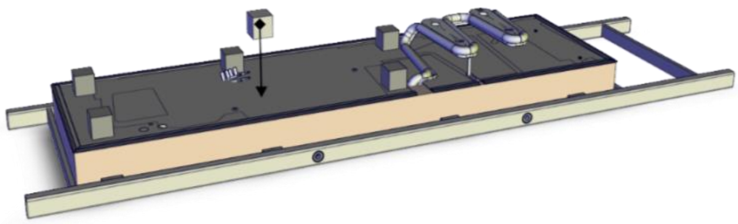
3 The backplate is sliced over the CU



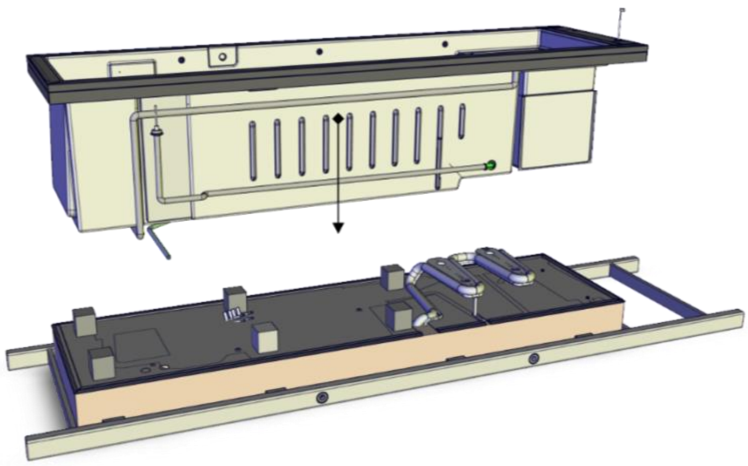
4 The CU is screwed unto the backplate from the inside out with the required screws



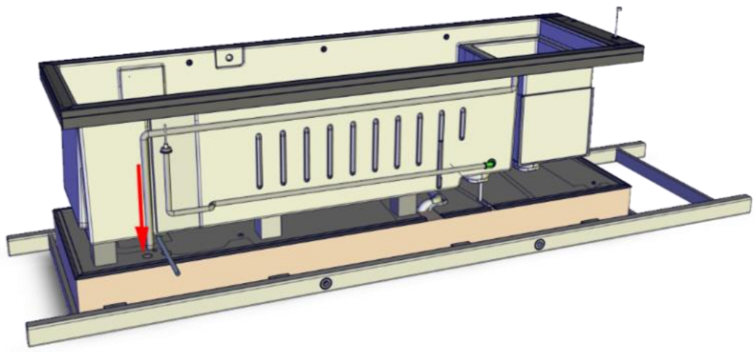
5 EPS blocks are placed at designated locations as distancer



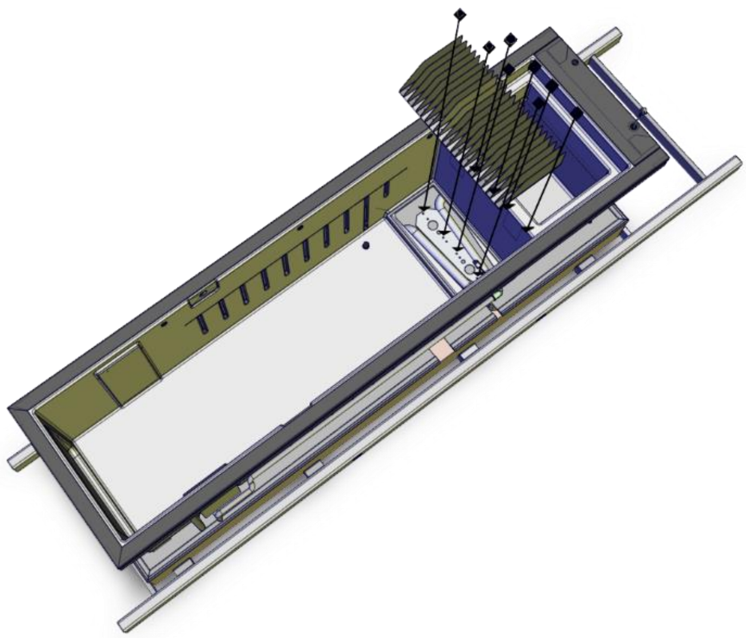
6 The breaker/liner sub-assembly is placed. This is the same assembly as is presently made including the attachment of the freezer.



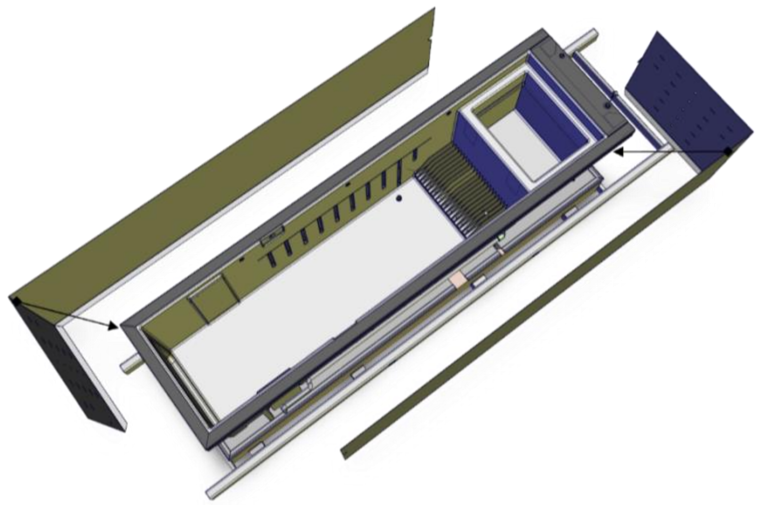
7 Cables are connected and joined with hotmelt (if necessary) from the inside out.



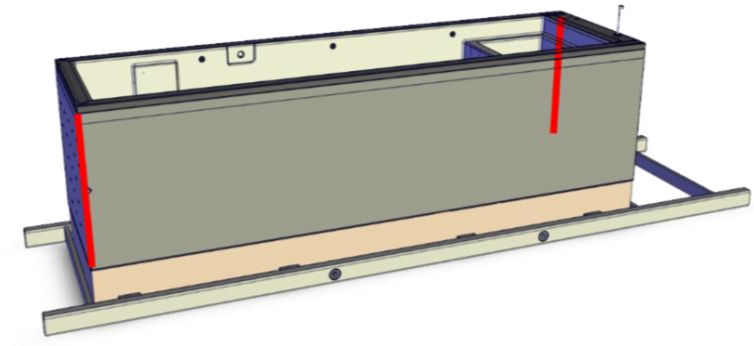
8 The fins and CU are screwed with special screws (they need to withstand temperature differences). The fins contain a special foam to make it foam tight.



9 The 2 identical wrapper pieces can be slided unto the backplate.



10 The wrappers either need to be taped (when multilayer) or geometry needs to be added when made out of sheet metal.



11 The transport pallet can now go to the foaming equipment, and it is foamed door up.

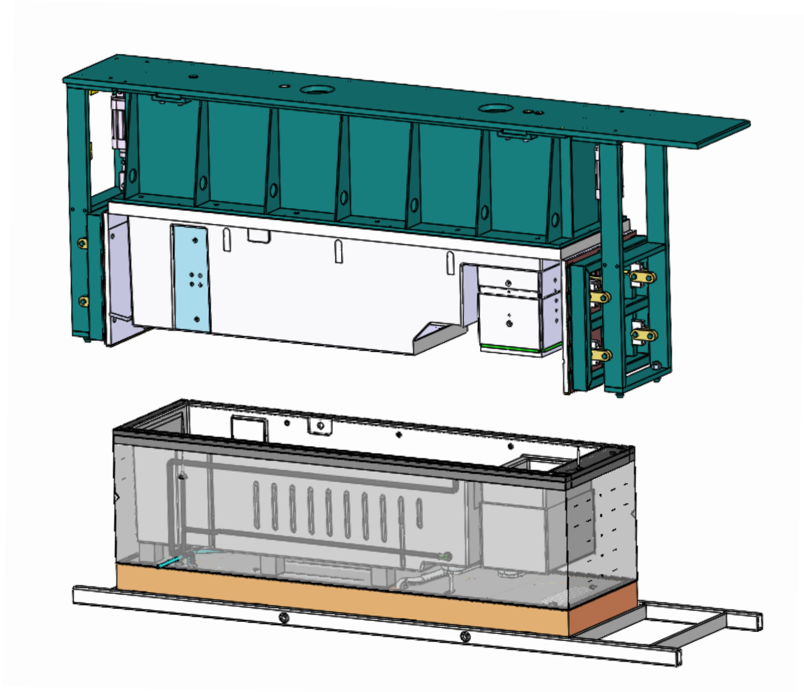


Figure 88: assembly steps of concept 2

Notable product and machinery design choices for concept 2

There are a couple of detail that are fundamental for this design.

1. **Connection wrapper to breaker** – a different technique is used that concept 1, a dry connection. This technique is used with the foaming of doors but not applied yet at cabinet foaming.
2. **Connection wrapper to backplate** – a similar design as in concept 1 but the orientation is different
3. **Connection fins to liner** – the fins are connection earlier in the process, how to make this piece foam tight?
4. **Cutout in core** – a cutout needs to be made in the core. How does it look like and what is the effect?
5. **Changed tubing CU** – a little change on the CU can ease the assembly and reduce tape necessary to avoid foaming leakeges

Connection wrapper and breaker

A different joining method is made for this concept between the breaker and the wrapper. The idea came from the methods used at door foaming. Here the mold is used to make a cold connection between certain parts. Cold connection means no tape or specific geometry, just two plates connected to each other.

Figure 90 shows the initial assembly done at pre-foam assembly between the two parts. In Figure 91 this connection is finalized in the mold by the pressure applied.

Figure 89: detail on connection breaker and wrapper concept 2

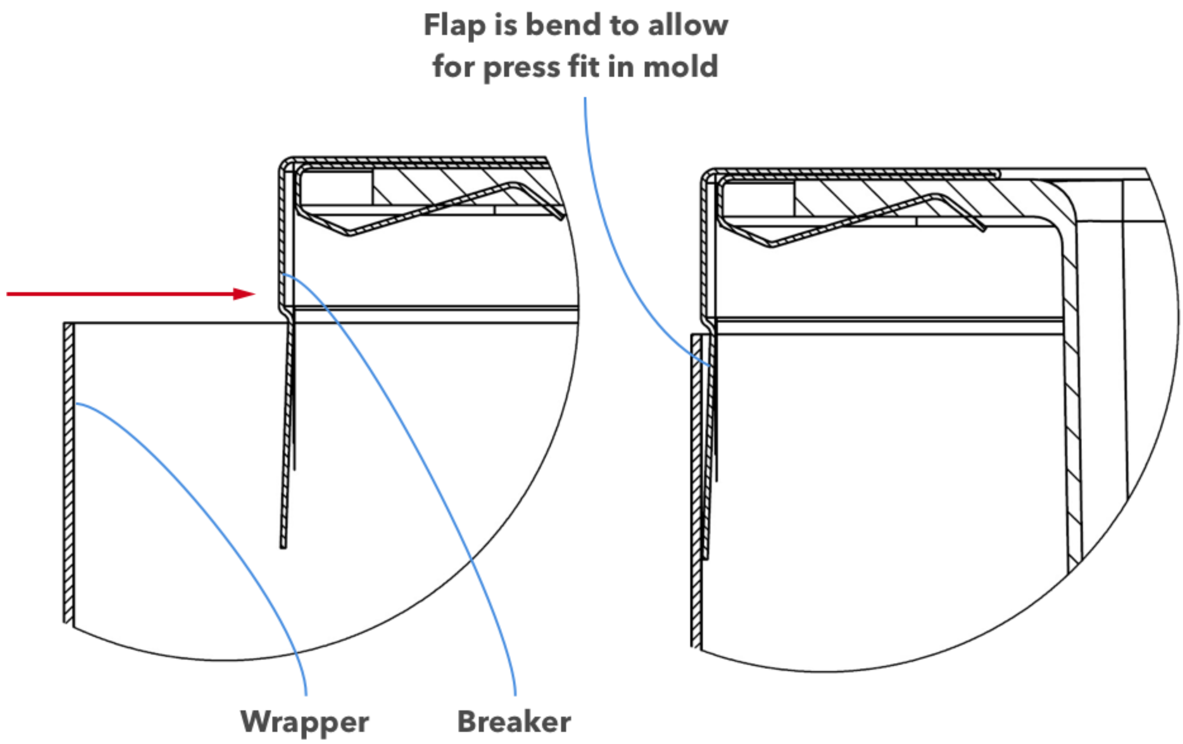


Figure 90: connection between wrapper and breaker during pre-foam assembly

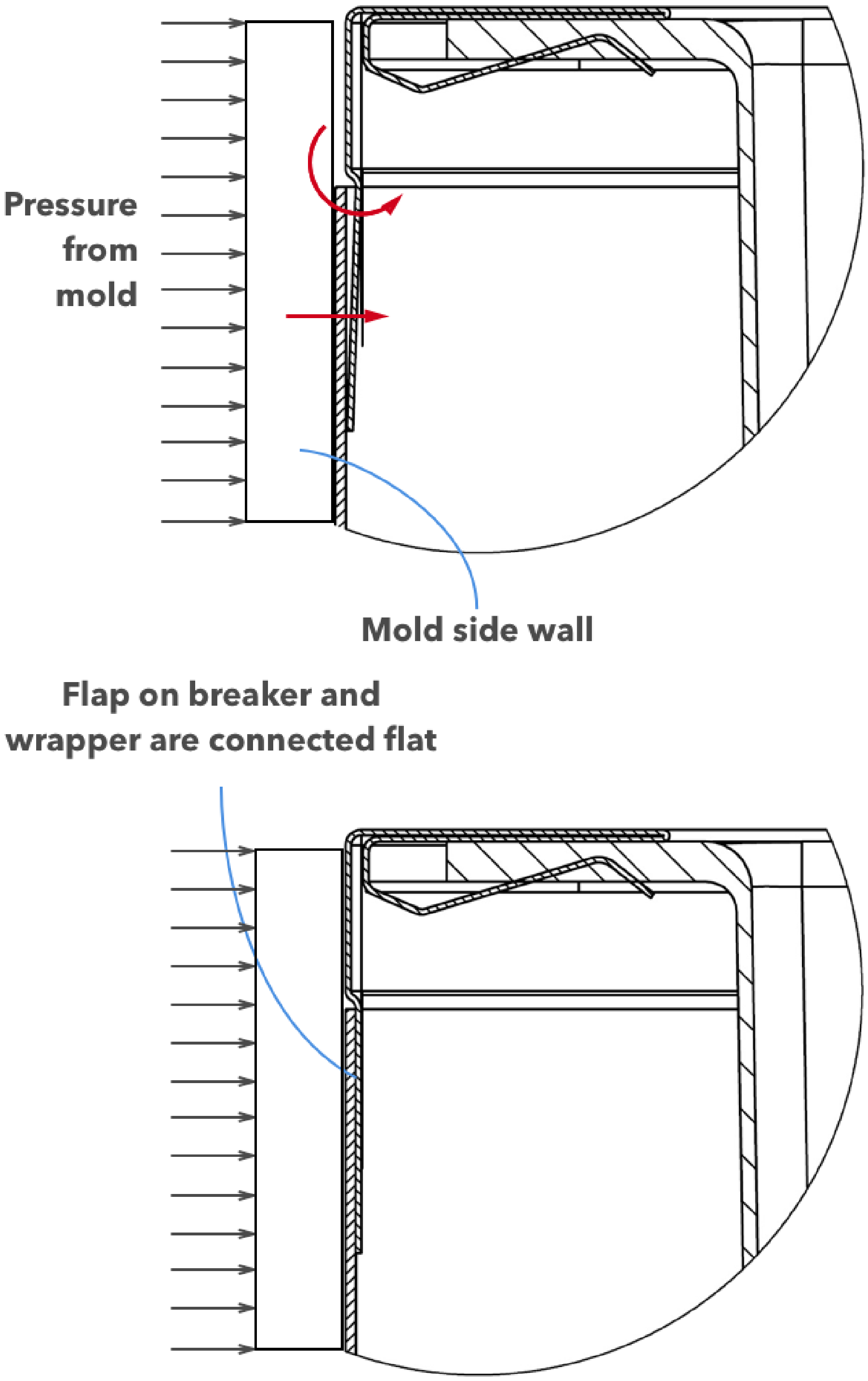


Figure 91: connection is finalized during foaming where the mold closes the connection

Connection wrapper and backplate

A geometry like concept 1 was chosen to join the wrapper to the backplate. The direction the joining is allowed is however new. The joining can be seen in Figure 93.

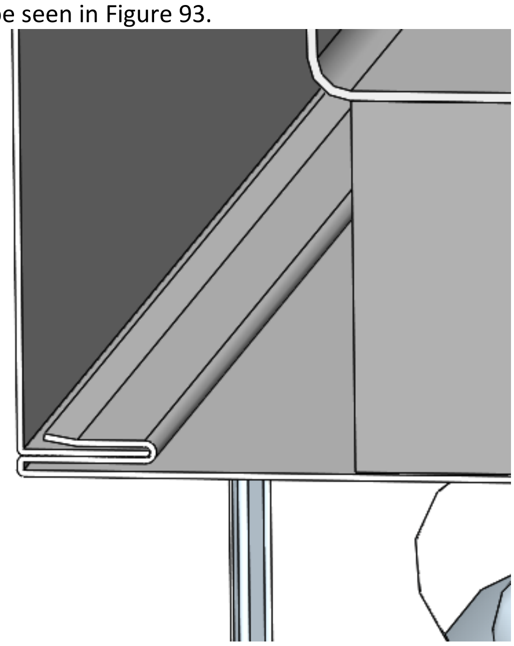


Figure 92: detail on geometry between wrapper and backplate concept 2

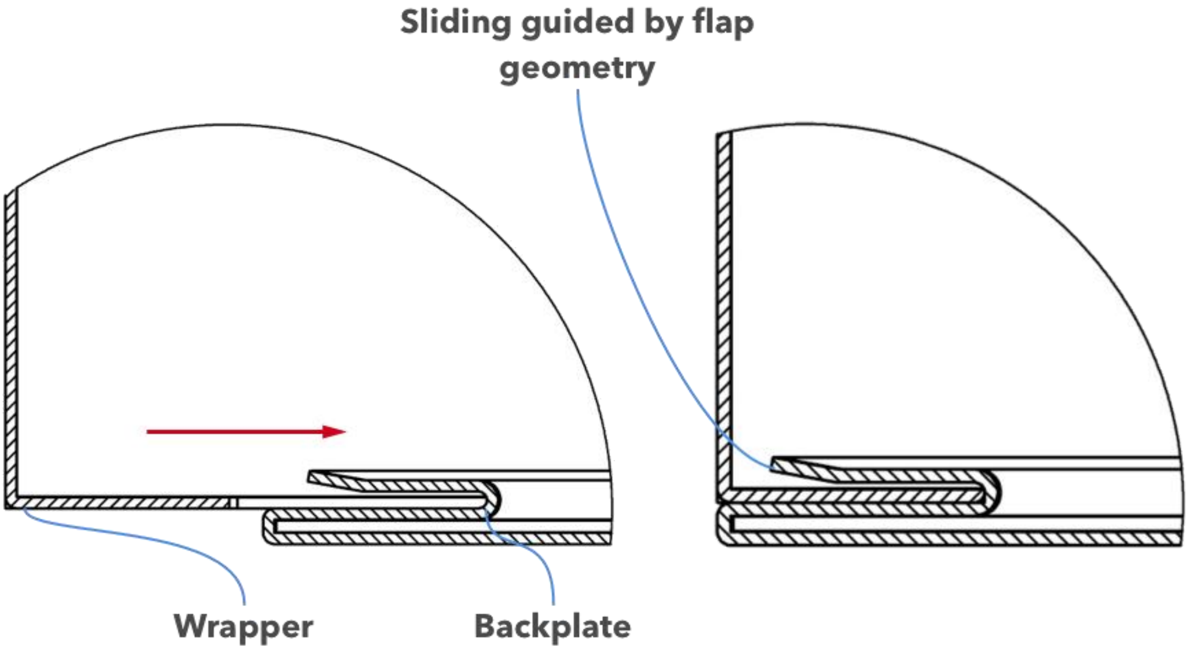


Figure 93: joining method between wrapper and backplate concept 2

Connection between fins and liner
A foam tight joining never made is between the fins and liner. This connection is necessary to avoid double assembly (initially of the process plate, then the fins). The method chosen to make it foam tight is a flexible foam tape as used in the IKEA fridge. It is placed all around the connection because no direct pressure is possible as with the breaker/wrapper.

The connection can be made by screwing the fins unto the CU. The tape can already be placed on the fins thus the assembly step only consists of the screwing. Figure 95 shows how this will happen and how the closure will be made.

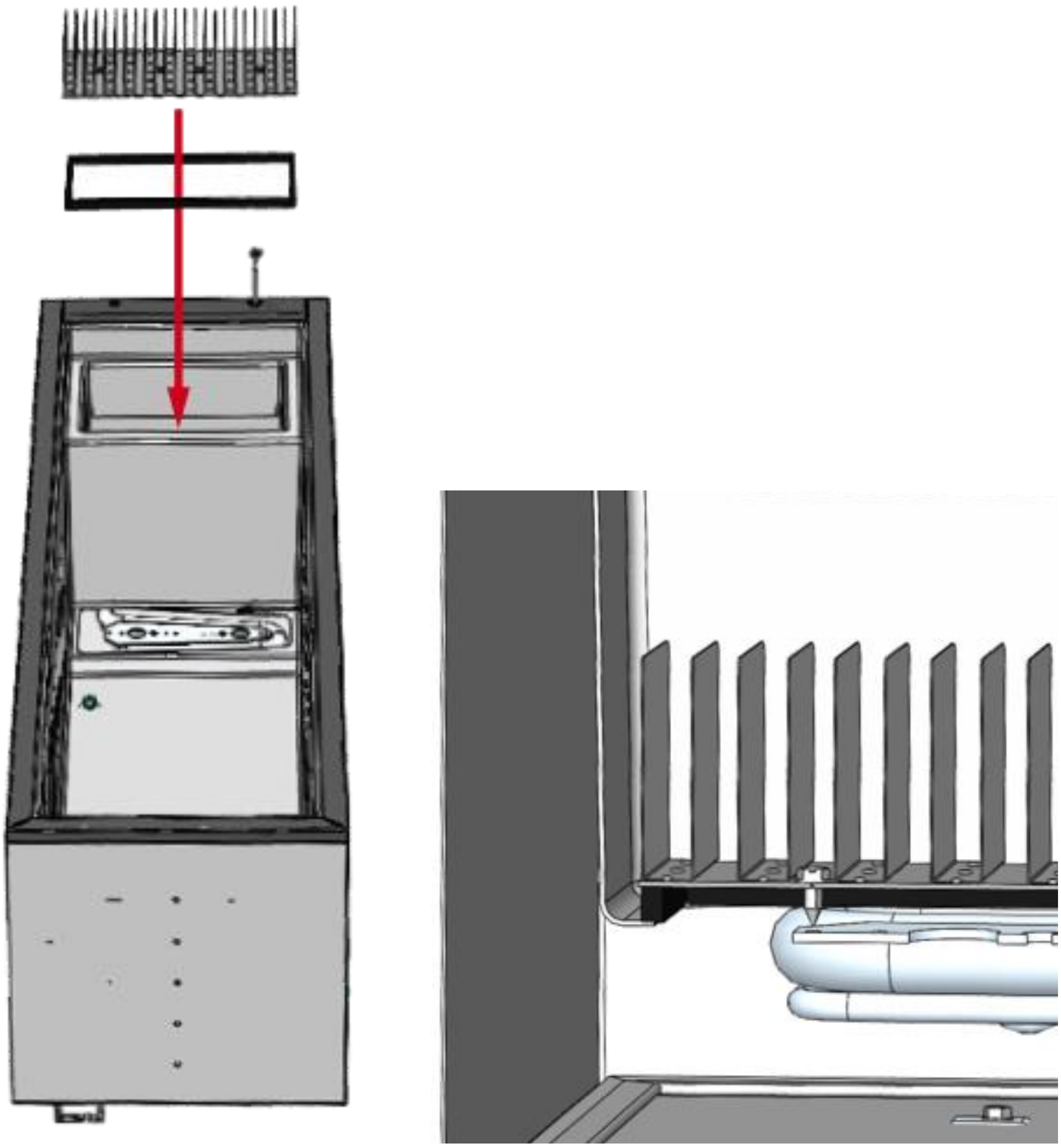


Figure 94: joining of fins to liner concept 2

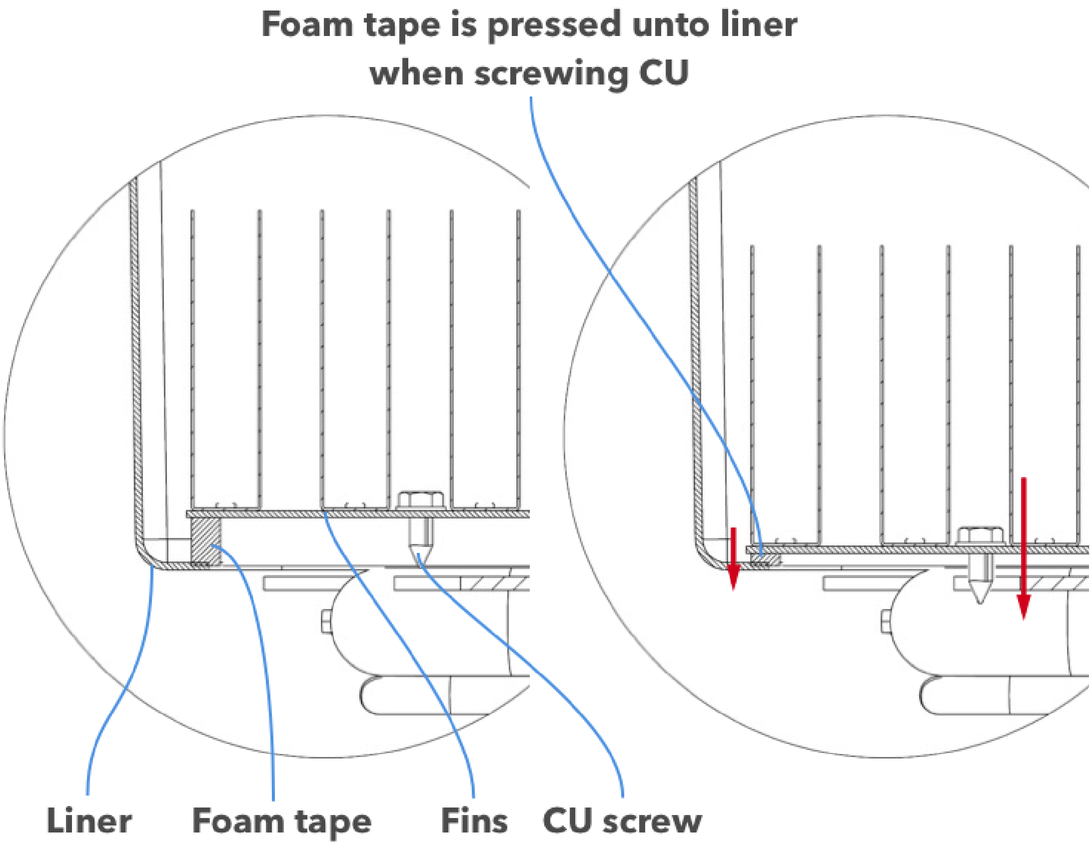


Figure 95: the connection being made between fins and liner concept 2

Cutout in core

The core of the mold needs to be adjusted to allow the earlier placement of the fins. Figure 97 shows the location of the cutout and Figure 98 and

show the details and feasibility of the change.

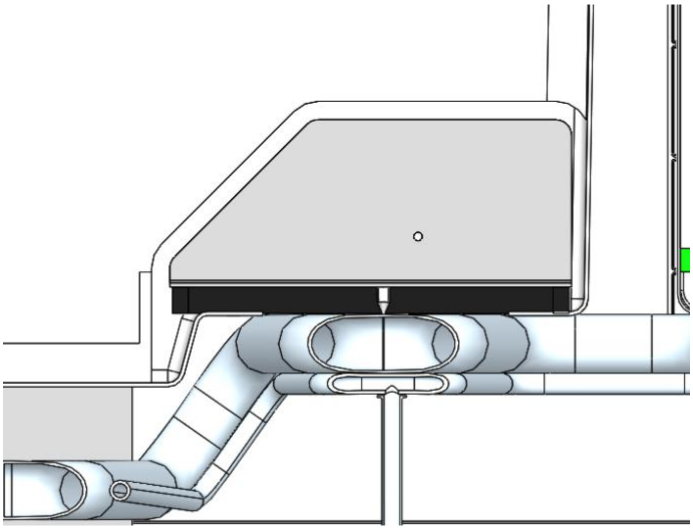


Figure 96: impression of cutout for fins with fridge in mold concept 2

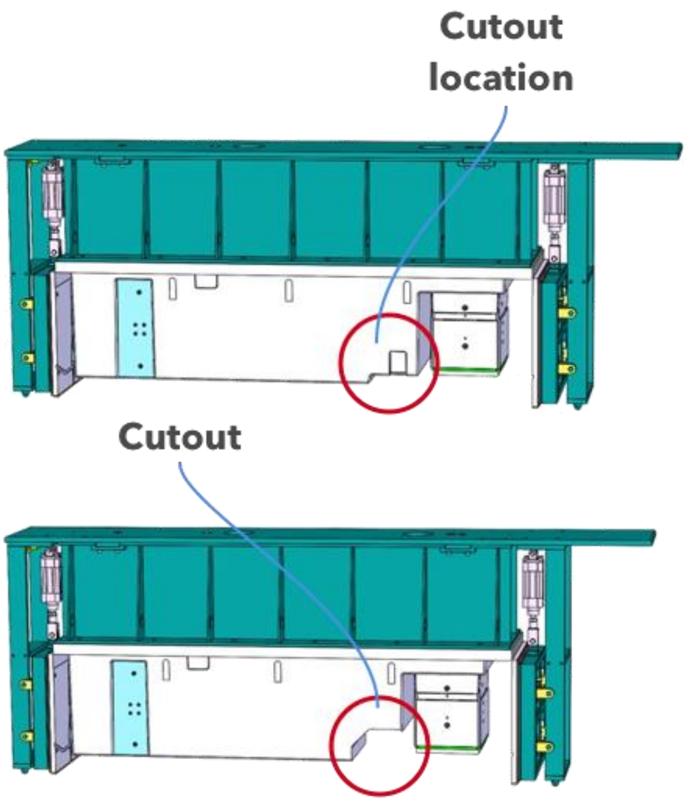


Figure 97: the location and general shape of cutout in core of the mold concept 2

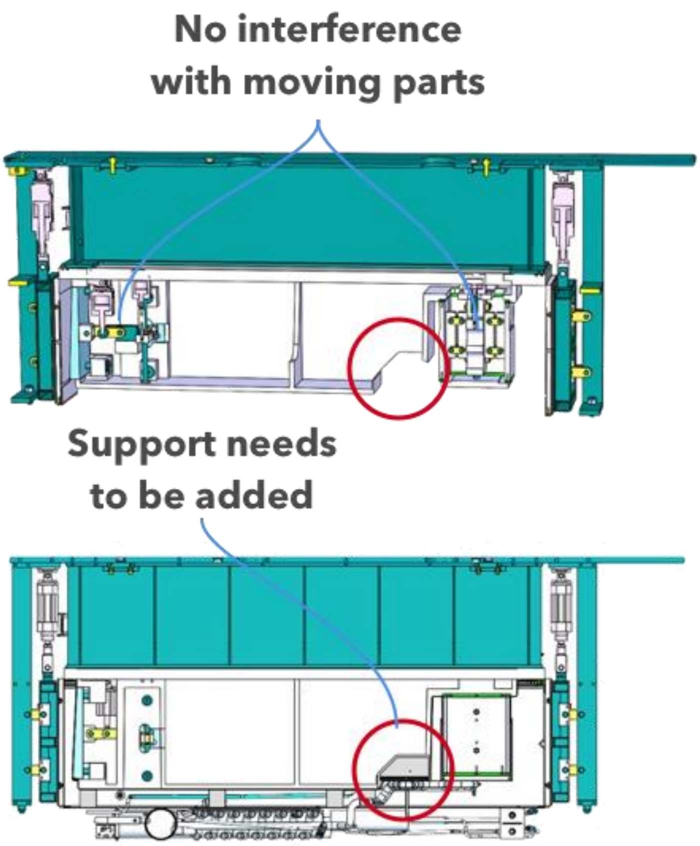


Figure 98: details on core cutout in concept 2

Concept 3 – N5000 series

The previous concepts were scoped on implementing one-step foaming. What if the scope is broadened with other problems in production together with a full metal body? Concept 3 tends to solve the breaker scratches and dents by allowing for the placement of only a cosmetic breaker at the end of the production process (before the door placement). In **Error! Reference source not found.** the exploded view of concept 3 is shown.

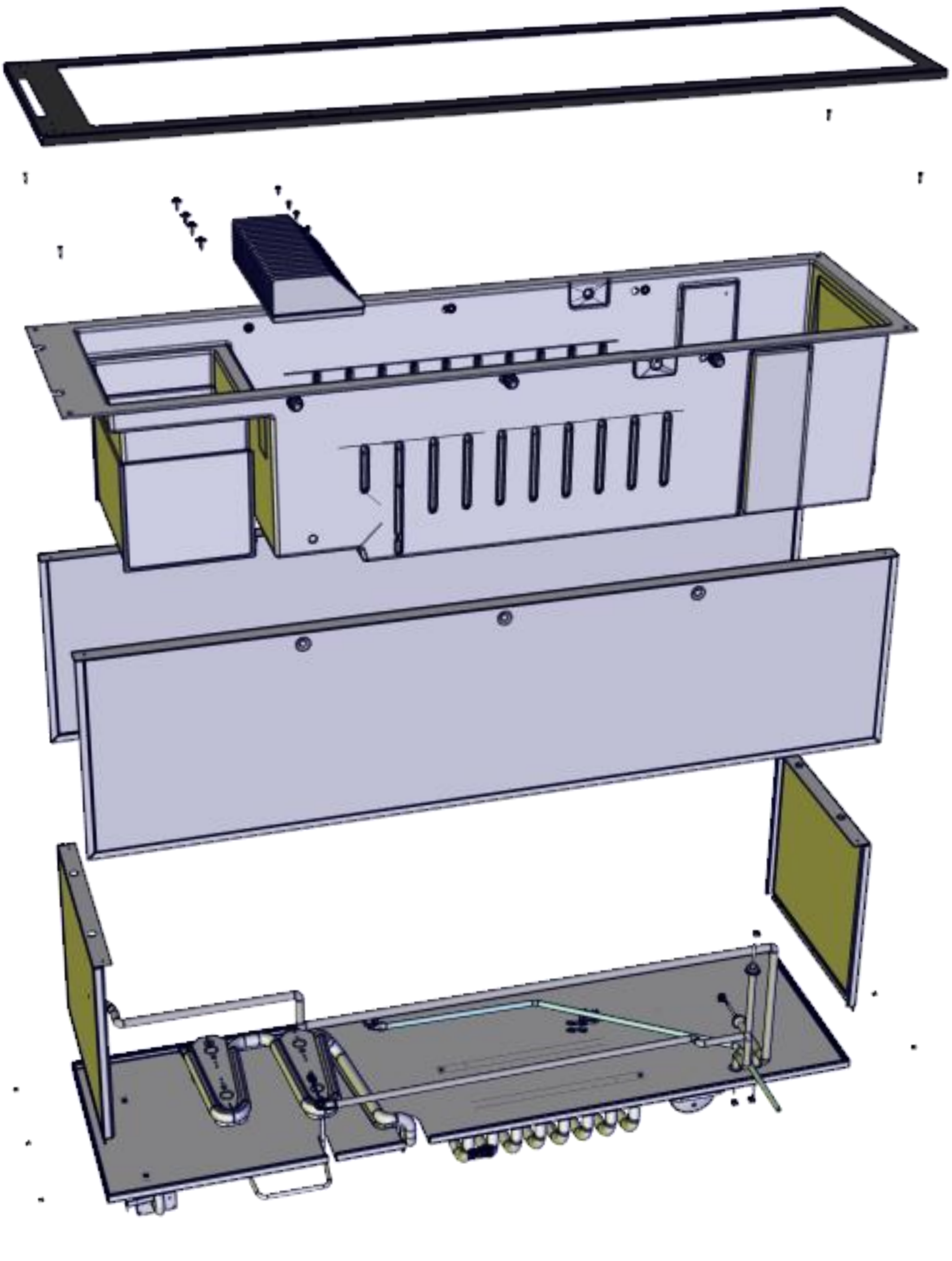


Figure 99: exploded view of concept 3

Table 13 shows an overview of all the changes. The next paragraphs explain the assembly steps and the latest paragraph explains the major changes, just as with the previous concept descriptions.

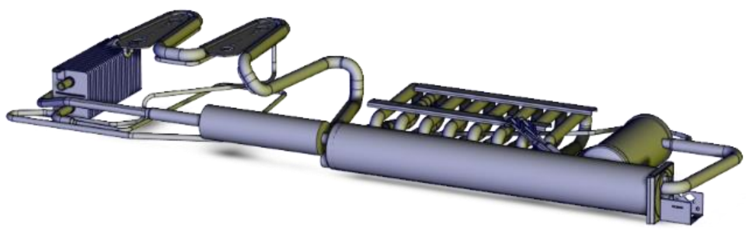
Table 13: overview of changes with concept 3

Category	Element	Change and approach on element

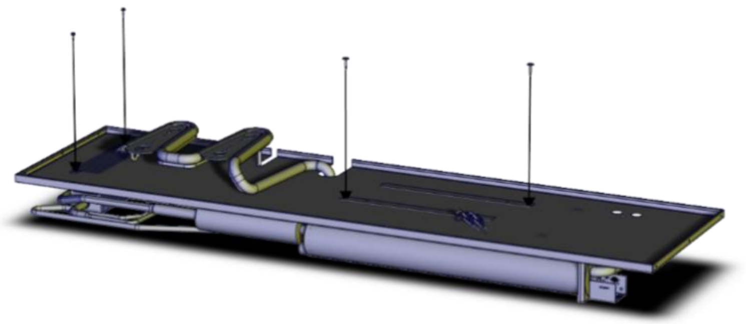
Product design	Breaker	Cosmetic breaker created which allows for rework elimination as reduction in production steps.
	Back plate	Metal plating as in one-step foaming feasibility with added geometry to allow for tapeless assembly of wrapper
	Wrapper design	4 pieces, 2x2 all made out of sheet metal
	Wrapper material	Full metal wrapping with different thicknesses for weight reduction
	CU tubing	CU tubing is changed a bit to allow for less tape to be used and to allow for easier assembly on one side
	Liner	The liner is altered to allow for better joining to wrapper and breaker.
Machinery design	Foaming equipment	Same as concept 1, only new top plate.
Assembly	Joining CU with backplate	Screw backplate from inside to outside. Screw thread and connection strength comes from CU instead of backplate.
	Fins placement	Fins can already be placed beforehand instead of final assembly reducing handling.
Requirements	Stability	Stability comes from smartly chosen thicker top and bottom plates together with full joining of liner to CU.
	Use of tape and hotmelt	Elimination of duct tape, but internally masking tape still needs to be used. No elimination of hotmelt.
	Foam tightness	Only corners form a risk of leakage as the new plate at the CU. Tubing CU needs to be taped on backplate.
	Dimensions	Due to full metal wrapping the dimensions are most stable.

Assembly steps concept 3

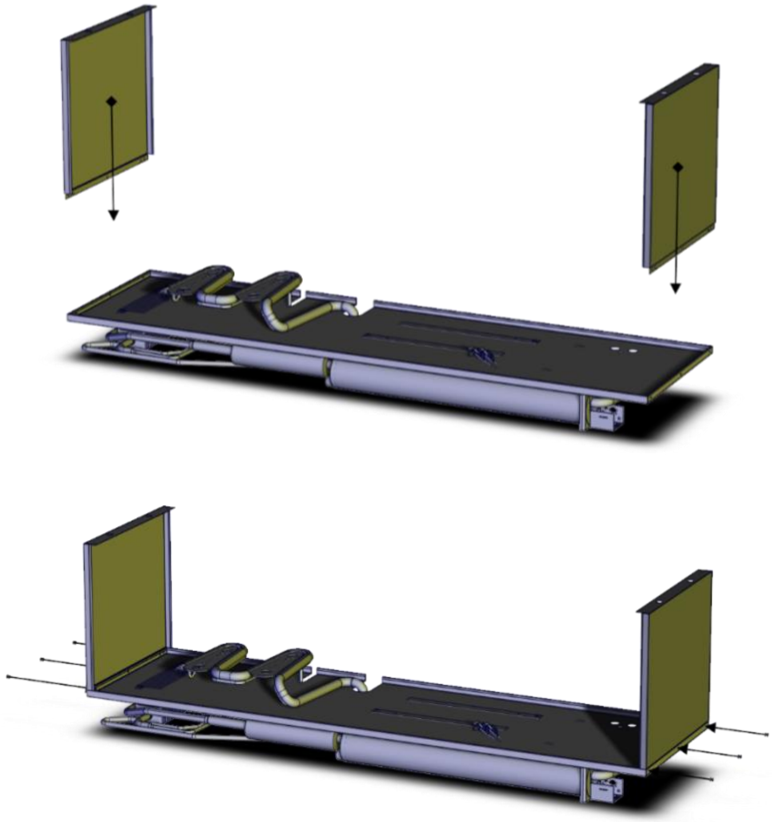
1 Place the CU on the worktable



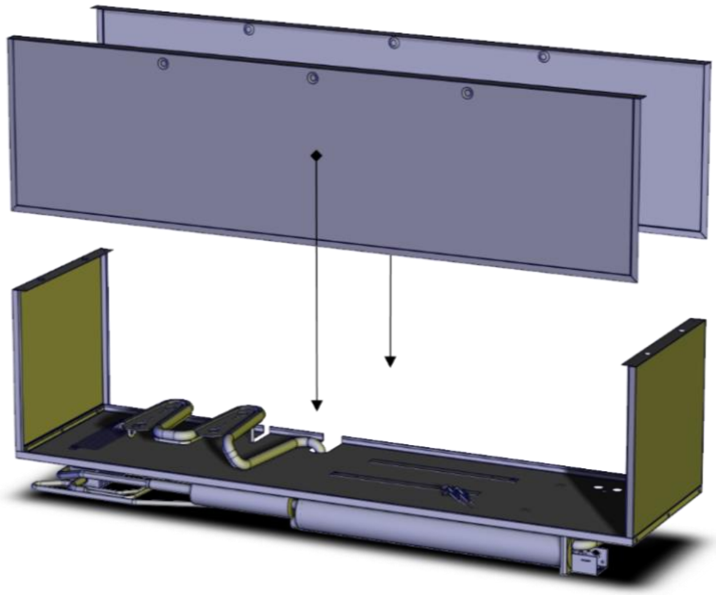
2 Join the backplate together with the CU



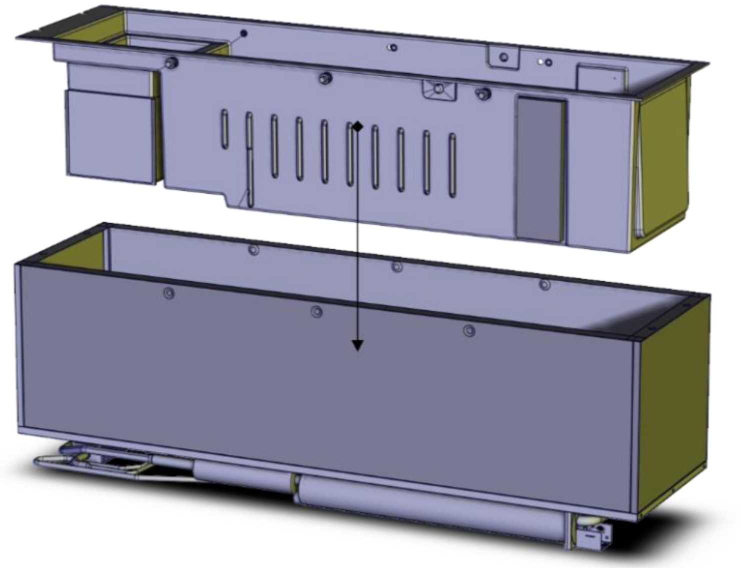
3 Place top and bottom parts and join them with rivets/screws to the backplate. The joining causes foam tight sealing.



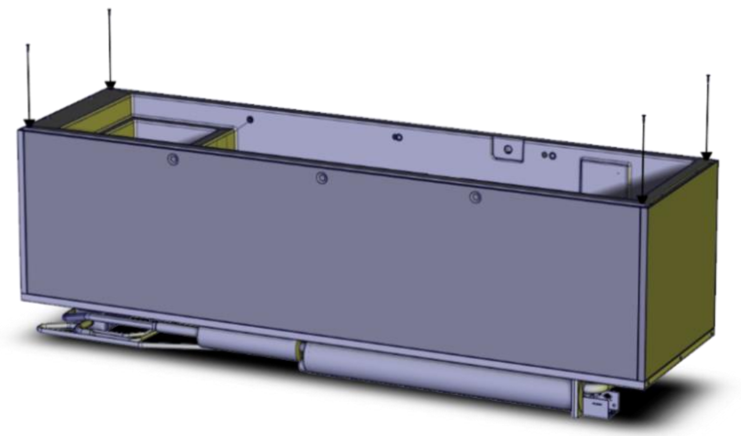
4 Place side plates by sliding them in the existing geometry



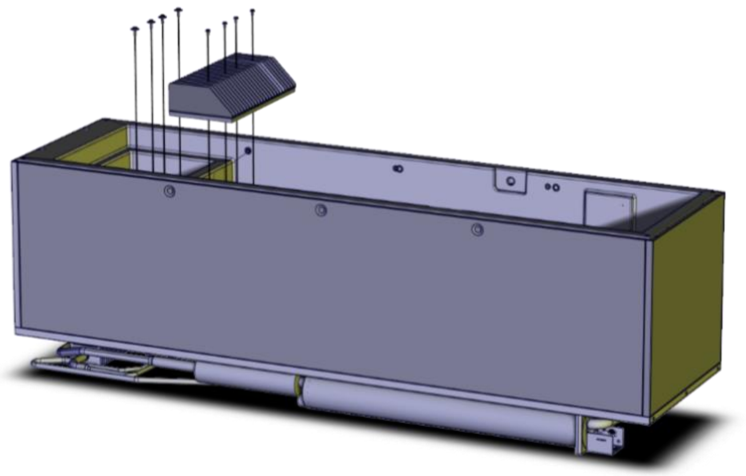
5 Place liner, before and during this step various cables and tubes can be connected.



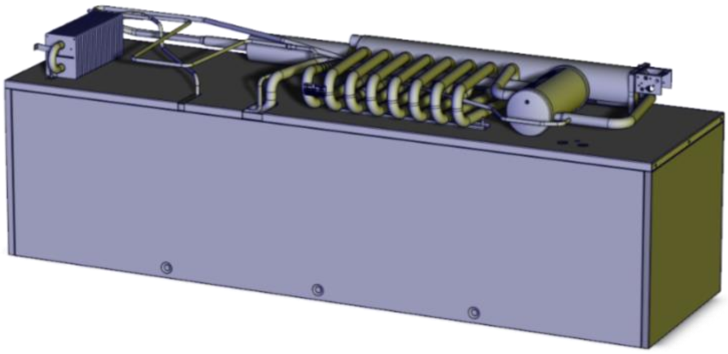
6 Screw the liner unto the metal wrapping. This will join the liner with 4 screws to both the top/bottom and side wrapper.



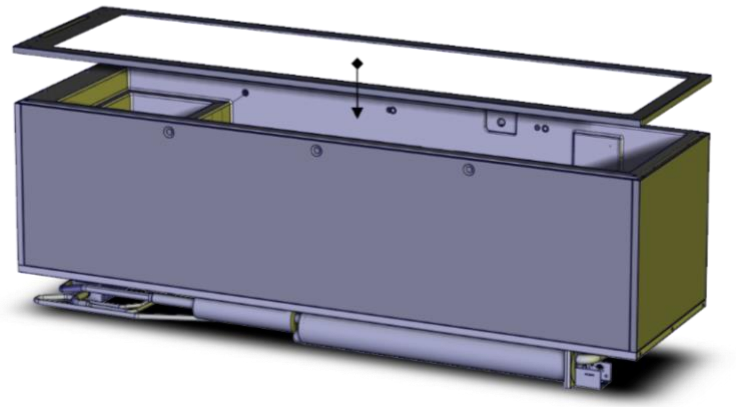
7 Screw the fins and the freezer to the CU



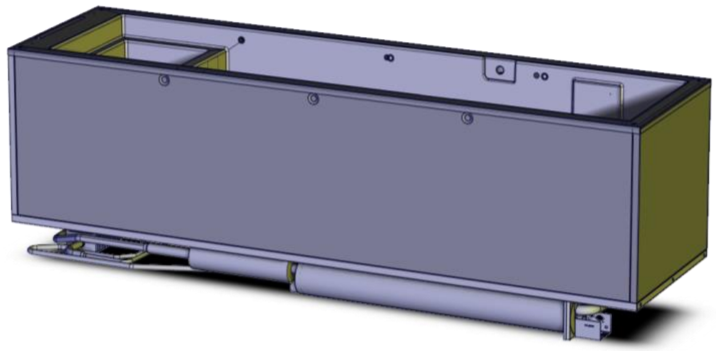
8 Flip the fridge to allow for foaming (on non-cosmetic surface)



9 After foaming attach cosmetic breaker with regular components. Before this step certain back-assembly steps could be taken to avoid damages.



10 The fridge is ready to be finished in final assembly.



Notable product and machinery design choices for concept 3

There are a couple of detail that are fundamental for this design.

1. **Cosmetic breaker with integrated screw locations** – instead of placing the wrapper at pre-foam it can be placed almost at the end of the line. Even allowing for eliminating the drilling robot.
2. **Variable thickness and symmetric sheet metal parts** – metal parts are heavier than the existing wrapping. By smartly designing certain pieces thinner than other the weight can be reduced and regulation can still be followed.
3. **Joining of wrapper and liner** – almost no tape is necessary for this design and no special connection is made for the liner/wrapper connection. This is achieved by a dry connection with pressure from the mold.
4. **Ability to be flipped** – to allow for easy assembly but still allow limited changes to machinery the cabinet is designed to be flipped before foaming.

<u>Cosmetic breaker with Integrated screw locations</u>
In Figure 100 the breaker can be seen as a loose part. The part already contains various screw locations which define the location of the necessary parts before they are drilled. The figure also shows the part that will be connected at the top and bottom. Figure 101 shows more detail on the attachment of the cosmetic breaker on the cabinet.

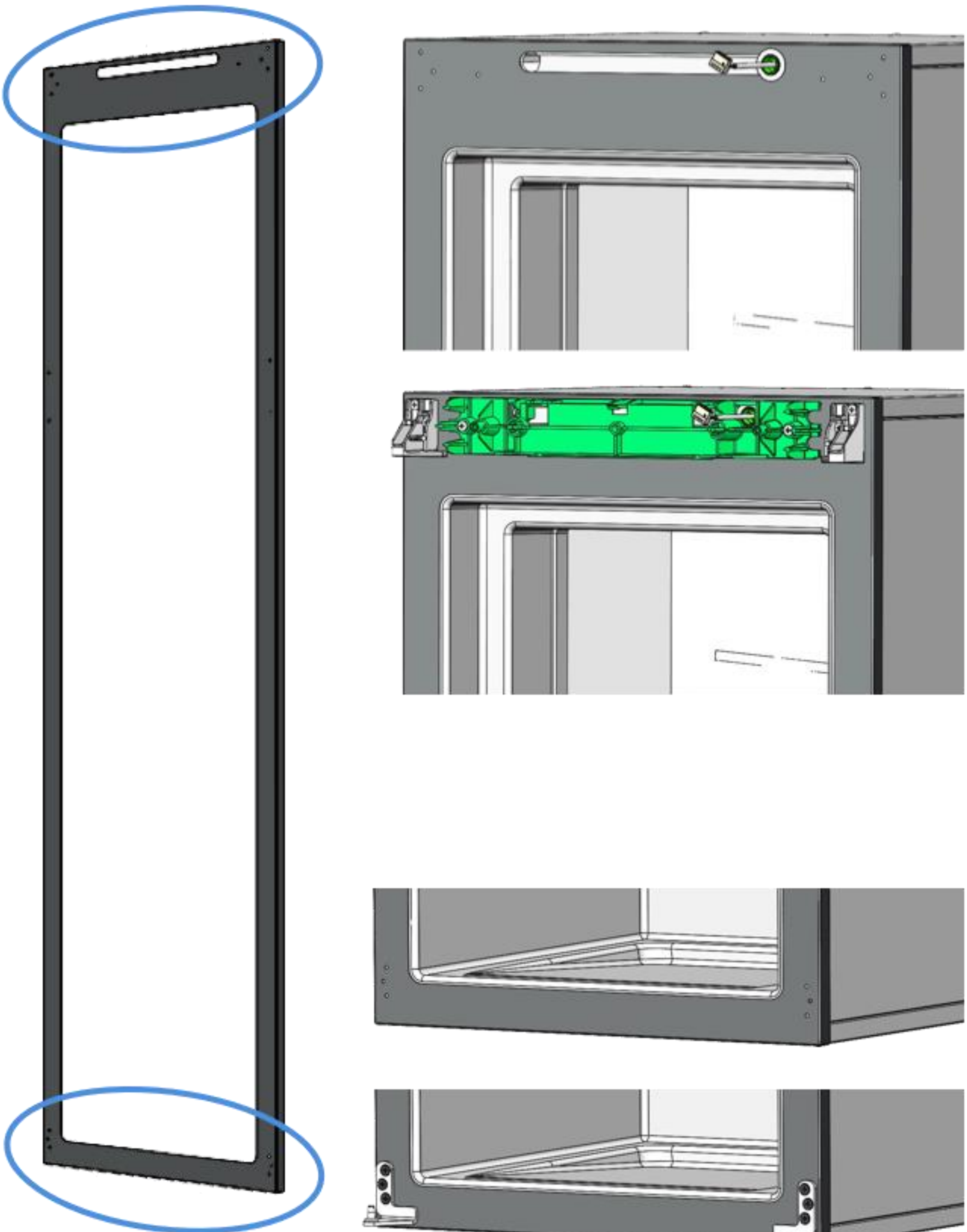


Figure 100: details on screw location and final assembly placement of parts

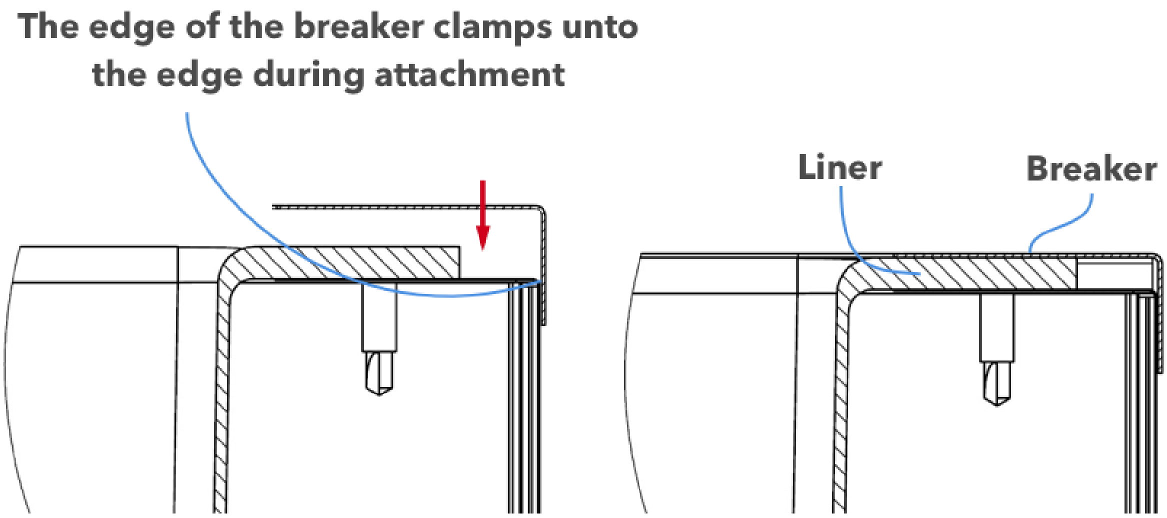


Figure 101: detail on placement of breaker on cabinet assembly

Variable thickness and symmetric sheet metal parts
Not each part needs to have the same thickness. The metal parts are heavy but by varying the thickness the total weight can be reduced. The top/bottom part needs to be a little thicker to be structurally supporting for the liner and the CU assembly. The side parts can be thin and non-structural to allow for weight reduction.

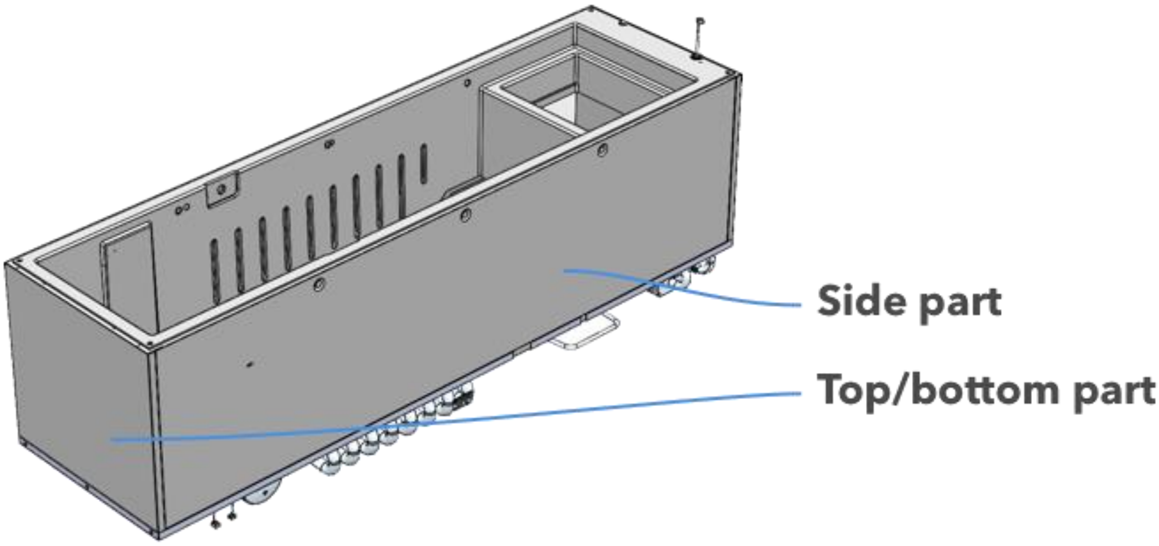


Figure 102: metal part designation with variable thickness

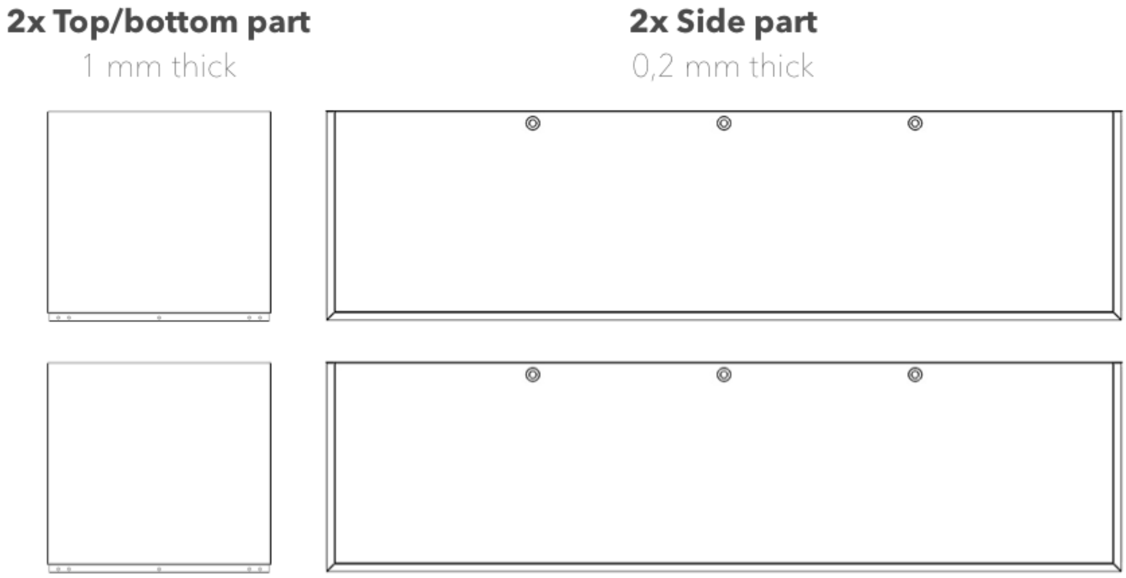


Figure 103: amount of metal parts with their thickness

<u>Joining of wrapper and liner</u>

This is a similar connection that is made between wrapper and breaker in concept 2. Now the connection is made between liner and wrapper.

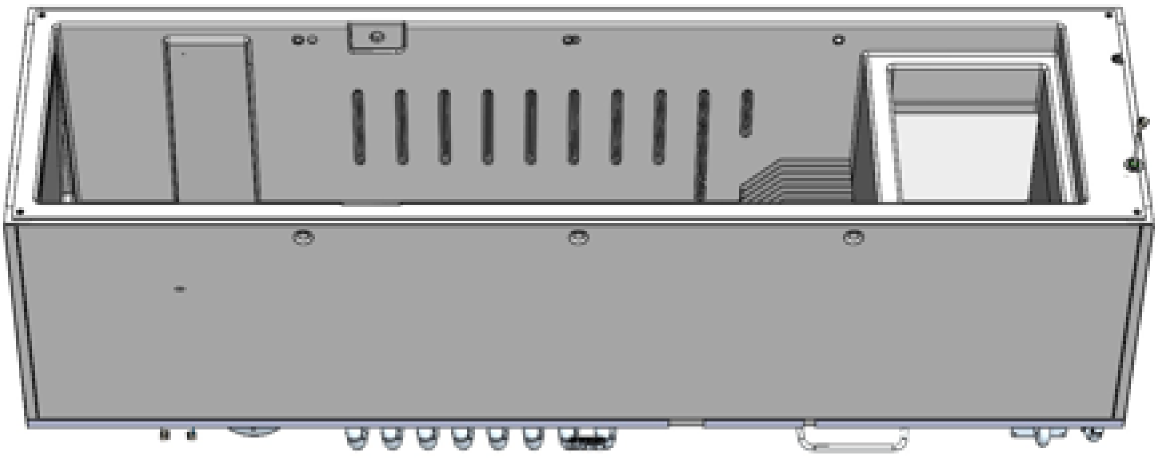


Figure 104: the liner is placed on the wrapping in concept 3

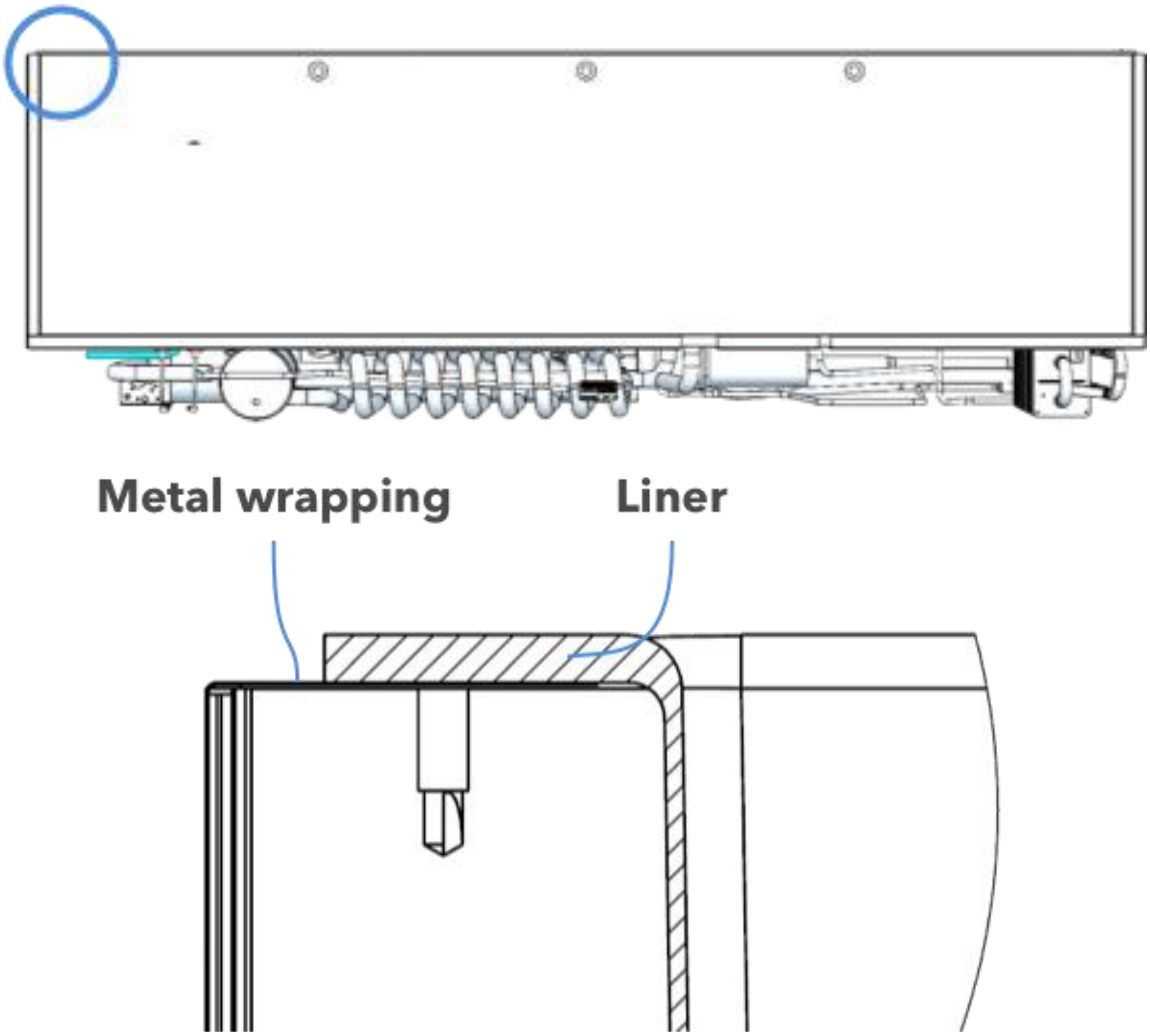


Figure 105: detail on the connection between liner and wrapping in concept 3

<u>Ability to flip fridge</u>

The whole cabinet is screwed/joined together structurally at pre-foam. The top/bottom parts are joined by rivets with the backplate. The top/bottom are then joined with the liner by screws. This means the whole assembly is kept together. This allows for flipping of the cabinet to have no change on machinery other than minimally necessary.

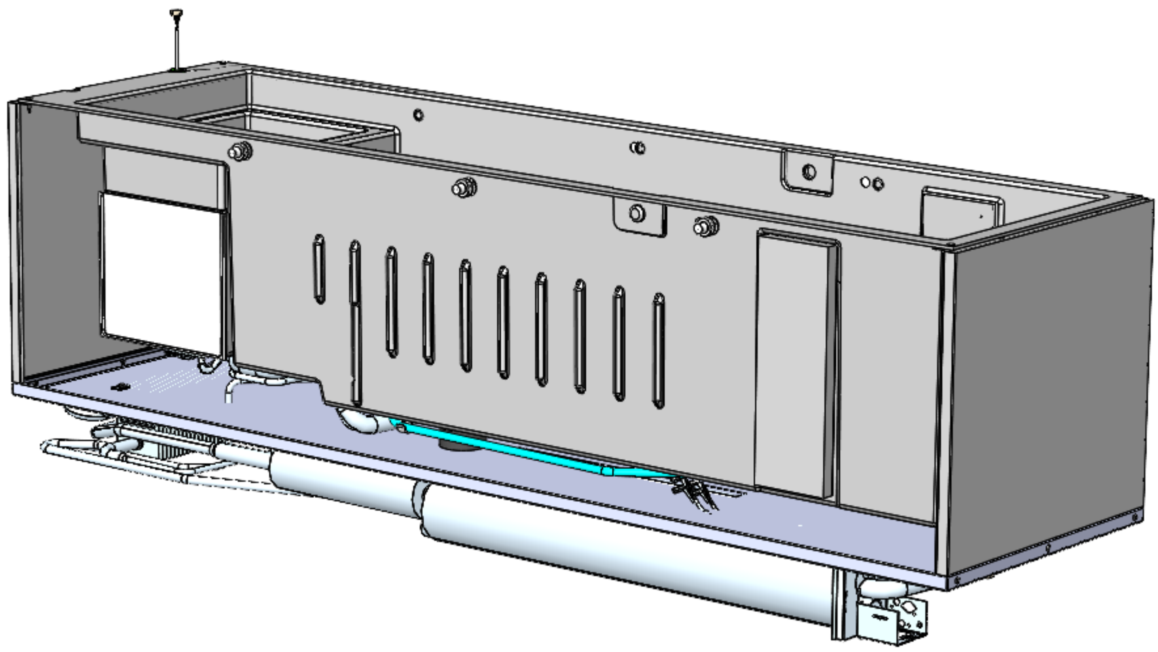


Figure 106: assembly should be structurally stable and enable flipping

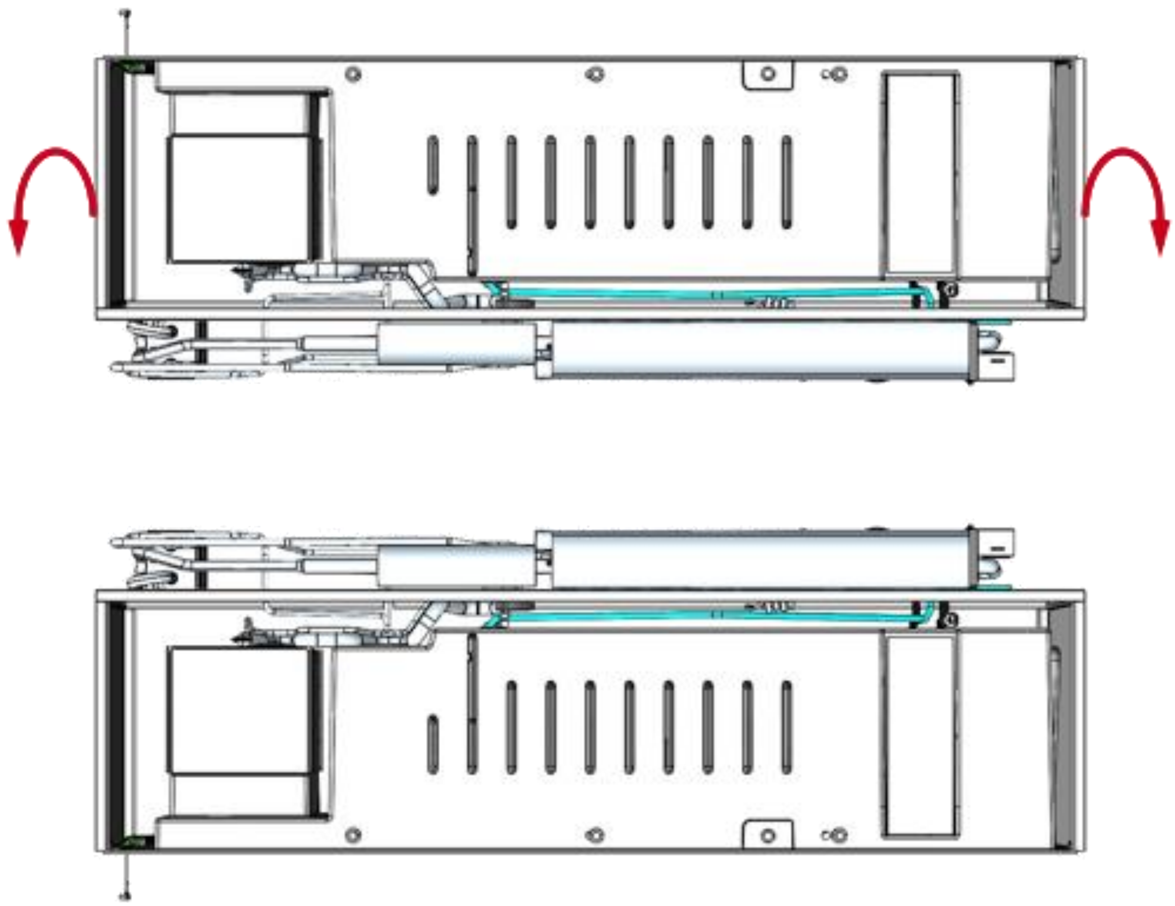


Figure 107: allowing of flipping

Concept choice

What concept fulfills the main drivers best and is thereby the best choice? The 5 main drivers were stated as follows:

1. +20% output with -20% floor space
2. Same customer experience
3. Cost neutral
4. Increased production worker value
5. Future proof

Increase in output

Table 14 gives an overview of the best and worse choices on each driver for each concept. Each of the concepts fulfills the main drivers but some do better than others. The first driver is split into two: +20% output and -20% floor space. The output increase cannot be defined as output increase but is defined in reduction in necessary FTE before foaming thus decreasing human dependency but at the same time allowing for more people to work on the line. This will in the end improve output by at least 20% by smartly placing people in the line. The calculation for the FTE reduction can be found in Appendix 8: business case. The best option in the sense of output is concept 3.

Table 14: overview of validation of concepts on main drivers

Main driver	**Concept 1**	**Concept 2**	**Concept 3**
+ 20% output	- 4,5 FTE / - 32%	- 5,5 FTE / -39%	- 8 FTE / -57%
-20% floor space	23% - Foaming machine + assembly tables	27% - Foaming machine + assembly tables + Fins assembly	>42% - Foaming machine + bending + rework + drilling robot + wrapper robot
Value production workers	Less taping	Less taping + heavy lifting	Less taping + focused work
Cost neutral	Depends	Depends	Depends
Future proof	Design not feasible for LF and still not fully recyclable	Limited recycling when choosing multilayer wrapper.	Yes
Same customer experience	Yes	Yes	Yes, but small changes are necessary that have minor impact

Floor space reduction and value increase workers

A visualization of the floorspace reduction is shown in Figure 108. The reduction is bigger than expected as can be seen on the calculations made. This is the same as the value addition of production workers. The reduction in FTE shows this measure the best because the designs are made in such a sense that the almost the only work on the fridge is adding value. A remark necessary to make here is the unclarity of the shift of work from one location to another. CU assembly moves to pre-foam thus taking space. This has been incorporated partly in this calculation but can decrease saved space by 5-10%. However, there is also an additional space saving at rework by concept 3. This is also a big saving especially when the design is implemented on all lines. The best option in the sense of floor space and value increase for workers therefore is concept 3.

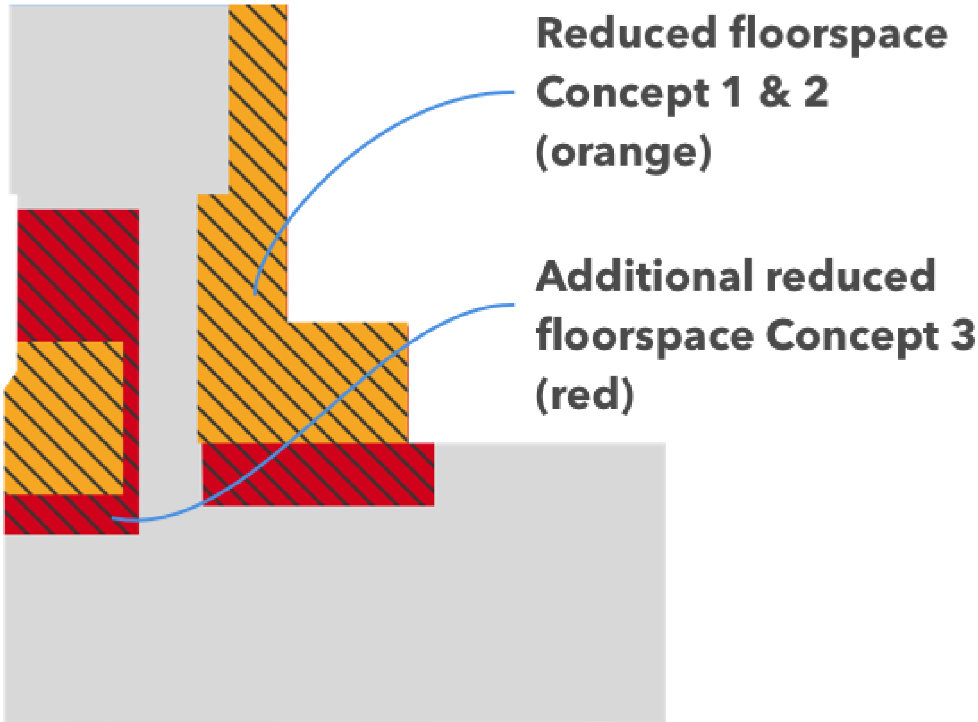


Figure 108: floorspace reduction of each concept (the difference between concept 1 and 2 is rather small and therefore not shown) on the beaker line

Costs

Table 15: Cost overview of each concept

What	New encasement baseline	Concept 1	Concept 2	Concept 3
Investments	€ 57.500	€ 110.901	€ 553.402	€207.000
FTE and rework saving p/y	€ 0	€ 180.000	€ 220.000	€357.500
BOM change with present BOM	**€ 30,88**	**€ 33,54**	**€ 35,34**	**€ 27,99**
Weight increase (theoretical)	8kg	10kg	10kg	10kg
BOM difference with new baseline	€ 0,00	€ 2,66	€ 4,46	- € 2,89
Cost price difference	€ 0,00	- € 1,84	- € 1,04	- € 11,83

Cost neutral is described in Table 14 as ‘depends’. That has to do with the fact that every concept is higher in BOM costs than the original fridge. A lot higher! This can be seen in Table 15 on the line with bold figures. The assumption made in this project is the high probability of the introduction of new encasement regulation. This changes the baseline of the cost comparison from the present BOM costs to the situation without one-step foaming but with implemented new encasement regulation. The first column shows this new baseline.

The new baseline is calculated based on the present Australian fridge BOM which shows a lot of resemblance with the probable changes for the new encasement regulation. Concept 1 and 2 show a BOM increase when only looking at BOM cost changes. When taking the FTE reduction into account this will have a BOM cost decrease on all concepts with Concept 3 as best. The investments necessary for concept 3 are twice as much as the lowest, concept 1. Concept 2 is quite high because of the big adjustments to machinery.

Future proof and customer experience

Customer experience isn't affected for each of the concepts except for the weight. All concepts will have significant weight increase which is even more than the baseline. The future testing needs to have more efficient weight management. Not all concepts are future proof. The worst is concept 1 because of the choice of the multilayer wrapper. This is also the case for concept 2 but solvable with sheet metal. Concept 3 is best in all options.

Final concept choice

When looking at the three concepts the best by far is concept 3. The downsides of customer experience and higher investments can be overcome. The investments are earned back within a year which is 3 years for concept 1 making the business case **best on all cases for concept 3**. The final concept will include more changes to optimize on the main drivers even further.

Final concept: N5000 series

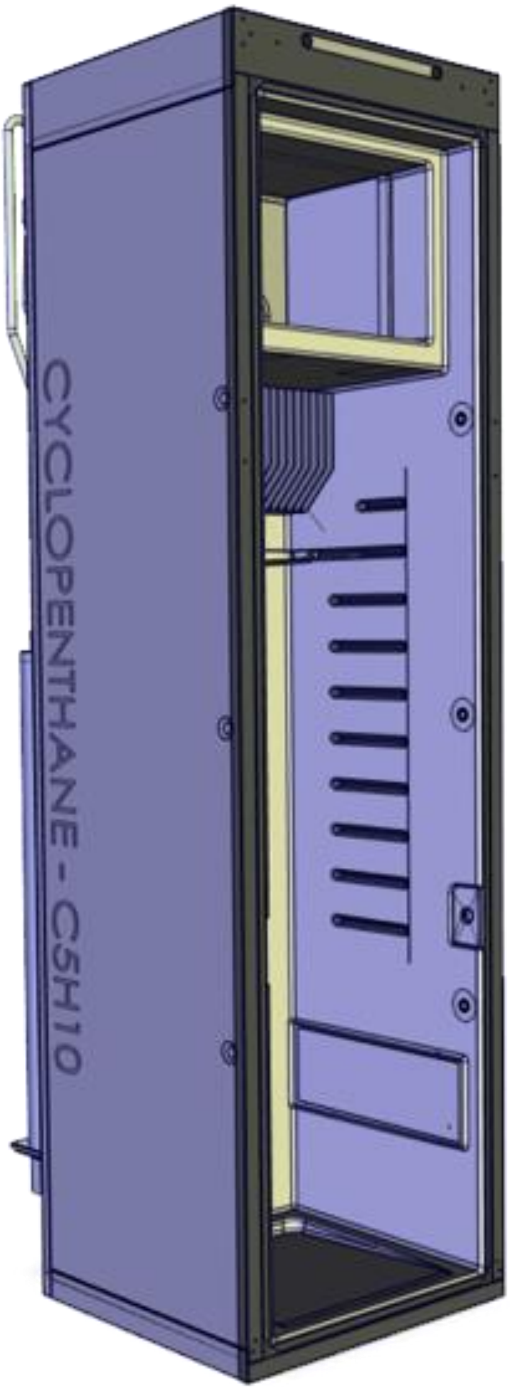


Figure 109: final concept

The final concept (seen in Figure 110) is an improvement on concept 3 and therefore shows a lot of resemblance. Though concept 3 was already quite feasible and promising it could be improved on little details. This was addressed in the analysis chapter on page 42 on the “Potential savings when optimizing value through DFMA”. This concept tries to achieve the maximum possible in the sense of DFMA within the context of this project.

The basis of this concept is a full-metal body with parts of various thickness to decrease weight. No tape or just a little bit of hotmelt in the corners is necessary to make the assembly foamtight. By varying the thickness, the parts that support the CU or counteract foaming force are thicker than non-structural parts. Additionally, to the metal body is the addition of the cosmetic breaker that can be attached at one of the last steps in production. This will reduce rework at the beaker fridge line by 10%.

The last win is by altering the littler parts like nutplates and grommets. Nutplates could also be made out of plastic parts with self-adhesive layer and grommets could have a wider base connection internally, as seen in the IKEA. This means that theoretically the routing and nutplates could be fully automated without using any tape or hotmelt.

The chapter describes the assembly steps and all the notable design choices made for the product and machinery. Not all changes will be discussed as part of the improvements is already discussed in the chapter about concept 3. An overview can be seen in Table 16 of all the changes.

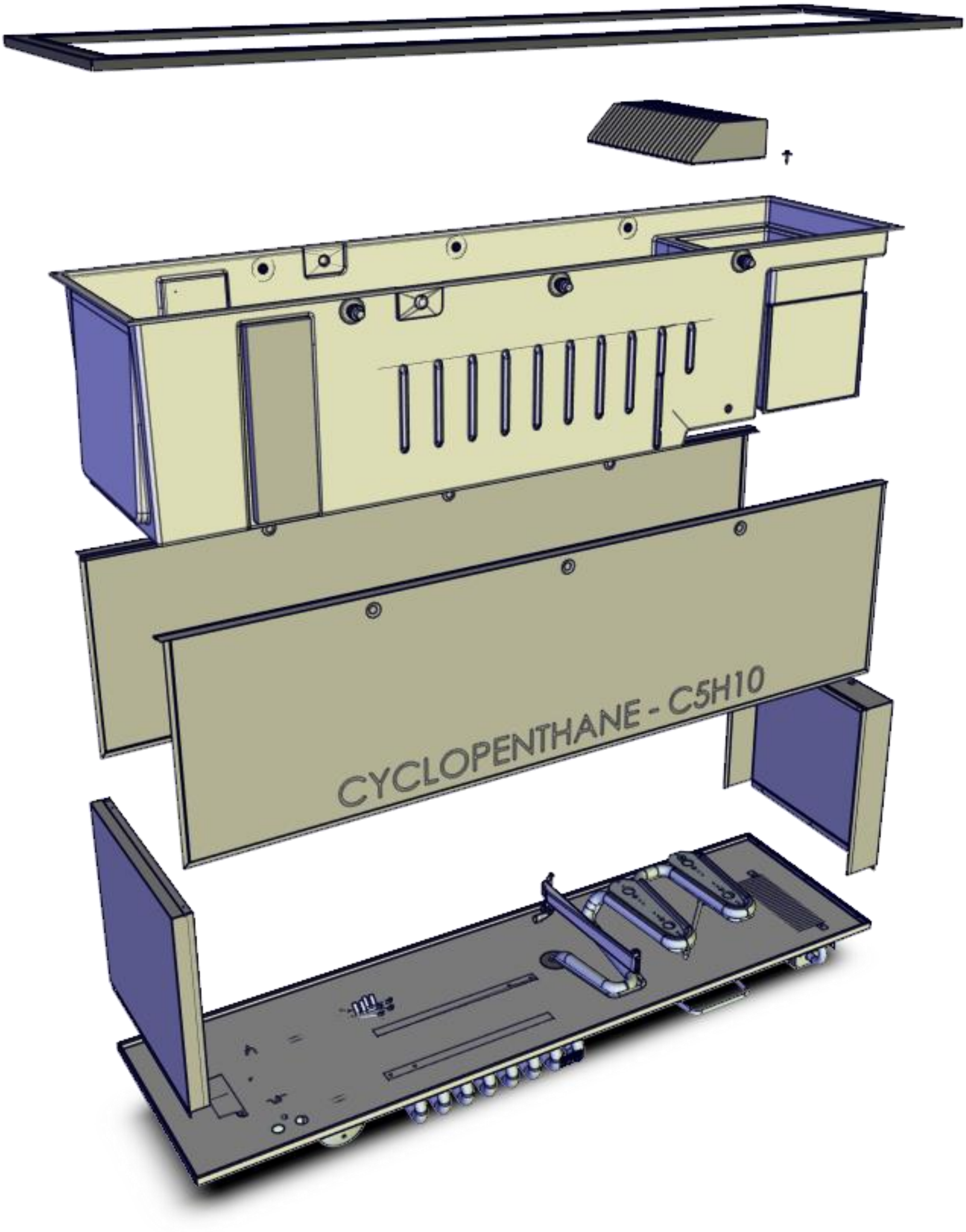


Figure 110: exploded view of final concept

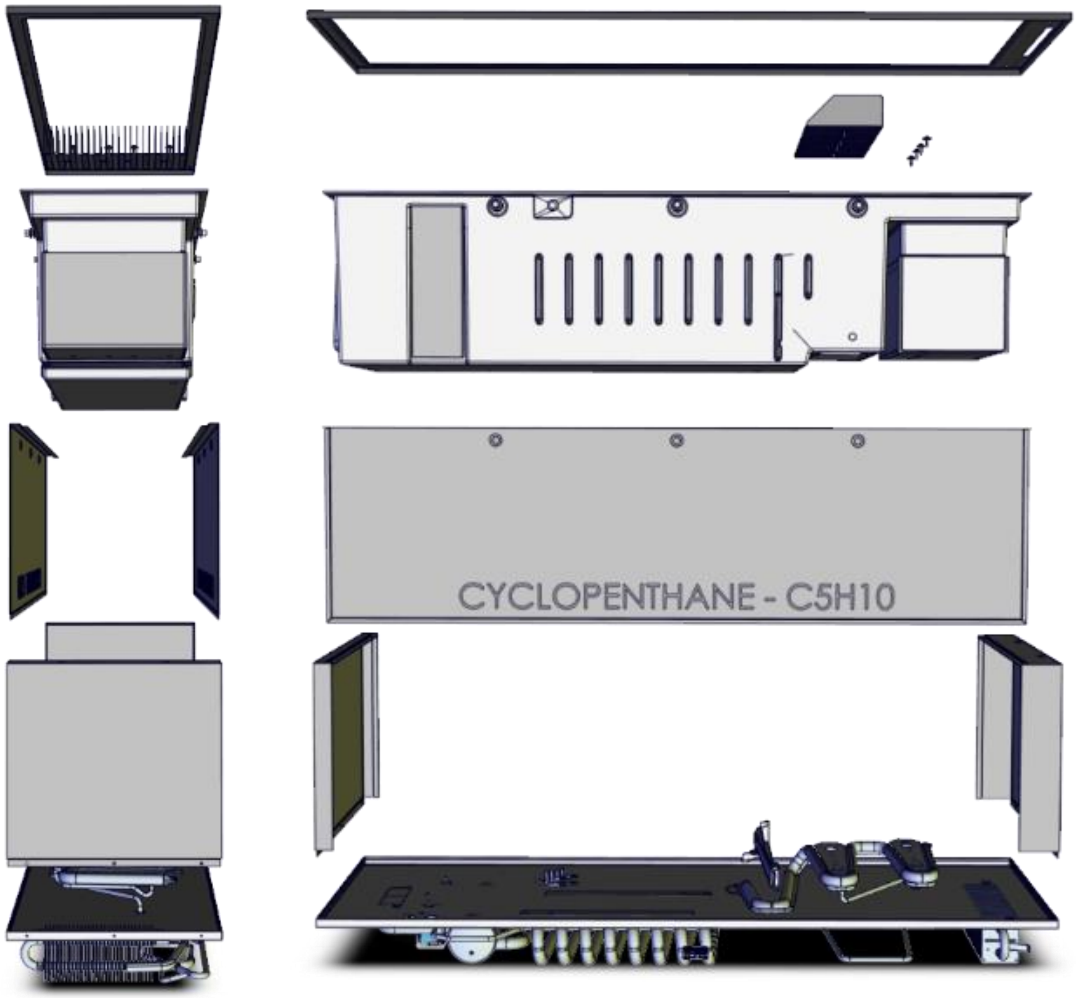


Figure 111: side and front view of final concept, exploded

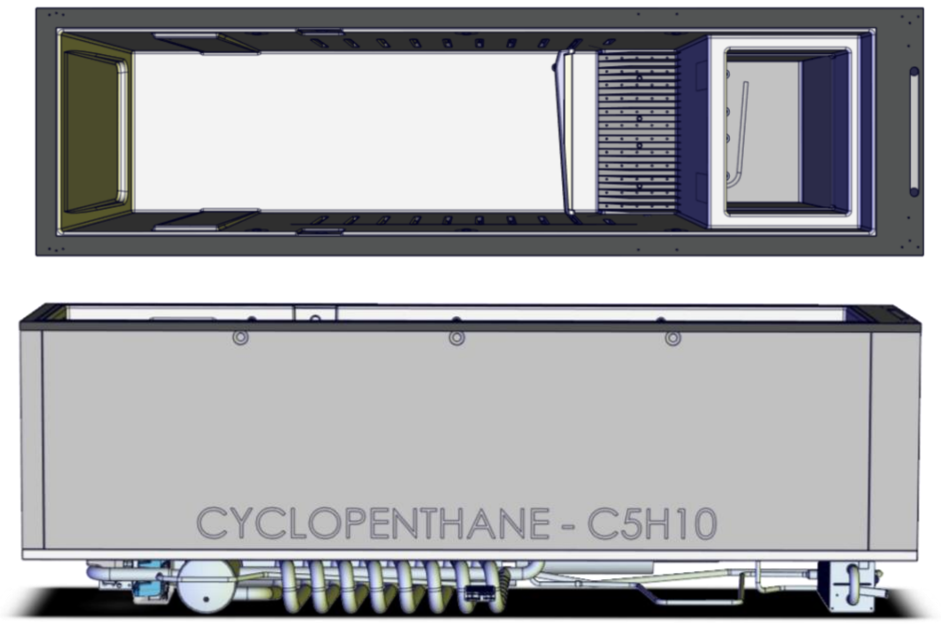


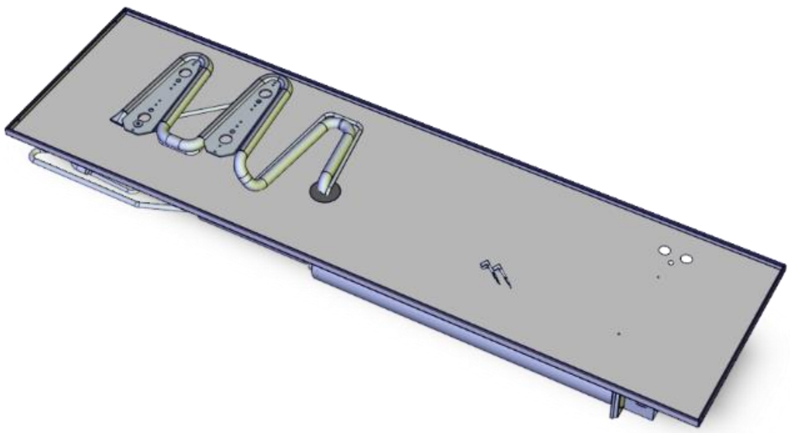
Figure 112: two orientations of the final concept

Table 16: overview of changes to design

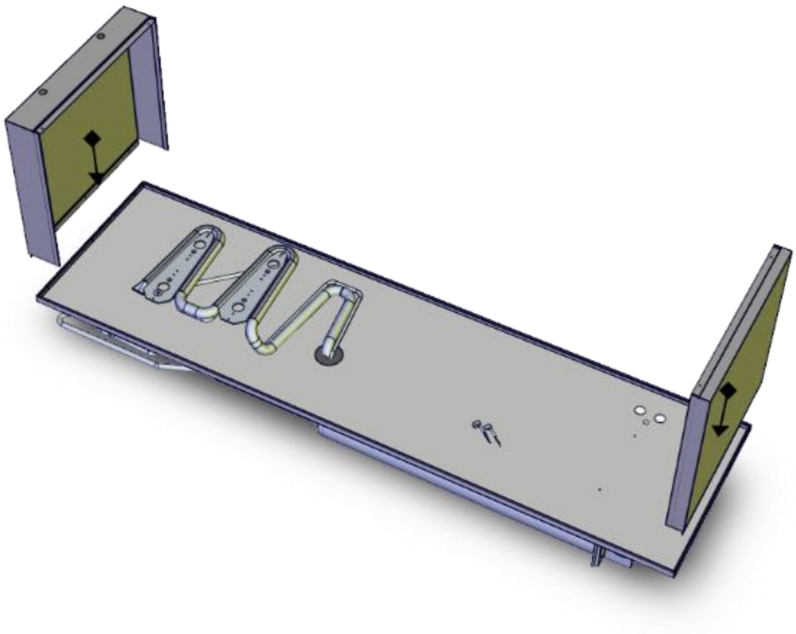
Category	**Element**	**Change and approach on element**
Product design	Breaker	Cosmetic breaker created which allows for rework elimination as reduction in production steps.
	Backplate	Joined with CU. Metal plating as in one-step foaming feasibility with added geometry to allow for tapeless assembly of wrapper.
	Wrapper design	4 pieces, 2x2 all made out of sheet metal with different thicknesses
	Wrapper material	Full metal wrapping with different thicknesses for weight reduction
	CU tubing	No change because backplate will be assembled together with CU so necessity to move tubing vanished
	Liner	The liner is altered to allow for better joining to wrapper and breaker.
Machinery design	Foaming equipment	Same as concept 1, only new top plate.
Assembly	Fins placement	Fins can already be placed beforehand instead of final assembly reducing handling.
	No hotmelt for parts, only sealing	Parts like cable grommets are not designed to be foamtight without the help of hotmelt. This design tends to change the design of the grommets in order to even allow for automation of routings.
	No nutplates	Instead of using the standard metal part
Requirements	Stability	Stability comes from smartly chosen thicker top and bottom plates together with full joining of liner to CU.
	Use of tape and hotmelt	Elimination of duct tape, but internally masking tape still needs to be used. No elimination of hotmelt.
	Foam tightness	Only corners form a risk of leakage as the new plate at the CU. Tubing CU needs to be taped on backplate.
	Dimensions	Due to full metal wrapping the dimensions are most stable.

Assembly steps final concept

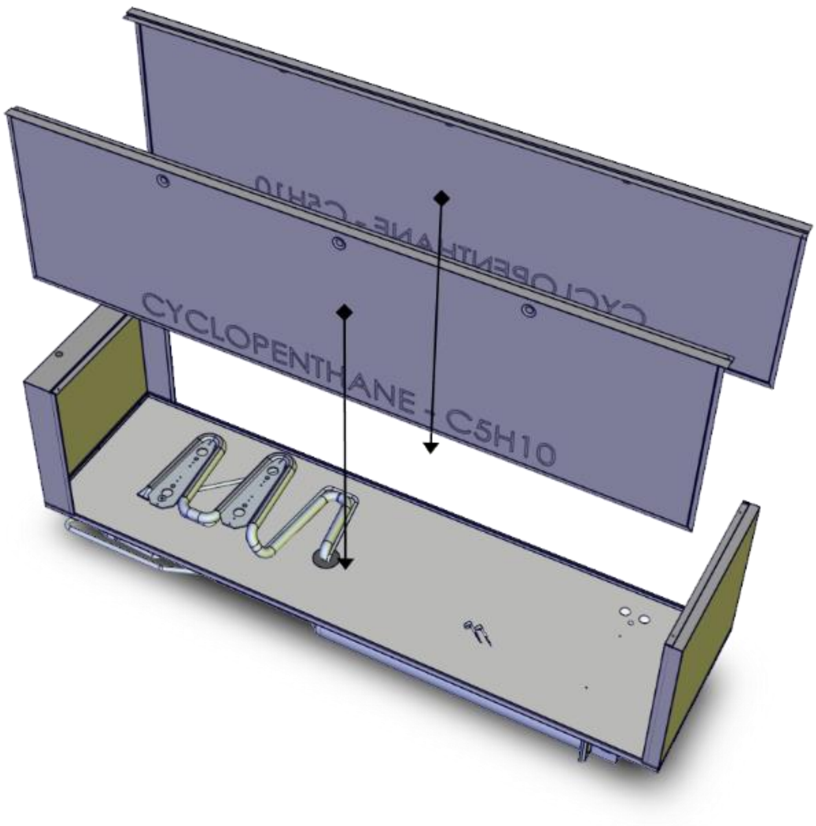
1 Place the CU with welded backplate on the work surface



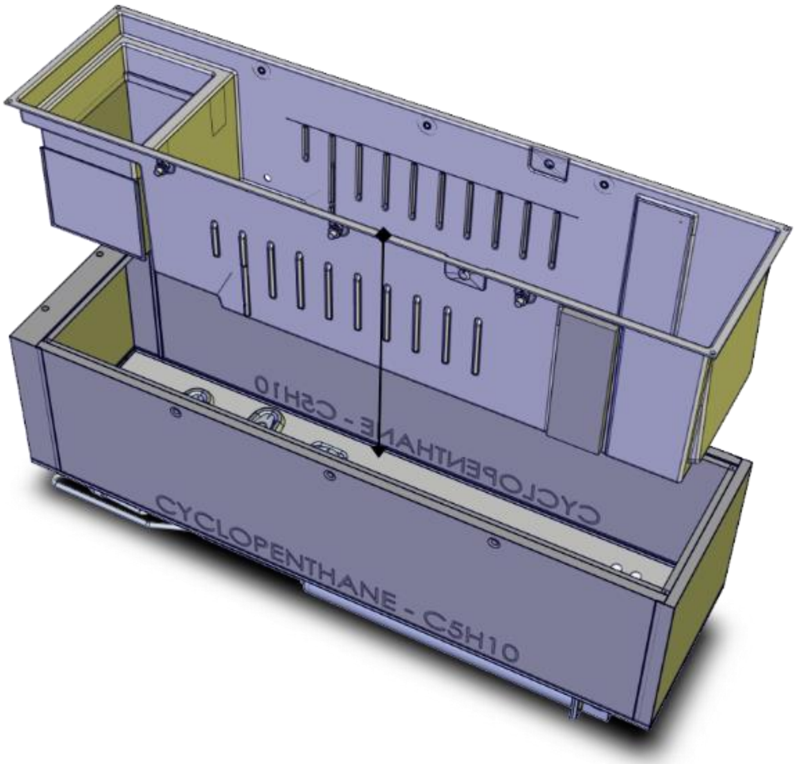
2 Place the top and bottom part on the backplate and join them by riveting



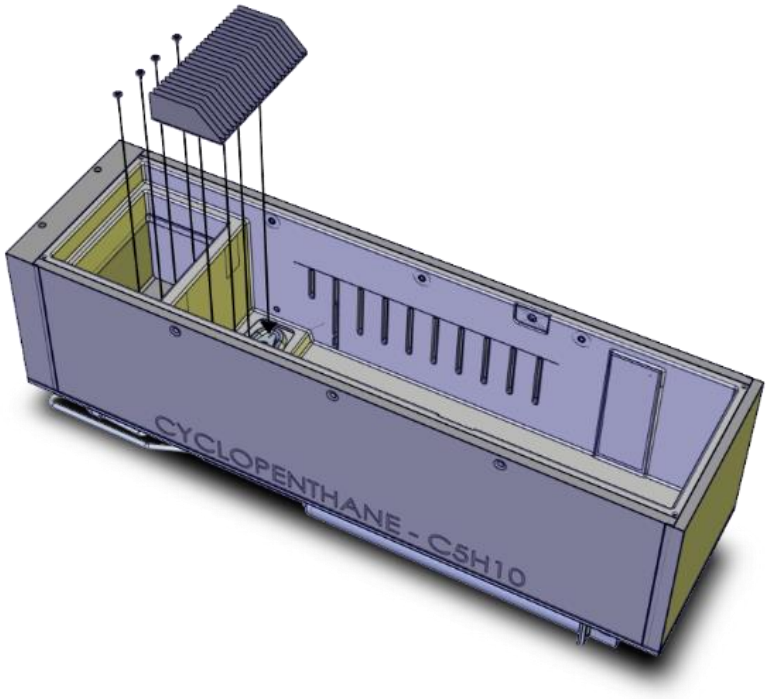
3 Place the two identical side plates into the geometry of the top, bottom and backplate



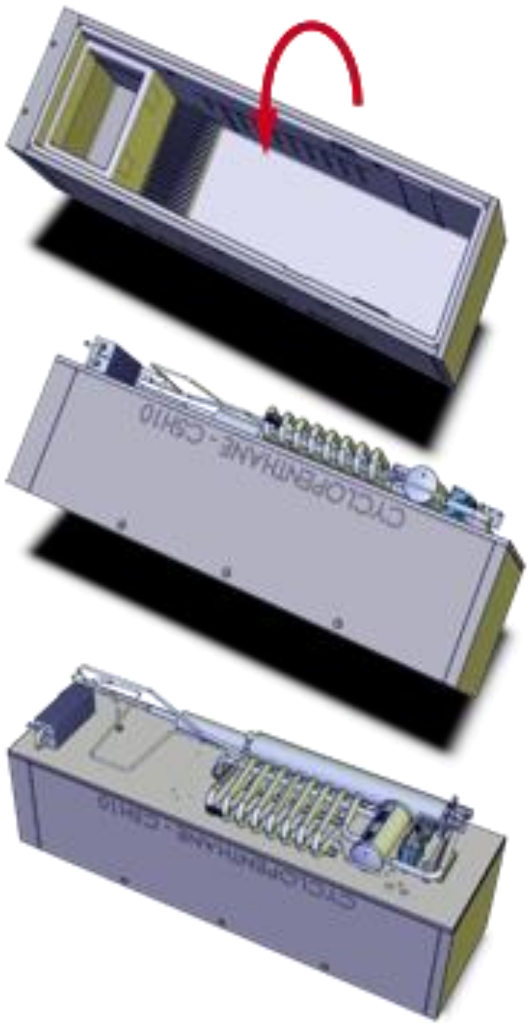
4 Place the liner in the indented geometry created by the top, bottom and side plates. Screw it on the corners.



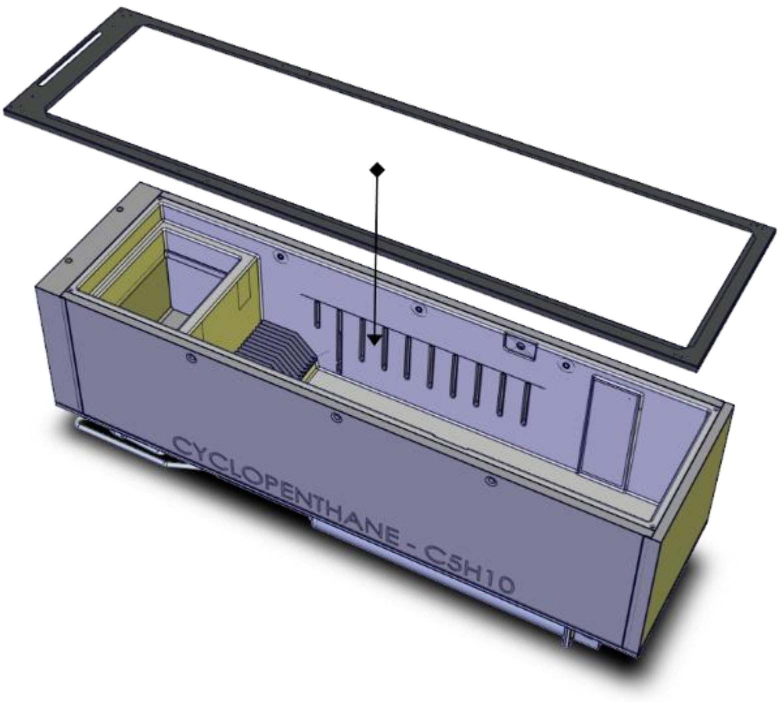
5 Screw the fins and freezer unto the CU via the liner



6 Flip the fridge to allow for foaming



7 After foaming flip the fridge again and allow for back assembly. The cosmetic breaker can be placed.



Notable product design and machinery choices

Liner joining to metal working

The liner is placed inside geometry of the cabinet, instead of placing the liner on top of the metal working in concept 3. This is done to better connect the breaker to the liner and to avoid an oversized liner.

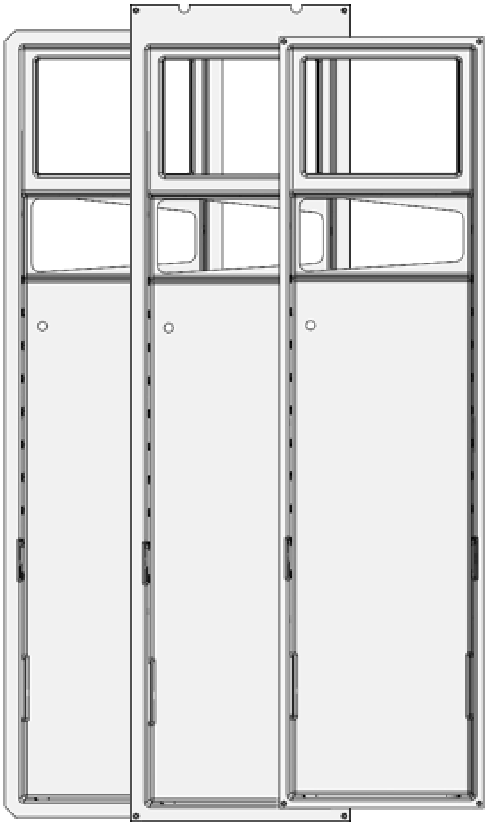


Figure 113: differences between liners. Left original, middle concept 3 and right final concept

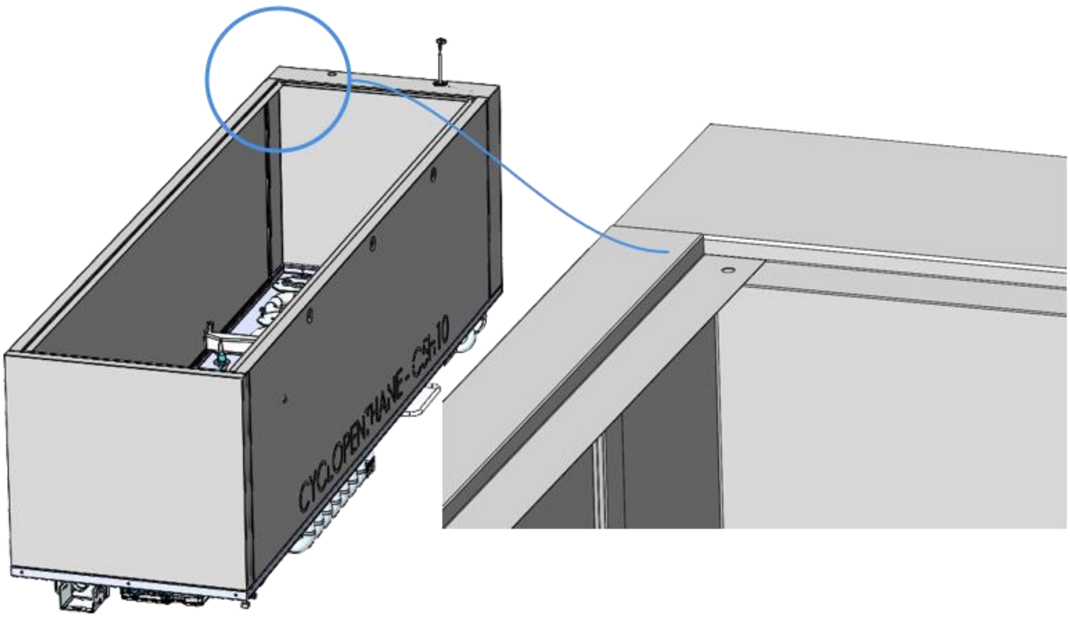


Figure 114: detail on indented geometry for liner + screw hole

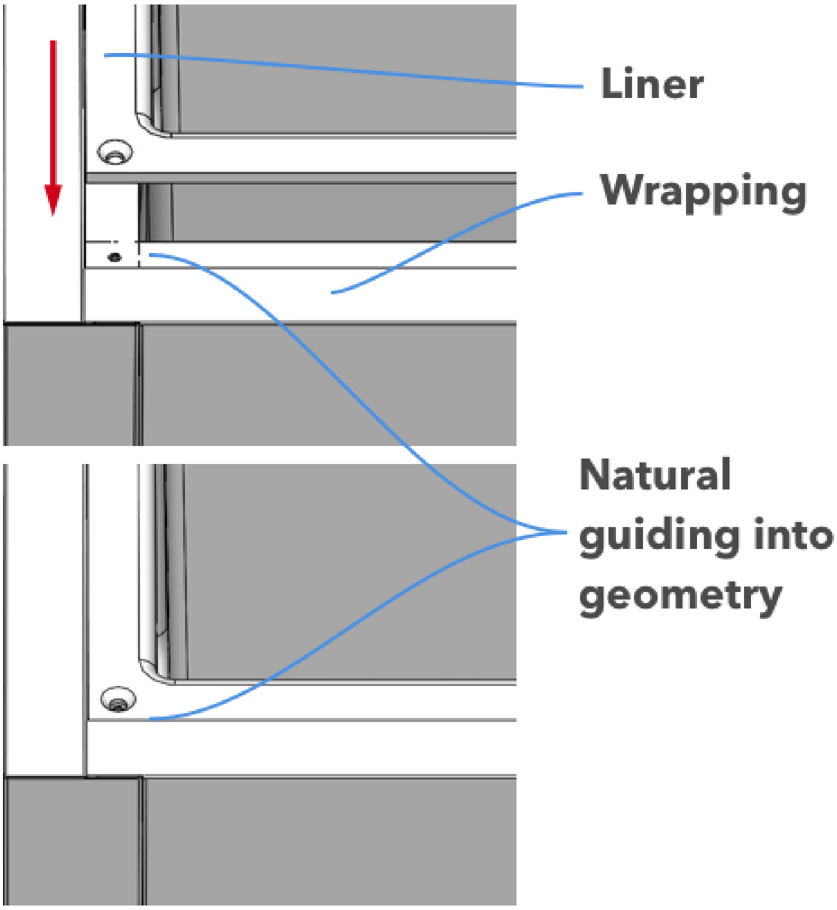


Figure 115: method of assembly of liner into wrapping geometry

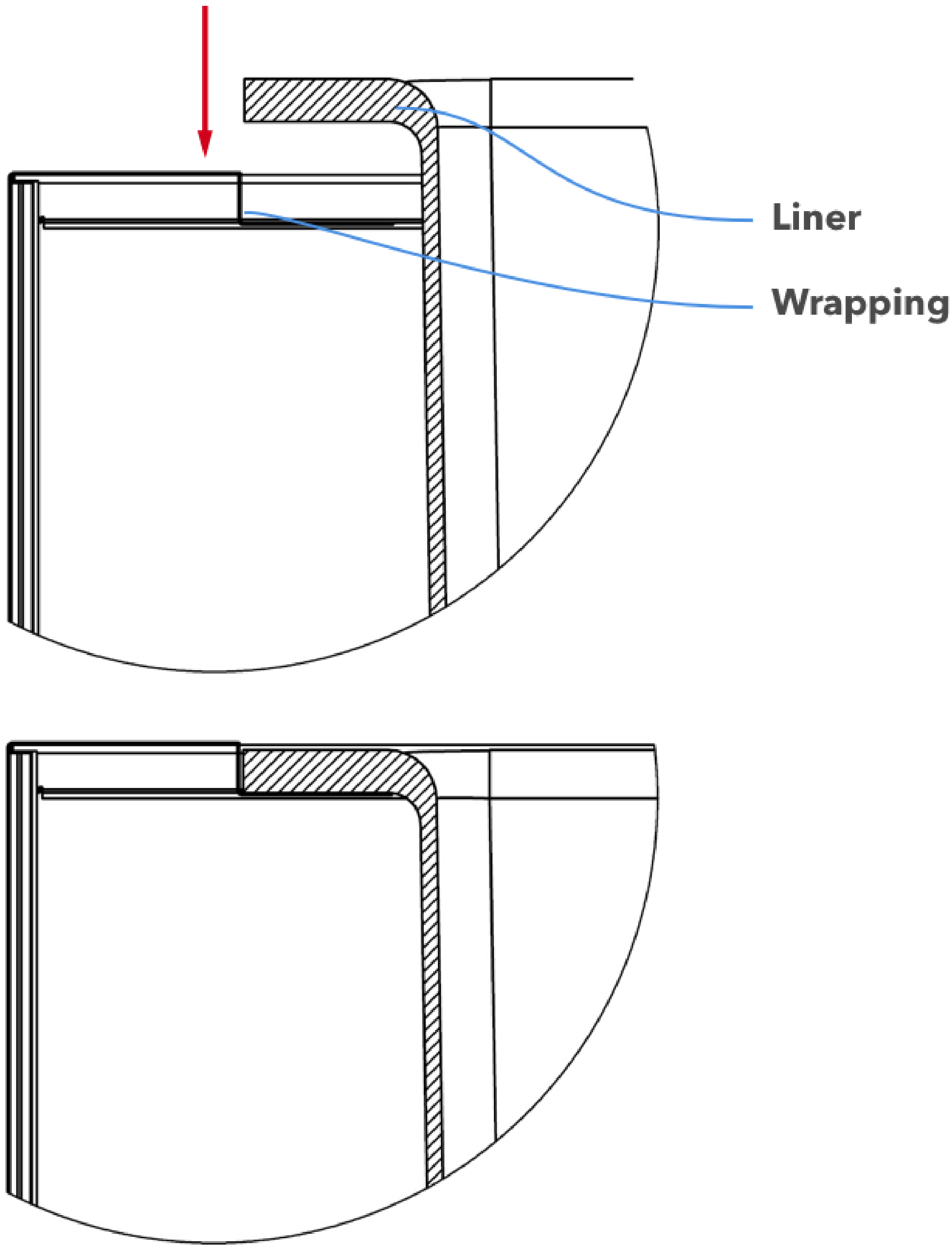
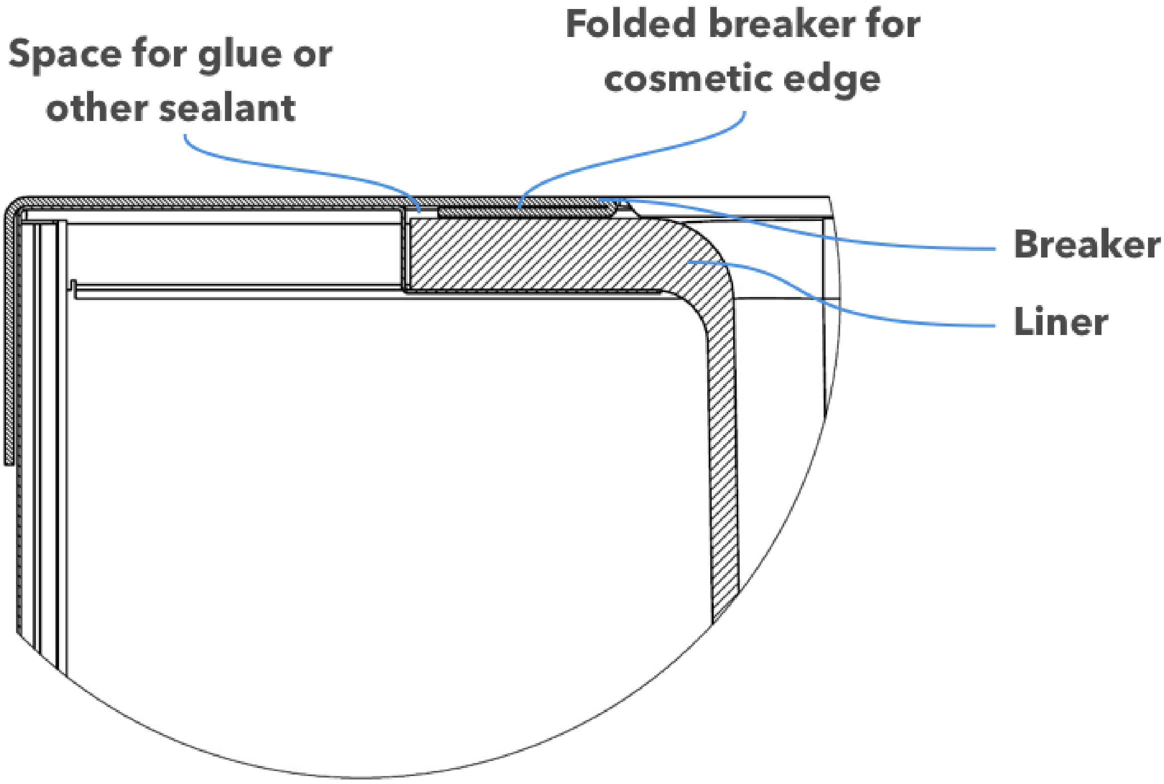


Figure 116: technical drawings on insertion of liner into wrapper

Connection breaker to cabinet

The breaker has a small bend to allow for a better cosmetic connection between the liner and the breaker as explained with the previous design. An additional advantage is the possibility to add a joining glue between breaker and liner as a little space is present.



New grommet designs

One of the biggest hotmelt consumer besides the sealing of gaps are the grommets. The idea is to change the grommets for montage of the fridge in the RV to allow for hotmeltless and automated assembly. This also counts for the cable grommets which could have similar geometry as the IKEA fridge. The bigger flange can prevent foam leakages more easy.

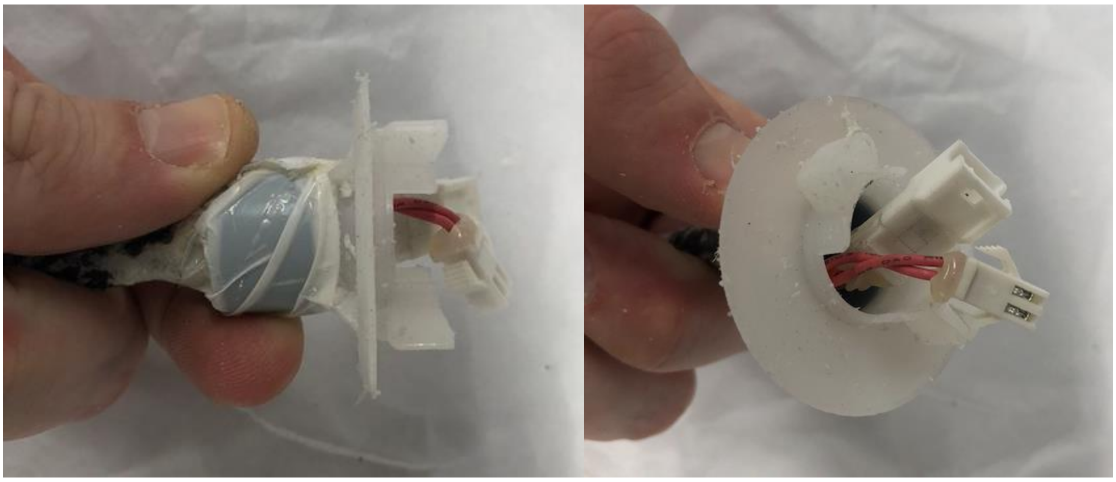


Figure 117: detail of cable grommet at IKEA fridge – possibility for Thetford?

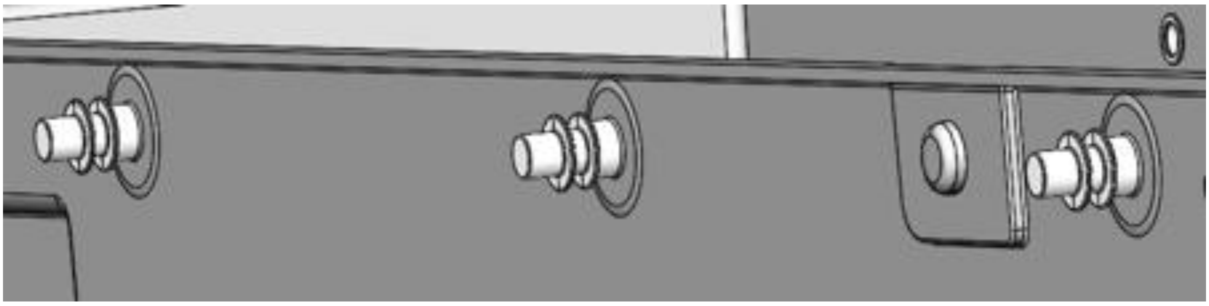


Figure 118: grommets on the inside of the liner

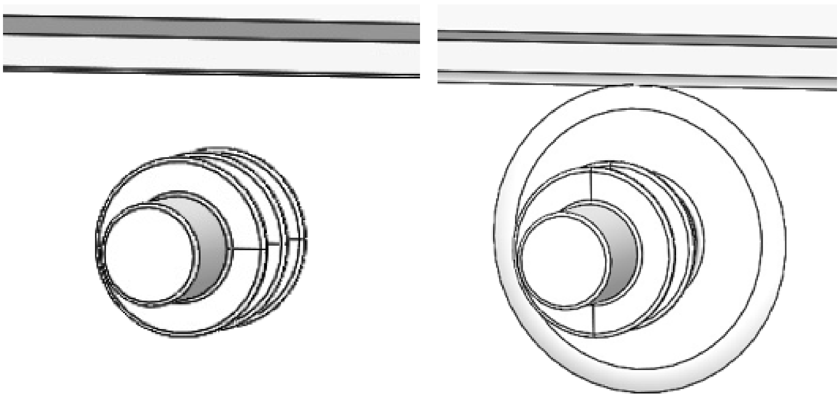


Figure 119: new grommet design (right) next to old design (left)

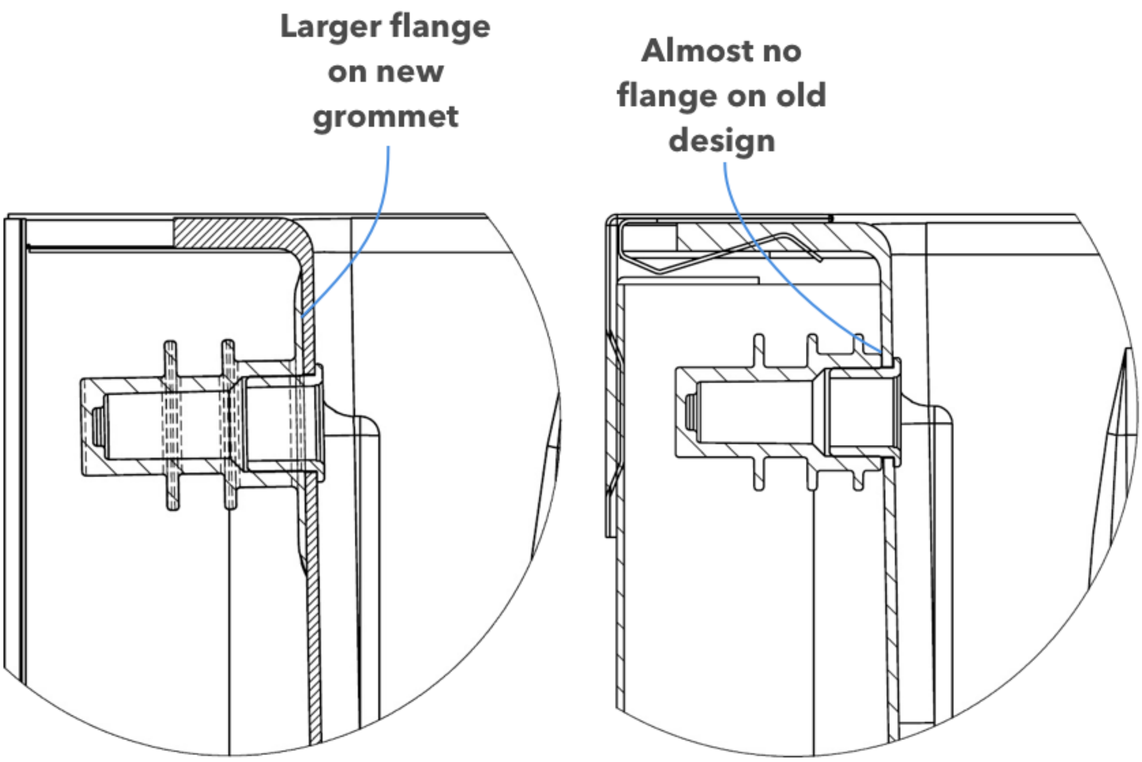


Figure 120: technical detail on old and new grommet design

New type of nutplates

A similar case as the grommets are the nutplates. Because metal wrapping is used the nutplates at a lot of places are eliminated, but not all. For the locations other nutplates are used the type used in IKEA fridges could be used. This overview is seen in **Error! Reference source not found.**.

Figure 121: 'nutplate' with screw from IKEA fridge

Business case final concept

The business case of the final concept should at least be better than concept 3. This is the case. It satisfies all the main drivers and it is better in the sense of BOM costs. The information can be seen in Table 17 and

Table 18.

Table 17: validation on main drivers of final concept

Main driver	**Final concept**
+ 20% output	-8,5 FTE / - 61%
-20% floor space	>42% - Foaming machine + bending + rework + drilling robot + wrapper robot
Value production workers	Less taping + focused work + no hotmelt for most connections
Cost neutral	See other
Future proof	Yes, even further automation possibilities
Same customer experience	Yes

Table 18: Costing final concept

What	New encasement baseline	Final concept	Remarks
Investments	€ 57.500	€236.000	New top plate, new molds for grommets, sheet metal bending machines
FTE and rework saving p/y	€ 0	€377.500	8,5FTE + 37.500 on rework
BOM change with present BOM	**€ 30,88**	**€20,88**	Reduction in price because of sourcing via TCCA
Weight increase (theoretical)	8kg	11kg	
BOM difference with new baseline	€ 0,00	- €10,00	
Cost price difference	€ 0,00	- €19,44	

Discussion

Did I really solve the problem as stated in the beginning? This chapter tends to explore this question by critically going through the whole project. Initially only the design process of going from the strategic problems to the operational design concepts is discussed. This is not the whole picture of the project as the method of incorporating stakeholders was an additional part as well. The chapter will continue into the conclusions.

The problem as seen with a regular design process

The problem explored by implementation of one-step foaming can be approached from different organizational levels: operational, tactical and strategic. Each level has a related and united end in the solution. With this assignment the start was a strategy problem caused by external and internal factors, the end should be an operational solution to that because of my product designer role. The strategic problem is the unclarity on the answer to the question: “How to remain competitive with the present and new products by defining the market required level for operational excellence?” For this project the operational outcome is a product design with its necessary manufacturing and assembly changes. So how does the solution as presented solve the strategic problems?

First start by asking the question if the present design and manufacturing changes solve the operational problems?

- Is it possible to do one-step foaming? Probably yes, but a prototype should validate this possibility. Only small sub-problems have been tested not the overall.
- Is this design feasible and can it be produced? Probably yes because
- Can it be done in the present equipment? Yes, but adjustments are necessary.
- Can the people in the factory make it? They are flexible enough to make everything work whether they like it or not.

Yes, the people can make it, but not well mentioned in this stage of the project and this report, is the added weight production workers need to handle. Yes, the product is going to be heavier. Yes, it can be made automatic. No, it is not made specific now. Ergonomics and worker safety (cutting themselves because of metal sheeting) need to be considered when optimizing the product design, during the line design and with sourcing. To conclude: yes the concepts are highly feasible but not details are made clear.

Second the question if the design solves the tactical problems. These are translated the main drivers as they are focussed on the specific factory in Etten-leur and extracted from both operational end strategic problems. Each concept has been validated on the main drivers and they seem to fulfil each of the main drivers. The final concept should be the ultimate answer to the main drivers. It even goes a step further by taking other problems into consideration that are not mentioned in the main drivers like breaker damages.

Though that sounds promising it does not mean it will be like this. There is always an uncertainty in how realistic the predictions are. Presently it only shows that the project should continue to explore and make the prediction more realistic.

A bigger issue though is the effect of the changes on a broader perspective. Incorporating the breaker damages in the redesign is one aspect, but how will the influence of the increased output be on the final assembly? Higher output from the foaming equipment can mean a pileup at final assembly. This will be the case as one of the final testing equipment is the slowest step already thus defining the line balancing. Solving the tactical problem therefore also creates new problems for the whole line which need to be incorporated as well when continuing the project.

An uncertainty that remains is the implementation of the encasement regulation. There is still a chance this won’t be implemented or is as strict as initially posed. If the made assumption is wrong this will have effect on the weight and BOM cost increase. Both are too high thus need to be reduced in that case. The proposed concepts should be altered to explore if both could be decreased with the new scope in the project.

The concepts solve the problems stated on tactical level when looking at the development. How they will really solve these problems will become clear over time when considering a broader scope of problems that can arise.

Last the question if it solves the strategic problem? There is a high chance it will but that will be discovered only when the project is implemented and continued. The best part is that there is a line from strategy towards the operation. This line is seen in this project and worked out that next steps to fulfil goals can be taken. As described by the gates of Prince2: we go from Phase 0 - Idea to Phase 1 - Concept and all the work done is the proper basis for the next phase.

Stakeholder engagement as product designer

The previous paragraph describes the flow in a regular product design project. The additional level in this project was the engagement of stakeholders and the implementation of DFMA. This level is especially interesting because the customer changed from external to internal customer. The engagement of stakeholders is always something a product designer needs to consider but the question here is what can be improved at Thetford. In other words: what is the problem now and how can this be solved?

The strategy at Thetford is changing just as the market. This means more emphasize needs to be put onto production as very important stakeholder as seen in the theory of being a market leader. Initially the problem of inefficient production wasn't there because of the market monopoly but now this is being threatened. So, one of the problems is the unknown implementation of both automation and production in product design to generate the most efficient manufacturing route for the lowest overall costs.

Though this was a part of the project it's not the main topic and a conclusion won't be put on this analysis. It helped in improving the design and taking automation and production as stakeholders in this project, but the scope was too small to do a companywide analysis that has useful outcomes for business process improvement. If conclusions would be made, they would be in the form of personal recommendations.

Conclusions

One-step foaming can be a huge leap forward for Thetford. Though this will only be the case if the assumption of new encasement regulation is true for the presented designs. Nevertheless, does it show what can generally be improved on the design and the impact this has. Starting with the huge amount of tape and ending the necessary design changes on cables. The leap forward is in both a more efficient method of assembly, thus more output, but also in the possibilities to start better automation.

The project can also serve as a base to generate a new base for operational excellence. For the product designer this means more integration of DFA in the design process and for process engineering the addition of automation. These are mainly recommendations because the suggestions are learned during the project. These are shown in the next chapter.

Though the leap forward is there to grasp, next steps still need to be taken place. It is my sincere wish the result will be extremely successful.

Recommendations

Not everything from the project could be stated as a real conclusion. It is better to place them as recommendation as mentioned in the discussion and conclusion. The recommendations are stated as general remarks based on the stakeholder engagement and DFMA and related to the continuation of one-step foaming.

General remarks for Thetford

- Get out of the comfortable box Thetford is in and explore to make the product, production and company better.
- Generate a vision on what the required minimal level of operational excellence should be for Thetford.

Stakeholder engagement and DFMA

- Incorporate automation requirements early in the design process. Active automation instead of reactive automation.
- Add a DFA cycle in the design process. DMA is already implemented as the effect for the product designer is high, but DFA could solve issues that would otherwise arise afterwards.

Continuation of one-step foaming

Project

- Make the concept as prototype and initiate the N5000 project
- Align with other projects of NPD in the sense of equipment but also automation

Design

- Develop concepts for large fridges as well to align design choices and thereby the sourcing of components.
- Redesign freezer part to eliminate tape there as well. Maybe increase the volume by taking space in the foam from the top (now 100mm, but could be 60mm)
- Rethink corrugated tubes. Them seem to add little value as shown in the IKEA fridge.
- Incorporate the AUS and US design (fins, feet, installation frame connections)
- Experiment and research different (cable) grommet design. This could be automated, no hotmelt or tape should be used and even the driptube could be assembled easier.
- Optimize thickness of backplate to reduce weight significantly

Production

- Increase the scope to also increase output on the final assembly line when one-step foaming enables this increase with the foaming equipment.
- Ergonomics are to be made more explicit in the next step of the design phase as they have a bigger impact that most product design at Thetford.

Other

- Smartly source expensive parts like the metal plating. Think of receiving a building package containing the wrapper and CU.

Bibliography

Thetford. (2019, 2). *Our DNA - Think, Feel, Act*. Retrieved May 4th 2020, from https://cms-nl.thetford-europe.com/sites/default/files/2019-07/Think%20Feel%20Act%20Thetford_screen.pdf

Voogt, A. (2019, 6 10). Onderzoeksrapport: Future assembly design iNDUS. BBA graduation report, Breda, The Netherlands: Avans Hogeschool.

Improvia. (2018). One Step Foaming - Concept Workshop. The Netherlands: Thetford internal documentation.

Treacy, M., & Wiersema, F. (1997). *The Discipline of Market Leaders.* INGRAM PUBLISHER SERVICES US.

Boothroyd, G., Dewhurst, P., & Knight, W. A. (2011). *Product Design for Manufacture and Assembly.* Boca Raton: CRC press.

Thetford. (2022, 01 30). *Facebook*. Retrieved from Thetford: https://www.facebook.com/Thetfordbv/posts/4173467902689306

Red dot. (2021). *Red dot*. Retrieved from https://www.red-dot.org/project/indus-53446

DKM. (2021). *DKM corporation*. Retrieved from Holding&affiliates: http://www.dkmcorp.com/holdings-affiliates

Monomoy. (2021). *Monomoy capital partners*. Retrieved from https://www.mcpfunds.com/

Arana Living Technology. (2021). *Alibaba.com*. Retrieved from 96L 12V 110~240V RV camper trailer refrigerator fridge: https://www.alibaba.com/product-detail/96L-12V-110-240V-RV-camper_62288964513.html?spm=a2700.galleryofferlist.normal_offer.d_title.7b844b55n27EiT

RVCOOL. (2022). *Youtube.com*. Retrieved from RVCOOL Dometic RM2652, RM2852 Cooling Unit Installation Video: https://www.youtube.com/watch?v=L8kBX9LzIJo

RVCoolAgain. (2022). *Youtube.com*. Retrieved from Replacing A Dometic Cooling Unit: https://www.youtube.com/watch?v=aebl5HJImKA

mrjschaffer. (2022). *Youtube.com*. Retrieved from How to Replace a Dometic RM-2862 Cooling Unit: https://www.youtube.com/watch?v=DtrQNvCRwa4

AZ expert. (2022). *Youtube.com*. Retrieved from NORCOLD 1200 Cooling Unit Failure + tips and tricks: https://www.youtube.com/watch?v=u9XJY7YMCCI

Cytiva. (2022). *Cytivalifesciences.com*. Retrieved from Industry 4.0: Bioprocessing digital transformation: https://www.cytivalifesciences.com/en/us/solutions/bioprocessing/knowledge-center/digital-transformation-in-biomanufacturing

Velling, A. (2021, 09 28). *Fractory.com engineering blog*. Retrieved from Design for Assembly: https://fractory.com/design-for-assembly-dfa/

Baker, K., & Poulter, S. (2017, 6 14). *Mail online*. Retrieved from Fears faulty FRIDGE was to blame for devastating fire which has killed at least twelve after years of warnings over 'exploding' appliances: https://www.dailymail.co.uk/news/article-4603616/Fears-faulty-FRIDGE-blame-devastating-fire.html

ERAC. (2018, 10). *ERAC.gov.au.* Retrieved from Information bulletin october 2018: https://www.erac.gov.au/wp-content/uploads/2020/06/Information-Notice-022-Refrigerators-Oct-2018.pdf

IEC. (2020, 09 06). *IEC webstore.* Retrieved from IEC 60335-2-24:2020 - Household and similar electrical appliances - Safety - Part 2-24: Particular requirements for refrigerating appliances, ice-cream appliances and ice makers: https://webstore.iec.ch/publication/65317

ECEEE. (2022). *ECEEE.org*. Retrieved from Ecodesign Directive: https://www.eceee.org/ecodesign/process/

ECEEE. (2022). *ECEEE.org*. Retrieved from ErP working plan: https://www.eceee.org/ecodesign/Horizontal-matters/working-plan/

NRC. (2011, 04 30). *NRC.nl*. Retrieved from Kostbare grondstoffen halen uit oude koelkasten: https://www.nrc.nl/nieuws/2011/04/30/kostbare-grondstof-winnen-uit-oude-koelkasten-12013299-a4547

Storgaard, M. (2022). *Go downsize*. Retrieved from How long do motorhomes last?: https://www.godownsize.com/how-long-motorhomes-last/

Verrijt, H. (2019, 09 19). *Eindhovens Dagblad*. Retrieved from Renewi in Eindhoven wil van plastic uit oude koelkasten nieuwe koelkasten maken: https://www.ed.nl/economie/renewi-in-eindhoven-wil-van-plastic-uit-oude-koelkasten-nieuwe-koelkasten-maken~a6412e88/?referrer=https%3A%2F%2Fmyprivacy.dpgmedia.nl%2F

Plastics.gl. (2011). *Plastics.gl*. Retrieved from Haier orders second plant with Vacuum-Assisted Injection technology from Cannon: https://www.plastics.gl/consumer/haier-orders-second-plant-with-vacuum-assisted-injection-technology-from-cannon/

TR Fastening. (2022). *TR Fastening*. Retrieved from EPW self-extruding screw: https://www.trfastenings.com/products/product-innovation/epw-screw

Limble CMMS. (2019, 06 06). *Limble Cmms*. Retrieved from Overall Equipment Effectiveness (OEE) - a practical guide: https://limblecmms.com/blog/oee-overall-equipment-effectiveness/

Appendix overview

1. Original design brief + changes
2. Interviews
3. DFMA analysis present production
4. IKEA fridge analysis
5. Competitor analysis
6. Detailed production flow including parts
7. List of requirements (operational level)
8. Business case